



The true cost of solving the plastic waste challenge in developing countries: The case of Ghana

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ABSTRACT

Mismanaged plastic waste is a major environmental concern, especially in countries of the Global South. Municipal solid waste management can not only alleviate environmental problems but also create jobs and promote local economic growth. However, providing appropriate waste management services is costly. The question is to what extent waste management policies that have proven to be successful in other geographies can help solve the challenge in developing countries. Specifically, the economics and financial flows along the value chain need to be known. In this paper, we shed light on these questions by presenting a novel, model-based method to elicit and assess the cost structure of the recycling sector in developing countries. We exemplify our method with plastics waste management in the Greater Accra Region of Ghana—an area particularly challenged by plastic waste. For this purpose, we surveyed over 80 participants of the waste management value chain and combined the data with insights from expert interviews and workshops. Based on this data, we built a bottom-up model with 67 parameters, reflecting all cost positions in the waste management value chain. We found that street waste pickers are the poorest and most vulnerable, earning only a fraction of the already low minimum wage. Middlemen and aggregators, while often being criticized for their earnings, also provide social-security-like services to waste pickers. In addition, formal and informal recyclers differ not only in earnings and size but also in recycle quality where the informal sector provides higher quality.

1. Introduction

The consumption of single-use plastic packaging has been increasing for decades due to population growth, economic development, changing lifestyles, and cheap raw materials (Quarley et al., 2015). This is problematic from a sustainability perspective because of high resource consumption and subsequent pollution (Geyer et al., 2017; SystemIQ, Pew Charitable Trust, 2020). A circular economy, being “restorative and regenerative by design,” addresses both aspects, as materials constantly flow in a “closed-loop” system, rather than being used once and then discarded (Ellen MacArthur Foundation, 2012). Recycling, one of the most prominent ways of closing the loop, has been established in Europe for decades. However, developing countries rarely have the appropriate infrastructure to collect and recycle materials (Fobil and Hogarth, 2009; Jambeck et al., 2015). Yet, many of these countries have seen a strong increase in plastic packaging (Kaza et al., 2018; UN Environment, 2018),

with negative effects on people and the environment (Jambeck et al., 2015; Hopewell et al., 2009).

Due to the low economic value of most waste, there is no automatic market-based formation of a municipal solid waste management (MSWM) system. Instead, even in industrialized countries institutional incentives are usually needed to set up and maintain a waste management sector. In addition, in places lacking the necessary infrastructure, the emergence of a MSWM system is often dependent on informal structures, especially for collection and sorting (Wilson et al., 2009). This is mostly the case in developing countries, where the waste management sector is split into a formal and an informal side (Wilson et al., 2006). While the formal sector is made up of public and private enterprises with legal and financial backing from the government, the informal sector stays below the radar of governmental control, but is, as a consequence, not eligible for subsidies such as pensions or medical insurance (Ezeah et al., 2013). The informal sector also often bears other negative externalities, such as fluctuating prices (Steuer et al., 2018) and

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Table of abbreviations

| | |
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| EPR | Extended Producer Responsibility |
| GHS | Ghanaian cedis |
| GPAP | Global Plastic Action Partnership |
| GRIPE | Ghana Recycling Initiative by Private Enterprises |
| HDPE | High-density polyethylene |
| kt | kilotons |
| LDPE | Low-density polyethylene |
| MESTI | Ministry of Environment, Science, Technology & Innovation |
| MM | Middleman |
| MSWM | Municipal solid waste management |
| OECD | Organization for Economic Co-operation and Development |
| PET | Polyethylene terephthalate |
| PP | Polypropylene |
| PPE | Personal protective equipment |
| Pppd | per person per day |
| PRO | Producer responsibility organization |
| PS | Polystyrene |
| PVC | Polyvinyl chloride |
| WIEGO | Women in Informal Employment: Globalizing and Organizing |

poor worker protection and workplace safety (Zolnikov et al., 2021), making people working in the informal sector the most vulnerable part of the recycling value chain (Wilson et al., 2006).

Major changes in the framework conditions for packaging waste—public debates on plastic (Heidbreder et al., 2019), the Chinese plastic ban (Huang et al., 2020), or the establishment of different organizations such as the “Alliance to End Plastic Waste”—have sparked a discussion about alternative ways to reorganize MSWM worldwide, but especially in the Global South. There are several possibilities to develop the informal sector through different instruments of sourcing, allocating, and distributing financial resources. Taxes, fees, and Extended Producer Responsibility (EPR) schemes are the most prominent among them, but a good understanding of the economics and financial flows along the value chain has to be ensured for any of these.

For example, so-called EPR schemes (Lindhqvist, 2000) generally require producers to take financial or physical responsibility for their products at the end of its life. Globally, over 400 have been set up globally (OECD, 2016). Many developing countries have embraced the idea to set up EPR schemes, e.g., in South Africa (Nahman, 2010), Colombia (Park Jooyoung et al., 2018), India, Thailand, or Brazil (Gupt and Sahay, 2015). From a societal perspective, the advantages of EPR schemes are potentially reduced organizational and financial burdens on governments, the possibility to integrate the informal sector, and reduced potential health risks from mismanaged waste OECD 2001. Experiences in Europe have shown that EPRs can be a key instrument to promote the circular economy (Liu et al., 2018; Xanthos and Walker, 2017; Lévi Alvarès and Rosa, 2017; European Commission 1/16/2018). The detailed design of EPR schemes varies (with regard to the following aspects: responsibility and governing structure of producer responsibility organization (PRO); organization of collection; competition between PROs; integration of governmental agencies and industry; financial and physical responsibility of PROs; voluntary or mandatory participation in EPR scheme), but a central question is the organization and financing of MSW collection and sorting. While the OECD suggests financing collection according to actual costs, these costs are difficult to identify, especially for the informal sector (Lohri et al., 2014). As a consequence, actual implementation often takes a top-down approach in which stakeholders agree on an overall budget and ringfence part of it

for MSW collection services. After implementation, managers gauge the effectiveness of the collection budget and possibly adjust it accordingly, however usually without detailed knowledge of actual costs (Bünemann et al., 2020). As an additional problem, the cost side is usually considered for the whole chain rather than for MSW collection alone² and data is lacking for EPR implementation in general (Pani and Pathak, 2021) and on the cost base specifically (Ighravwea and Edemb, 2020) (only Jaligot et al., 2016 focus on the informal sector only, and concentrate on one material stream while applying a value chain analysis). In consequence, the true costs of MSWM systems in developing countries are largely unknown, and cases of EPR implementation in some of these countries draw on stylized facts, rendering the financing of the informal sector a black box. Thus, although financial flows are central to EPR schemes, there is no established methodology to elicit these costs in different economies or geographies. Hence we ask how the cost for a MSWM in developing countries can be identified in a transparent and systematic manner in order to internalize external costs.

We shed light on this question by presenting a model-based method to elicit and assess the cost structure of the informal and formal recycling sector in developing countries. To exemplify our analysis, we chose the Greater Accra Region in Ghana, where the use of plastic packaging has become widespread in the past decade. Ghana has been ranked the seventh dirtiest country in the world in 2015 (UNICEF and WHO, 2015) and, due to its coastal location, its capital Accra suffers from an ocean plastic problem—a fact that prompted the government of Ghana to set a target of zero plastic leakage into oceans and waterways (The Presidency - Republic of Ghana January 10, 2019). In our analysis, we were especially interested in un-managed or littered and/or lightweight material on dumping grounds, which is particularly prone to end up as ocean plastic. To arrive at a realistic representation of the true cost of recycling these waste streams, we chose a bottom-up approach and surveyed over 80 participants in the waste management sector around Accra. We clustered this data along different geographies and material types to build a model that can provide a comprehensive view of the current plastic waste management sector and its cost base.

Based on this approach, we first provide an overview of the actors involved in the collection, sorting, and recycling of plastic waste in the Greater Accra Region. Second, we develop and apply a method to elicit the true cost of the entire value chain, including the informal sector. We show the costs and revenues for all actors, as well as the cost of collecting, sorting, and recycling different plastic types. Third, through multiple sensitivity analyses, we provide a schematic overview of potential cost developments and a more comprehensive view on the true cost of waste management. We consider this a true cost approach as, unlike previous studies, our bottom-up model covers the entire value chain, including the informal sector and the cost that occur there.

Our findings can not only provide Ghanaian policymakers and plastic producers with the information they need to finance a MSWM system, but can be easily adapted to other (developing country) contexts. This will help to initiate a more fundamental discussion about a sustainable design of the recycling industry, and consequently about the use of plastic packaging in these countries.

The paper is structured as follows: We explain our methods in section 2 and present our results in section 3. In section 4, we discuss our findings and insights for policymakers as well as the plastic packaging value chain before we conclude in section 5.

² Studies focus, for example, on optimizing the technology mix for national recycling systems (for an overview: ElSaid and Aghezzaf, 2020); on the profitability of different waste fractions (Amina et al., 2020); or on the evaluation of waste charges on a household level in developed and developing countries (Puig-Ventosa and Sastre Sanz, 2017; Wu et al., (2015); Welivita et al., (2015).

2. Method

Our method consisted of three steps: First, we conducted a field survey to understand the setup and cost of the plastics waste management value chain in the Greater Accra Region, from picking to recycling. We then validated the results through cross-checks and discussions with local stakeholders. Second, and in parallel with the first step, we conducted interviews and workshops with local recycling businesses as well as global experts to gain an in-depth understanding of the peculiarities of the local industry. Third, we built a mathematical model to further analyze the results and calculate the sensitivity of the most significant parameters.

For the first step, we created a survey consisting of three main parts: 1) demographics, 2) cost and earnings, and 3) qualitative questions. The demographic questions allowed us to classify respondents. The questions about costs—e.g., for equipment, transport, and labor—as well as material prices and earnings were used as model inputs to calculate profitability and costs. While our focus was on the most commonly littered polymers (low-density polyethylene (LDPE), high-density polyethylene (HDPE), polyethylene terephthalate (PET), and rigid polypropylene (PP) – see Supplementary Material), we also asked respondents about other materials to get a complete picture of their income streams. Qualitative questions on topics such as the relationship between value chain participants and material quality complemented our findings with additional information.

While the full survey had 60 questions, the actual number and sequence of questions depended on the role of the respondents and their answers to previous questions (see Supplementary Material for the survey). The survey was conducted in form of personal interviews by a local research assistant from the University of Ghana and took place between 23 September and October 26, 2020. While interviewees were approached randomly, locations were chosen based on existing waste management activities (e.g., public places and dumping sites for waste picking, industrial areas for recycling hubs—see Appendix A).

In the first survey round, we received 85 responses from the four groups of waste pickers, middlemen, aggregators, and recyclers (see Supplementary Material for a more detailed description of the waste management value chain). To increase the validity of the data, we ran several cross-checks and queries, after which 70 valid responses remained.² While there are several thousand waste pickers active in the Greater Accra Region, we ensured generalizability and representativeness by randomizing the time and place of the interviews as well as cross-checking our findings with middlemen, aggregators, and recyclers. To guarantee a broad coverage of middlemen, aggregators, and recyclers, we collected contact details from local experts, internet searches, and waste pickers. For example for recyclers, we used the list provided by Seureca (2019) in February 2019 as a starting point. However, out of 19 listed recyclers, we excluded 7 that focused more on the processing of recyclate than on the recycling itself. Several others went out of business, changed their name, or were not responsive. At the same time, we identified additional recyclers from the informal sector that were not among the 19. We followed a similar approach for middlemen and aggregators to generate a representative data sample of each value chain step. Fig. 1 summarizes responses along the waste management value chain with a short description of each type of actor. The classification of a respondent can differ depending on the polymer under consideration, i.e., aggregators often sort PET bottles by color, but do not do this for other materials. Solid arrows indicate standard material

flows, while dotted arrows denote variants.

In the second step, and in parallel to the survey, we discussed our approach and findings with local and global experts from the waste management and recycling industry. We conducted 10 interviews between April 2020 and March 2021 to better understand the Ghanaian market overall, as well as the underlying dynamics between the value chain players. Furthermore, we participated in four official events to debate the development of the plastics recycling market and EPR schemes as a potential financing mechanism (see Appendix B).

In the third step, we built a holistic model by combining the input data from the survey with the expert interviews. This allowed us to conduct three distinct analyses: 1) the comparison of average volumes and earnings per group; 2) the calculation of the total costs of collection, sorting, and recycling; and 3) the parameter sensitivity for different groups. For 1), we calculated costs and revenues in both a best- and worst-case scenario (min/max) depending on factors like buying/selling prices or material quality. The comparison of processed volumes, costs, and earnings led to the formation of subgroups in each value chain step, which we discuss in section 3.1. By subtracting the total costs from the expected earnings based on the collected and processed material volumes, we calculated the annual earnings per value chain player. Furthermore, dividing costs by material volumes provided us with costs per kg, which allows for a better comparison across respondents and—when buying prices are included—materials as well (see section 3.2). For 2), we further combined the results along the value chain to compute the total cost of collection, sorting, and recycling for 1 kg of different materials, allowing for an overarching assessment of the profitability of the current system and the requirements for financing mechanisms such as EPR. Finally, in 3), we tested the sensitivity of different parameters such as equipment costs for waste pickers or buying and selling prices for middlemen, aggregators, and recyclers to calculate the influence of certain factors such as new legislation or price pressure on the model and subsequently on the profitability of the various players (see section 3.3).

Since some of the quantitative data referred to weeks (e.g., collection volumes) and others to months (salary) or years (machinery costs, rent), we extrapolated all data to an annual basis, assuming 50 working weeks across the value chain. All financial data were collected in the local currency of Ghanaian cedis (GHS). Taxes are not reported separately in the following, since they are either paid inconsistently across the formal and informal sectors or directly included in purchases, e.g., for equipment and machinery. Fig. 2 depicts a structural overview of the model.

3. Results

3.1. Value chain overview

Based on our survey, we first characterize the different players along the value chain and their cost structure (see Table 1) to use as input parameters for the model. The survey results show that cost and income both vary widely between the players along the value chain and also between the formal and informal sectors within a single value chain stage.

3.1.1. Waste pickers

Waste pickers can be split into three different groups depending on their location, equipment, and collection habits. In line with Seureca (2019), we found that street waste pickers are almost exclusively elderly women, collecting solely LDPE water sachets in their neighborhood, at markets, or public places such as bus/train stops or private compounds. In contrast, the other waste pickers work on the Medie and Kpone dumping grounds, picking diverse valuable materials such as HDPE, PP, metals, and paper, and selling them to nearby middlemen and aggregators. Only two of the 43 waste pickers collect PET bottles, illustrating their low value due to the lack of recycling infrastructure for PET in Ghana (Keesman, 2019). Waste pickers usually only incur costs for

³ The initial set included one duplicate, one waste picker paid by volume rather than weight, two end-product manufacturers, and 11 responses that did not seem credible, given the broad ranges and lack of internal consistency. In general, we conducted these validity checks especially with regard to data on salary or royalties and rent, as the largely informal workers could have an interest in ensuring that the results could be interpreted in their favor.

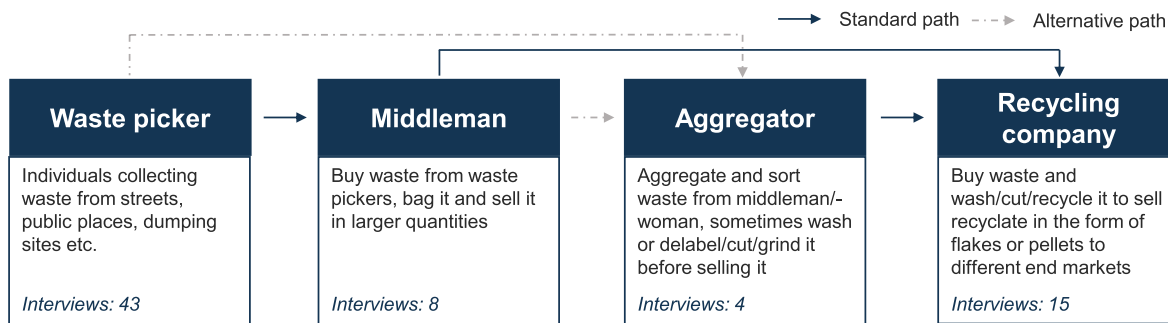


Fig. 1. Types of interviewees along the waste management value chain.

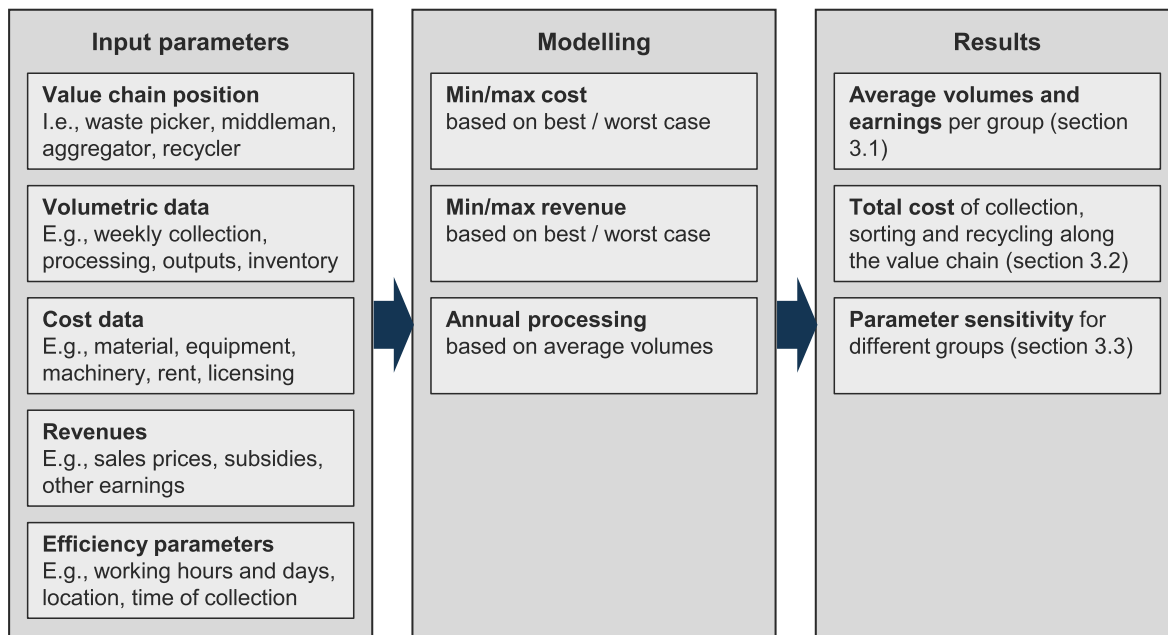


Fig. 2. Structural overview of the model.

equipment, with the dumping ground workers wearing more personal protective equipment (PPE). Kpone waste pickers additionally pay for “borla taxis” to transport the materials from their point of collection to the middlemen and aggregators at the entrance of the dumping ground.

Since many waste pickers have few savings, they can quickly become dependent on middlemen, who sometimes provide them with bags and PPE for collection. To gain higher margins, some waste pickers also work directly with recyclers. Nevertheless, waste pickers at dumping grounds make a decent salary for the informal sector, often earning several times the minimum wage of around GHS 12 per day (WageIndicator.org 2020). On the contrary, street pickers earn very little, at around GHS 2–5 per day, which is why they often use picking only to top up household income. Furthermore, the earnings of all waste picker groups are drastically reduced during the rainy season and subsequent flooding, since collection cannot proceed and material can get washed away.

3.1.2. Middlemen and aggregators

While middlemen only collect and sometimes pre-sort the material, aggregators often do more steps like de-labeling or washing, depending on the plastic. All respondents then bag the materials and bring them to recyclers for further processing. Most middlemen and aggregators buy several or all common polymers from waste pickers—however, three respondents specialize in only one material (all PET). Since the material is usually not collected, they have to proactively approach waste pickers

to pick PET for them. Furthermore, all respondents but one have employees (between three and 15), although many of them work only on an ad-hoc basis and earn close to minimum wage—around GHS 12–20 per day. Apart from labor costs, middlemen and aggregators pay for PPE for their workers as well as for a means of transport to collect the material from waste pickers and bring it to the recyclers. This is a prerequisite for the job, as they handle between five and 13 tons per week on average. Overall, all aggregators and all except one middleman in our sample make quite a good salary—up to over GHS 1m per year, which is even more than some recyclers. This illustrates their position of power in the value chain, based on their strong networks and high local visibility. As the eight middlemen (five from Kpone and three from Darkuman, a town in the western area of the Accra Metropolitan District) and four aggregators showed many common characteristics, we consolidated them into a single group for the following analysis, to allow for better comparability.

3.1.3. Recyclers

Recyclers can be separated into formal (seven respondents) and informal (eight respondents) subgroups, depending on their business structure and appearance. Formal recyclers work with PET (6) and HDPE (6), but also PP (4) and LDPE (3). On the contrary, informal recyclers work with HDPE (6), LDPE (5), and PP (3), but we did not find anyone working with PET. Overall, some recyclers focus on one material

Table 1
Summary of responses along the identified types of value chain players. * = The difference between input and output is based on inventory buildup and processing losses.

| Type | Street waste pickers | Medie waste pickers | Kpone waste pickers | Darkuman middlemen | Kpone middlemen | Aggregators | Formal recyclers | Informal recyclers |
|-----------------------|---|--|---|--|--|--|---|---|
| Location | Public places (markets, streets) | Medie dumping ground | Kpone dumping site | Darkuman – cable and wireless | Kpone dumping site | Central locations around Accra | Industrial areas around Accra | Darkuman – cable and wireless |
| Working hours | Every day, 4h in mornings and evenings (part-time) | 8h during daytime on 5 days (full-time) | 8h on 6 days (full-time) | 10h on 6 days per week (ø 3 employees) | 8h on 6 days (ø 5 employees) | 9h on 5–6 days per week (ø 5 employees) | 9h on 5–6 days per week (ø 24 employees) | 10h on 6–7 days per week (ø 15 employees) |
| Education | Primary school | Junior secondary school/middle school | Junior secondary school/middle school | Senior secondary degree | Primary school or no education | University degree | University degree | Mixed from no education to university degree |
| Age and gender | 49 years on average, all female | 33 years on average, both male and female | 34 years on average, only male | 38 years on average, both male and female | 52 years on average, both male and female | 29 years on average, only male | 28 years on average, both male and female | 45 years on average, only male |
| Equipment | Sometimes (s.t.) gloves, waste bags & facemasks (ø GHS 7/month) | <i>Worker clothing common:</i> Gloves, waste picker, waste bags, facemasks, boots (ø GHS 56/m) | <i>Special clothing required:</i> Gloves, waste picker, waste bags, facemasks, boots (ø GHS 99/m) | Gloves, waste bags & facemasks for employees (ø GHS 114/m) | Gloves, waste bags & facemasks for employees (ø GHS 251/m) | Gloves, waste bags, facemasks and s.t. boots for employees (ø GHS 225/m) | Gloves, waste bags, facemasks, special clothing, helmets, ear protectors (ø GHS 1790/m) | Gloves, waste bags, facemasks, s.t. helmets or ear protectors (ø GHS 525/m) |
| Collection/processing | Only plastics (ø 25 kg/week) | Plastics and metal (ø 371 kg/week) | Plastics, metal and s.t. paper (ø 583 kg/week) | Plastics and s.t. metal (ø 9 t/week) | Plastics and s.t. paper (ø 13 t/week) | Plastics and s.t. paper (ø 5 t/week) | Only plastics: ø41.4 t input and 31.1 t recycle output per week* | Only plastics: ø18.4 t input and 14.2 t recycle output per week* |
| Transport | Middleman pick up the waste or within walking distance | Middleman/aggregator picking up the waste | Transportation with Borla taxis to on-site middlemen/recyclers | Own truck to collect material and transport to recyclers (ø GHS 1,560/m) | Transport material from dumping site to recyclers with cars/trucks (ø GHS 450/m) | Own truck to collect material and transport to recyclers (ø GHS 1,060/m) | Own truck to deliver materials, often shipped for export (ø GHS 1,814/m) | Pay for material delivery to producers or sell at site (ø GHS 163/m) |
| ø Earnings (min-max) | GHS 617 p.a. (270–1,500) | GHS 4,450 p.a. (3–5,7k) | GHS 9,120 p.a. (1.5–25.8k) | GHS 218k p.a. (145–261k) | GHS 290k p.a. (3k–1m) | GHS 110k p.a. (36.5–215k) | GHS 1,252k p.a. (–335k–5.5m) | GHS 1,166k p.a. (120k–3.5m) |

only, while others seem to mix several materials and sell lower-quality recycle.

Formal recyclers pay three times as much per employee for PPE, with an average of GHS 1790 per month. This suggests better working conditions at formal recyclers, which are also reflected by the fact that injury costs are only half of those reported by informal recyclers. They also pay significantly more for transportation, since they often transport the material to manufacturing companies or ship it abroad, whereas informal recyclers often sell directly from the warehouse.

Informal recyclers are characterized by the fact that they do not pay substantial rent or licensing fees, working in an area with little governmental oversight. On the other hand, almost all of them pay significantly higher electricity fees, as they do not own generators but require a stable electricity supply for their operations, which is more expensive. However, they might also hook cables if possible.

Material buying and selling prices for informal recyclers in Darkuman are much higher across polymers compared to formal recyclers, as they are for middlemen in the area. This might be because they buy mostly washed, clean materials and produce pellets or granulate that can be sold for higher prices, giving them a better margin. Interestingly, formal recyclers mostly sell flakes, as they do not own extruders because of the high investment costs.

The yield after processing is abnormally high across almost all respondents compared to European recyclers (Hsu et al., 2021), calculated at 96.3% (formal) and 98.1% (informal). This results in very high average returns, with GHS 1,252k for formal and GHS 1,116k for informal recyclers per year. However, the returns also include unsold stock, as markets are only slowly developing for some materials. If this inventory is excluded, the returns for eight recyclers drop significantly, with six even making losses. Furthermore, returns do not equal the salary that respondents pay themselves, since they often have long-term contracts, bank loans, and installment payments to cover. One recycler in the scale-up phase is even making losses, which can only be covered by grants and project funding.

3.2. True costs calculation along the value chain

In the next step, we computed the true cost for plastics collection, sorting, and recycling for the various players in the value chain. Therefore, we focus on waste pickers who collect more than 50% of the total volume with the four polymers in focus (LDPE, HDPE, PP, PET). Twelve waste pickers collecting mainly cardboard or metal are excluded, since their collection rates per hour as well as resulting costs and profits differ too much from others. Fig. 3 shows the associated costs per kg of plastics for waste pickers, middlemen, and aggregators, as well as recyclers. Material prices—i.e., the sales process linking the value chain steps—are not accounted for in this figure, as they increase along the value chain and thereby distort the comparison of processing costs.

Waste pickers in Kpone have the highest cost, at an average of GHS 0.25 per kg, due to their professional equipment and need for “borla taxis.” Interestingly, their costs per kg are even higher than for middlemen and aggregators, underlining the relatively professional equipment required at the dumping ground. Furthermore, middlemen and aggregators handle larger volumes, across which they can spread their equipment expenditures. Although aggregators process the material, e.g., by removing labels or cutting off caps, they do not have significantly higher costs per kilo than middlemen. This could be an indication – among others – that they use basic equipment and cheap casual labor. The highest costs are borne by recyclers, as they also have to pay for machinery, licensing, utilities, and rent. The wide range can be explained by different operating procedures and their efficiency: While some recyclers handle transport themselves or only process small quantities, others have outsourced this and scaled up processing.

In the next step, we included the raw material prices for middlemen/aggregators and recyclers. Since waste pickers do not pay for collection, the chart only shows the costs for equipment and transport for them. We

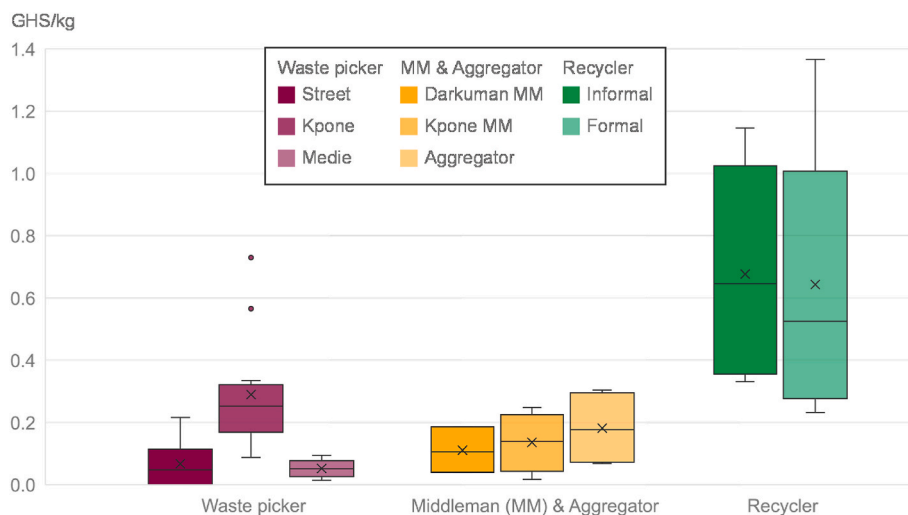


Fig. 3. Cost for collection, sorting, and recycling per value chain player (excl. raw material).

split the total costs by polymer as shown in Fig. 4 because material prices differ significantly (see Appendix C).

Street pickers only collect LDPE, which is why there are no costs indicated for the other polymers. Middlemen at Darkuman pay less for LDPE, but twice as much for HDPE, and higher prices for PP than the middlemen at Kpone and aggregators; since they purchase washed materials, they can offer higher quality. For all respondents, the costs for PET collection are the lowest, due to the low average buying price of GHS 0.4–0.6 compared to LDPE (GHS 0.6–0.9), HDPE (GHS 0.7–2.3), and PP (GHS 0.7–1.7). The same applies to recyclers, since PET is not fully recycled and re-granulated in Ghana, but baled or ground up for export. As mentioned above, informal recyclers pay significantly more for input materials than formal recyclers. Overall, material costs make up the largest part of total costs among all respondents (except waste pickers, of course), with a share between 46 and 97%.

In the following, we look at the exemplary costs for 1 kg of HDPE from collection through formal and informal recycling for two potential flows of material among the different groups, as depicted in Fig. 5a,b.⁴

The total costs from picking at Kpone dumping ground to formal recycling are 18% lower than for the flow from Medie dumping ground to informal recyclers in Darkuman. Although in line with our previous results, this might seem counterintuitive, as informality usually drives down prices (Gall et al., 2020). The main difference comes from earnings. In the formal recycling flow, the total earnings sum up to GHS 1.13, whereas the informal flow pays out GHS 2. Medie waste pickers' comparatively high return per kg could be interpreted as a risk premium since they have less PPE. Also, collection volumes are higher in Kpone, resulting in waste pickers accepting lower prices per kg as they still make a decent living. Other costs for middlemen are comparable, with Darkuman middlemen paying more for transportation. Formal recyclers of flakes have significantly higher costs, but also pay less for the material (GHS 1.4 on average, vs. GHS 1.7 for informal flake recyclers). The largest difference, however, lies in the extrusion step, where costs for informal recyclers are almost three times as high as for formal ones. The main drivers are—once again—the raw material price, labor, and

utilities. In both cases, the material is sold for GHS 3.5–3.8, with one outlier selling at GHS 4.8–5.0, providing a high margin for formal pellet producers (GHS 1.02 on average) but a comparably low one for informal pellet producers (GHS 0.45).

Comparing these findings on costs for HDPE to the other material streams and calculating the margins (i.e., final selling price minus costs incl. raw material) for each type of middleman, aggregator, and recycler shows that the average margin varies considerably: While the formal recyclers' margin is 19% on average, it is 34% for the Darkuman middlemen (for details, see Appendix D). These numbers are substantially different from the findings of Seureca (2019), who report 60–72% margins for middlemen and aggregators. However, they did not include costs but only took the margin between buying and selling price. Following this approach, our analysis generates similar results.

3.3. Sensitivity analysis

To ensure the model is robust with regard to modifications of the input parameters and to provide insights for policymakers on the effects of possible interventions, we conducted a sensitivity analysis for the 12 most important parameters along the value chain. Table 2 gives an overview of the parameters and the respective changes. To compare sensitivity, we used the average earnings per subgroup, normalized to 100% in the base case (as discussed in section 3.1, earnings do not reflect the actual income for recyclers, as they also include stock and exclude long-term contracts and installment payments – they are, however, the best estimate of business success). Since all subgroups have positive average returns in the current state, we focused mainly on limit values rather than increasing them further. Fig. 6 summarizes the results of the analysis.

For waste pickers, we calculated the sensitivity for three parameters: a rise in equipment cost, changes in collection quantity, and an increase in the selling price. Improving PPE (e.g., gloves, boots, reflective jackets) is vital, since waste pickers are exposed to infectious diseases, toxic materials, and other physical hazards on a daily basis (Wilson et al., 2006). While Kpone (96%) and Medie (91%) waste pickers suffer only small earnings reductions, street waste pickers make significant losses, at –68% on average. The costs exceed their earnings, showing they would not be able to pay for the equipment themselves. In the next analysis, we estimated what would happen if the waste pickers' average processing volumes were adjusted to the lowest or highest performing quartile of the subgroup. The returns of Kpone waste pickers are most affected by this change, since they have the widest spread of processing volumes, with some pickers collecting a lot of heavy materials like

⁴ Each flow is set up so that the stated selling price of one player in the value chain matches the buying price of the next, meaning they could in practice trade with each other. To keep the current cost view, we deducted the costs already incurred from the raw material price when calculating the costs for the next value chain player. For example, the Kpone middlemen pay on average GHS 0.9 for 1 kg of HDPE from waste pickers. Since the waste pickers spend GHS 0.29 per kg on equipment and transport, the net raw material cost (or waste picker salary) is GHS 0.61.

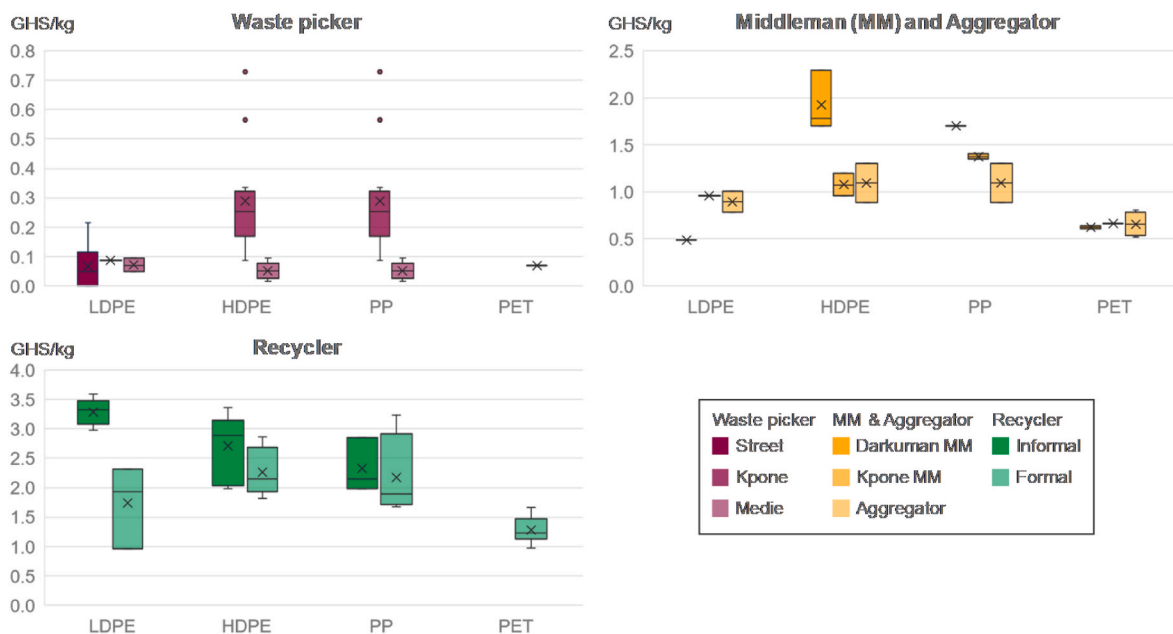


Fig. 4. Cost for collection, sorting, and recycling per value chain player (incl. raw material).

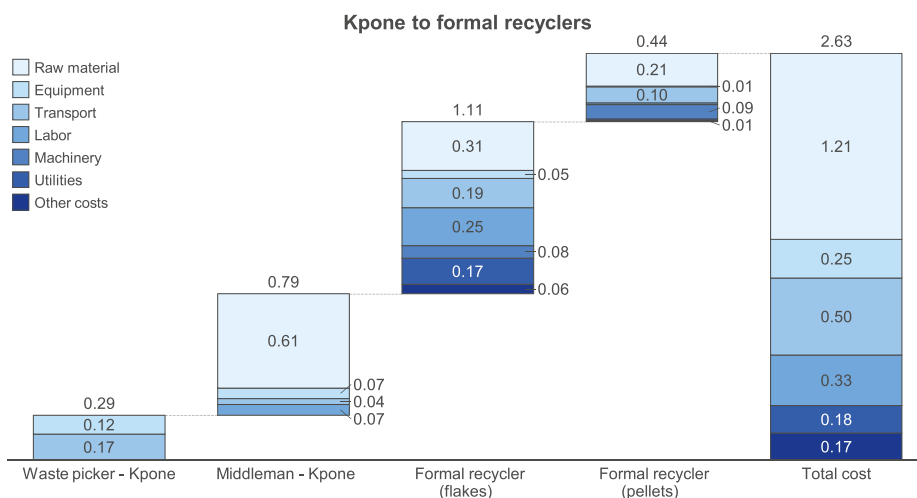


Fig. 5a. Total cost from collection through formal recycling for 1 kg of HDPE.

copper and aluminum. In the third analysis, we looked at an increase in selling price, which could be enforced by regulatory measures. This directly translates into similarly rising returns for all three groups, due to their low costs overall. If costs were to rise simultaneously, the percentage increase would be higher.

For middlemen, aggregators, and recyclers, we have calculated the sensitivity of an increase in buying price, a decrease (increase) in selling price, and a variation of the processing volume, as well as a 25 or 50% increase in labor cost. Darkuman middlemen and both groups of recyclers are particularly sensitive to price changes, with average reductions of up to 75% for a 25% drop in sales prices. While the effect of a variation in processing volume is rather linear, it is greatest for aggregators and recyclers, since they have lower earnings per kg. In turn, rising labor costs do not have significant effects on any of the sub-groups—showing that the respondents might be able to pay better wages.

For recyclers, we also calculated a reduction in processing yield, given that the data provided has been significantly above industry averages. A slight reduction to 80% already reduces recyclers' earnings by

over a third, with five of them even making losses. Even a yield of 50%, which is comparable to European mixed-stream recycling efficiencies (Hsu et al., 2021), would lead to negative average returns. This suggests that either the yield is kept high at the expense of quality, or that recyclers are less profitable than they claim.

4. Discussion

We discuss our findings in three broad directions: First, the special situation of the waste pickers as the most vulnerable of the informal part of the value chain; second, the challenges for the different recyclers to increase output quality; and third the different policy options that are currently discussed and how these could contribute to solve the plastic crisis in a developing country like Ghana.

For Africa to realize the opportunities that waste resources present, particularly to help reduce rising urban poverty, it is imperative to implement strategies to increase earnings for waste pickers. Comparing the different earnings along the value chain shows that profit is especially low for waste pickers—a finding that is in line with studies in

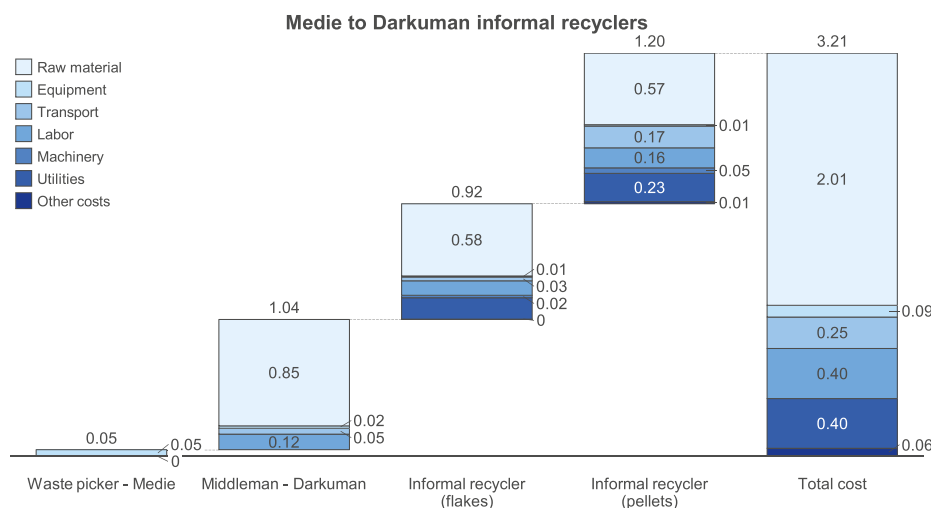


Fig. 5b. Total cost from collection through informal recycling for 1 kg of HDPE.

Table 2
Overview of parameter changes for sensitivity analysis.

| Value chain | Input parameter | Change |
|------------------------|---------------------|---|
| Waste picker | Equipment cost | Increase to GHS 902 for street and GHS 1,852 p. a. for Kpone and Darkuman waste pickers |
| | Collection quantity | Change to highest/lowest quartile for each subgroup |
| Middlemen/ aggregators | Selling price | Increase by 25%/50% |
| | Labor cost | Increase by 25%/50% |
| | Buying price | Increase by 25% |
| | Selling price | Decrease by 25% |
| Recycler | Processing volume | Increase/decrease by 25% or 50% |
| | Labor cost | Increase by 25%/50% |
| | Buying price | Increase by 25% |
| | Selling price | Increase/decrease by 25% |
| | Processing volume | Increase/decrease by 25% or 50% |
| | Yield | Decrease to 50/60/70/80% |

similar geographies (Fergutz et al., 2011; Lohri et al., 2014). Our analysis shows that pickers can increase their earnings by cutting costs, i.e. saving on safety measures. However, as our sensitivity analysis indicates, this is especially problematic for street pickers, who are already the worst equipped. Another possibility to increase their earnings is to collect more, which—according to our sensitivity analysis—would have a substantial impact. However, given the socio-demographic background of the street pickers, this is more of a theoretical possibility, as waste picking is only one job among several, and must fit with family and caregiving responsibilities that rarely allow more working hours to be spent on waste picking. Hence, the current cost structure of the MSWM system builds upon the fact that waste pickers can only turn a profit if they go without the necessary PPE. Any instrument for financing the MSWM system should take this into account and be mindful of the danger of reinforcing a lock-in into a socially unfavorable situation if the true cost of waste collection is ignored, i.e. the especially low earning of the waste pickers that need to be carefully considered.

In contrast, a change in waste pickers' cost base, e.g., in labor cost, has only a tiny impact on the earnings of middlemen and aggregators—although they are sensitive to changes in volume. Hence, they have an interest in establishing and maintaining a broad and stable network of waste pickers to deliver their material. Arguably, the intermediaries are not required at all; recyclers could pick up material directly from waste pickers. Discussions with recyclers have shown that they welcome direct interaction with waste pickers and are even

considering loose employment to receive consistent volumes and utilities. Middlemen and aggregators have often been criticized for their earnings, which do not seem justified by their level of value creation. However, they cater to waste pickers' needs beyond buying and reselling the collected waste, often providing social security-like support.

The value chain as discussed above can be labeled "informal" – although a substantial part of the waste that is collected, the waste from the dumping grounds, stems from "formal" waste management. However, while recyclers are only active in either the formal or the informal side, they buy from sources in both. The differences are visible in recyclers' current setup—namely in their business model and most surprisingly with regard to their earnings. While informal recyclers generate higher revenues and pay higher wages, formal recyclers process a larger quantity of material to balance their higher operating costs from licensing etc. Hence, a change in yields has a more pronounced impact on their earnings.

The main difference between the two types of recyclers is the quality of the recyclate they sell: While some informal recyclers have invested in an extruder that enables them to produce pellets, the formal recyclers do not have the same machinery, and focus on processing larger quantities of oftentimes lower quality—hence, they can only sell lower-quality output. However, from a market-based perspective, the quality of the recyclate is the key parameter for the development of the recycling sector, not only in Accra but globally. With increasing quantities of waste and rising recycling standards around the globe, the differentiating factor in the recyclate market is quality. Our sensitivity analysis revealed some weaknesses in the current system, such as a heavy dependence on current market prices as well as the tradeoff between yield and quality: Increasing the quality requires advanced sorting (e.g., sort out composites) and technical advancement of the recycling technology compared to what is currently installed including sufficiently qualified personnel. Another issue, however, is finding reliable buyers, as the plastic product market in Ghana still relies almost exclusively on cheaper virgin material. Surprisingly, the declared prices would be competitive on international markets, but the prices that can actually be achieved—at least for HDPE, LDPE, and PP—could be inferior, as input material and processing standards are of low quality. As a result, a lot of material is currently flowing into low-value applications such as bricks or pavement blocks. The key to increasing quality would be better sorting and cleaning, as well as knowledge development. However, this would also reduce recyclers' currently high yields. If sales prices did not rise accordingly, many recyclers would lose their profits, as discussed in the results. Nevertheless, this development will be essential in the long term in order to produce value-creating raw materials and reduce plastic pollution by improving its circularity.

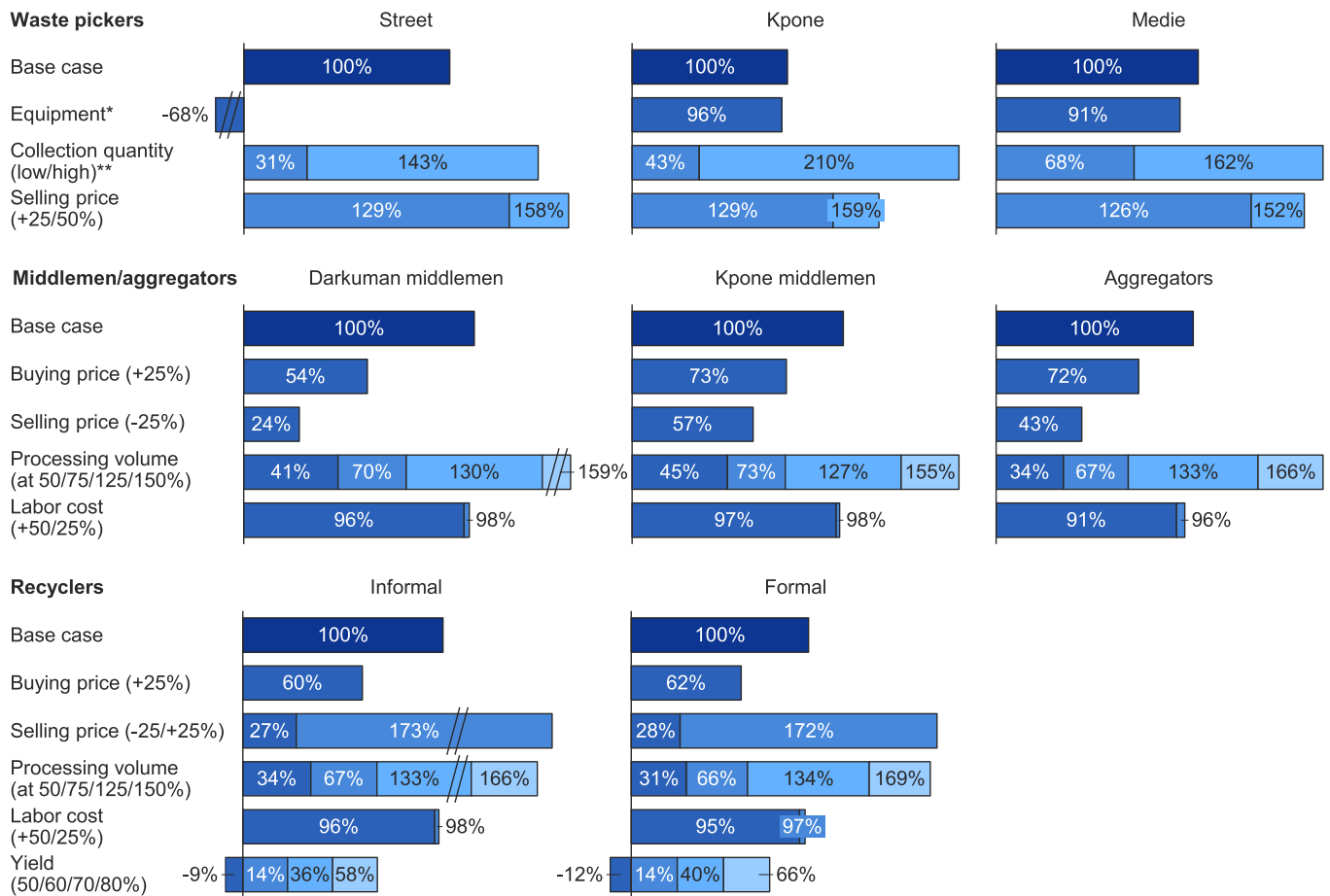


Fig. 6. Sensitivity analysis. * = Equipment costs for waste pickers are adjusted to afford a decent level of equipment – for details see Appendix E. ** = Collection quantity is adjusted to the lowest or highest performing quartile for each subgroup.

Municipal solid waste management systems can not only help solve these problems but also create jobs and promote local economic growth (Gall et al., 2020). However, costs for MSWM can amount to 20–40% of total municipal revenues in developing countries (Coffey and Coad, 2010). At the same time, neither these costs nor the environmental and social burden of waste is included in the costs of plastic packaging, and thus design for recyclability is neglected (Massarutto, 2014; Watkins et al., 2017). Different approaches exist to overcome this obstacle and finance appropriate infrastructure, either by regulatory intervention or by voluntary agreement of packaging producers. Taxes, fees, and EPR schemes are prominent concepts to hold producers liable for the treatment of plastic packaging waste.

To conceptualize such schemes, our analysis suggests that there is a need for two different forms of financing. First, recyclers, especially formal ones, cannot afford to scale up their business. On the one hand, capital costs in developing countries are high, and investments have to be made over a long time horizon (Schmidt, 2014). On the other hand, substantial investments are needed to scale up recycling capacity and quality. With this envisioned scale-up, global demand for higher-quality recyclate could be met (ICIS, 2019), and higher earnings could be generated. As our sensitivity analysis shows, earnings for recyclers from higher sales prices would increase more than proportionally. Second, waste pickers have no capital costs, but high operating costs relative to

their income in order to buy the appropriate equipment. Opposed to that, their salary is so low that it does not allow them to build up vital savings—e.g., for times of flood. Given our findings on the true costs for this part of the value chain, any MSWM financing approach should carefully consider the waste pickers in particular as the most vulnerable element in the value chain.

Our true cost analysis reveals that financial help for the transformation of the current set-up is needed, and estimates the amounts required. The goal of any policy intervention would be at least threefold: 1) scale up MSWM, starting from improving collection and recycling infrastructure and efficiencies (Pluskal et al., 2021); 2) ameliorate the working conditions of the waste pickers, especially those working on the streets; and 3) improve the MSWM output quality to sustain a solid MSWM system in the long run, possibly with interaction on international markets. As laid out in the introduction, different instruments exist to tackle this challenge, with EPR schemes being those most prominently discussed at the moment (Watkins et al., 2019). Our findings could serve policymakers as a basis for the assessment of the respective fees in a bottom-up manner. This perspective seems especially important for the developing country context, as a top-down approach could reinforce the current MSWM setup, including the unfavorable conditions for waste pickers. Following the bottom-up approach and carefully considering the results of our sensitivity analysis may well lead to a situation where

the implementation of any “polluter pays” principle may render the introduction of certain plastics into a developing country market obsolete, with far-reaching consequences for producers as well as consumers. An additional regulatory approach for the above-mentioned challenges could be transition finance, to cover the high upfront investments for starting a recycling business. For example, this could take the form of joint ventures with leading international waste management companies. However, while this is necessary to transform the MSWM sector in Ghana, it will not be sufficient in itself. The creation of sustainable end markets for the recycle (Demets et al., 2021) as well as the scale-up of collection and sorting will be needed too.

One more fundamental question is to what extent an upscaling of the recycling sector in these countries would also mean “formalizing” much of the informal sector (Sasaki and Araki, 2013; Fei et al., 2016). In the current MSWM value chain, the two levels of formalization are deeply intertwined. Consequently, formalizing the informal side would most likely influence the whole value chain, including the business model of the formal side. As also shown in the sensitivity analysis, the effects of one parameter change, such as selling price, differ sharply among the players. The reasons for the existence of the informal recycling sector, or the absence of an established and fully functioning formal sector encompassing all steps from collection to production of recycle are manifold. From a financial perspective, risk capital for building the infrastructure is difficult to access, especially in developing countries (Ayeleru et al., 2020). The resultant lack of recycling plants translates into low demand for most waste streams, which are hence not collected. Institutional or regulatory incentives would be necessary to finance the collection and sorting of waste streams (Rodić and Wilson, 2017). In addition, in countries where informal (and formal) MSWM systems exist, path dependencies have been created and manifested—e.g., by the role of middlemen (Sasaki and Araki, 2013).

In the current setup, waste pickers are not necessarily benefitting from changes in the market, due to their dependence on the rest of the value chain. This observation shows the importance of the true cost approach that we take in this paper, which addresses the inclusion of the informal sector. Overall, efficient collection of waste, increased recycling, and recovery can improve waste management, improve the welfare of waste pickers and ultimately reduce environmental risk in Ghana. High investments in innovation in recycling and immediate soft support for waste pickers and middle agents in the form of PPE can help achieve these ends.

5. Conclusions

In this paper, we raised the question of what the true costs of a municipal household waste management system in a developing country are, where they occur in the value chain and how they can be identified in a transparent and systematic manner. We developed a methodology that enabled us to build a bottom-up model with 67 parameters reflecting all cost positions in the waste management value chain. Our cost model provides the first in-depth insights into the cost of the recycling sector for plastic packaging in a developing country context. We arrived at these insights by identifying the relevant subgroups along the value chain, calculating their costs and revenues as well as averages, compiling the total cost of collection, sorting and recycling for different materials and conducting a sensitivity analysis for the 12 most important parameters. We shed light on the reasons for the costs we observed,

whether and to what extent these costs are obstacles for increased recycling and what financial needs would follow from substantially changing the system in order to upscale recycling both in terms of quantity and quality.

Since this is the first in-depth analysis of the true costs of collection, sorting, and recycling in a developing country with only a few points of comparison for our data, we have taken a range of precautionary measures to validate our data, such as additional triangulation interviews, cross-checks with local experts, and exclusion of implausible respondents or single data points. Nevertheless, we cannot rule out the possibility that individual data points are distorted, for example, if interviewees wanted to increase or decrease their (observed) earnings. For this, it will be interesting to compare our results with future studies in a related context. In addition, we would recommend future studies to better understand the actual steps towards and barriers for the implementation of MSWM systems taking into account the cost data insights from this study. This could include studies that detail the financing mechanisms for the costs we elucidated, for example through an EPR, or ethnographic studies that observe or action research that accompanies the establishment of an MSWM system. In this context, it would be especially helpful to study and observe the set-up of collection points and the subsequent impact on the costs of the MSWM system. Furthermore, society’s willingness to separate recyclables through community engagement is certainly an interesting field to research, bringing along a large potential to reduce sorting complexity (Vassanadumrongdee and Kittipongvises, 2018). Relatedly, future studies could improve our understanding of how to embed waste management in developing countries in international markets, for example by investigating the role of brand owners and their efforts to reduce plastic packaging or improving technological solutions that would allow market participants from developing countries to increase recycle quality and compete in international markets.

CRedit authorship contribution statement

Catharina R. Bening: Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Funding acquisition. **Sebastian Kahlert:** Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Edward Asiedu:** Validation, Investigation, Writing – review & editing, Project Management.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2021.129649>.

Appendix

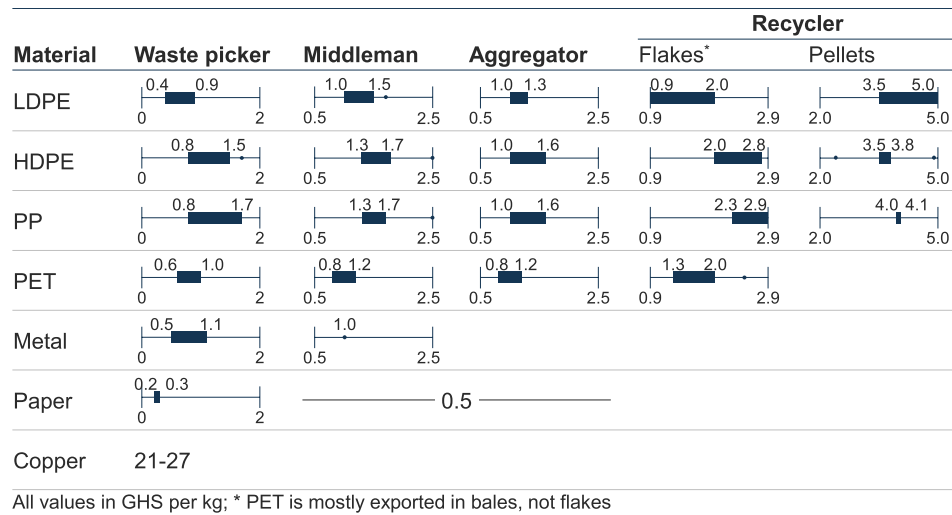
Appendix A. - Interview locations in the Greater Accra Region



Appendix B. - List of expert interviews and events

| Function | Time |
|---|---|
| Local recycling NGO (ASASE) | Several times between April 2020 to February 2021 |
| Chemical industry representative (AEPW) | Several times between April 2020 to February 2021 |
| Recycling plant operator (Ghana) | October 2020 |
| EPR expert (German Environment Agency) | October 2020 |
| Global NGO to tackle plastic waste | November/December 2020, February 2021 |
| Expert office on packaging and EPR (cyclos) | January 2021 |
| Southeast Asian EPR consultant (WWF) | January 2021 |
| Recycling plant operator (Ghana) | February 2021 |
| Local formal waste management provider | March 2021 |
| European External Action Service in Ghana | April 2021 |
| Event | Time |
| GPAP Kick-off meeting | September 2019 |
| Turning Off the Tap (EMF, SystemIQ) | November 2020 |
| 1st EPR Webinar (GIZ) | December 2020 |
| 3rd EPR Webinar (GIZ) | June 2021 |

Appendix C. - Selling prices for different materials in GHS per kg



Appendix D. - Margins per material and subgroup

| Subgroup | LDPE | HDPE | PP | PET | Average |
|-------------------|------|------|-----|-----|---------|
| Darkuman MM | 51% | 25% | 34% | 39% | 34% |
| Kpone MM | 35% | 26% | 8% | 36% | 23% |
| Aggregator | 20% | 21% | 21% | 37% | 32% |
| Formal recycler | 12% | 14% | 26% | 27% | 19% |
| Informal recycler | 22% | 14% | 25% | N/A | 23% |

Appendix E. - Equipment costs for sensitivity analysis in GHS

| Equipment | Price per item | Required per month | Total cost per month | Total cost per year |
|---|----------------|--------------------------------------|----------------------|---------------------|
| Waste picker 1 - Ningua Road | | | | |
| Gloves | 40 | 1 | 40 | 480 |
| Shovel | | not required | | |
| Metal picker | 5 | 0.2 | 1 | 12 |
| Waste bag | 2 | 10 | 20 | |
| Wrapping cable | | not required | | |
| Facemask | 5 | 2 | 10 | 120 |
| Boots | | not required | | |
| Helmets | | not required | | |
| Ear protectors | | not required | | |
| Reflective jacket | 50 | 0.08 | 4 | 50 |
| Cutlass | | not required | | |
| Other costs (e.g. phone, injuries) | | Included in salary for waste pickers | | |
| Total equipment cost per year | | | 75 | 902 |
| Waste picker 2/3 - Medie/Kpone dumping grounds | | | | |
| Gloves | 60 | 1 | 60 | 720 |
| Shovel | | not required | | |
| Metal picker | 5 | 0.2 | 10 | 12 |
| Waste bag | 2 | 10 | 20 | 240 |
| Wrapping cable | | not required | | |
| Facemask | 90 | 1 | 45 | 540 |
| Boots | 150 | 0.2 | 25 | 300 |
| Helmets | 20 | 0.2 | 3.3 | 40 |
| Ear protectors | | not required | | |
| Cutlass | | not required | | |
| Other costs (e.g. phone, injuries) | | Included in salary for waste pickers | | |
| Total equipment cost per year | | | 154 | 1,852 |

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