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Effect of the ICT-enabled reclaimer system on the informal waste recycling system in Cape Town, South Africa: The Regenize model

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Abstract

The impact of information and communication technology (ICT)-enabled waste management systems on municipal solid waste, waste reclaimer integration, and resource recovery is critical, particularly in the informal recycling sector. This study investigates the effects of the ICT-enabled waste management system in Cape Town, South Africa, with a focus on the Regenize model. Leveraging digital technologies, the Regenize model aims to improve waste picker integration and resource recovery within the local waste management system. A qualitative research methodology involving semi structured interviews with key stakeholders in Cape Town's ICT-enabled waste reclaimer system, data triangulation, and thematic content analysis was employed to investigate the system's transformative potential. Preliminary findings indicate the Regenize system's alignment with extended producer responsibility (EPR) principles and its embodiment of local entrepreneurial innovation. Waste pickers' active participation as cocreators of waste management mobile platforms has transitioned them from traditional waste collectors to technological contributors, enhancing their role in the waste management ecosystem. Furthermore, the ICT-enabled waste reclaimer system has significantly regularized the status of foreign waste pickers, providing them with essential rights and access to banking services through mobile platforms. By utilizing Internet and Communication Technologies (ICTs) and the Internet of Things (IoT), the Regenize model not only improves resource recovery but also promotes sustainable waste management practices. This represents a substantial step towards inclusive urban waste management in Cape Town. The study's implications extend beyond Cape Town, offering valuable insights for enhancing waste management practices and promoting sustainability across South Africa's broader waste management landscape.

KEYWORDS

ICT-enabled waste reclaimers system, integration, Internet and Communication Technologies (ICTs), Internet of Things (IoT), waste reclaimers

1 | INTRODUCTION

The solid waste management (SWM) system in most South African cities consists of waste disposal (waste-to-landfill) and archaic (end-of-pipe) treatment practices. The Department of Environmental Affairs (DEA, 2018) determined that an estimated 90% of the total generated waste in South Africa ends up in landfills and illegal dumpsites, while only 10% is recycled. This alarming situation depicted by low levels of recycling, recovery, and reuse in South African cities resulted in separation at source programs by 2016 and aimed at "diverting 25% of recyclables from landfill sites for reuse, recycling or recovery" (Godfrey, 2021). However, municipalities did not achieve this goal because the few municipalities that implemented separation at source programs focused on specific suburbs and did not cover the entire extent of the municipality boundaries (Godfrey, 2021; Godfrey & Oelofse, 2017). The Second South Africa Environment Outlook Report highlighted two notable challenges confronted by the SWM sector: "limited understanding of the main waste flows…and absence of a recycling infrastructure which will enable separation of waste at source and diversion of waste streams to material recovery and buyback facilities" (DEA, 2018). Furthermore, accessible and reliable data on the material flows and associated network dynamics of formal and informal waste management systems, for example, waste pickers, are lacking (Govender, 2017). These inefficiencies from outdated infrastructures and technologies in the current SWM regime have resulted in low recycling levels and calls for improving material flow and urban symbiosis in South African cities.

According to the 2020 Waste Management Strategy, approximately 55 million tonnes of general waste are generated in South Africa, and only 11% was diverted from landfills (GreenCape, 2021). Waste pickers play a crucial role in collecting various types of dry recyclables, including paper, cardboard, glass, plastics, metals, tetrapacks, and multilayer materials (Department of Environment Forestry and Fisheries, 2020; Godfrey, 2021). Increased urbanization and consumption in South African cities and the absence of mandatory and punitive waste reduction tactics will result in increased municipal solid waste generation. Consequently, more significant efforts will be required to curb the increase in MSW waste generation through waste minimization strategies to divert waste from landfills to save municipalities' landfill airspace, which is depleting (DEFF, 2020). Furthermore, several municipalities in South Africa are running out of landfill spaces and ensuring adequate compliance with decommissioned landfills, which is costly. In 2020, the municipality and private sector landfilled an estimated 1.7 million tonnes of MSW in the city of Cape Town, with the city landfilling 1.6 million tonnes (GreenCape, 2021). Of the 25 municipalities in Western Cape, 22 have less than 5 years of landfill airspace remaining (GreenCape, 2021). The landfill sites in the city of Cape Town are on Amber Alert and require attention (Figure 1). This worrying situation of depleting landfill airspace has motivated municipalities to adopt innovative waste MSW management models.

Municipalities in South Africa have adopted the zero-waste concept as a sustainable option for MSW based on its inefficiencies and environmentally polluted landfill and incineration solutions. The zero-waste concept stimulates "sustainable production and consumption, optimum recycling and resource recovery, and restricts mass incineration and landfilling" (Zaman, 2014). Central to resource recovery and recycling is collecting recyclable materials, which is performed chiefly by informal waste pickers. Informal waste pickers, or waste reclaimers, "reduce the amount of waste in municipal landfills, recover discarded material, and reintroduce it into value chains for the benefit of the environment and public

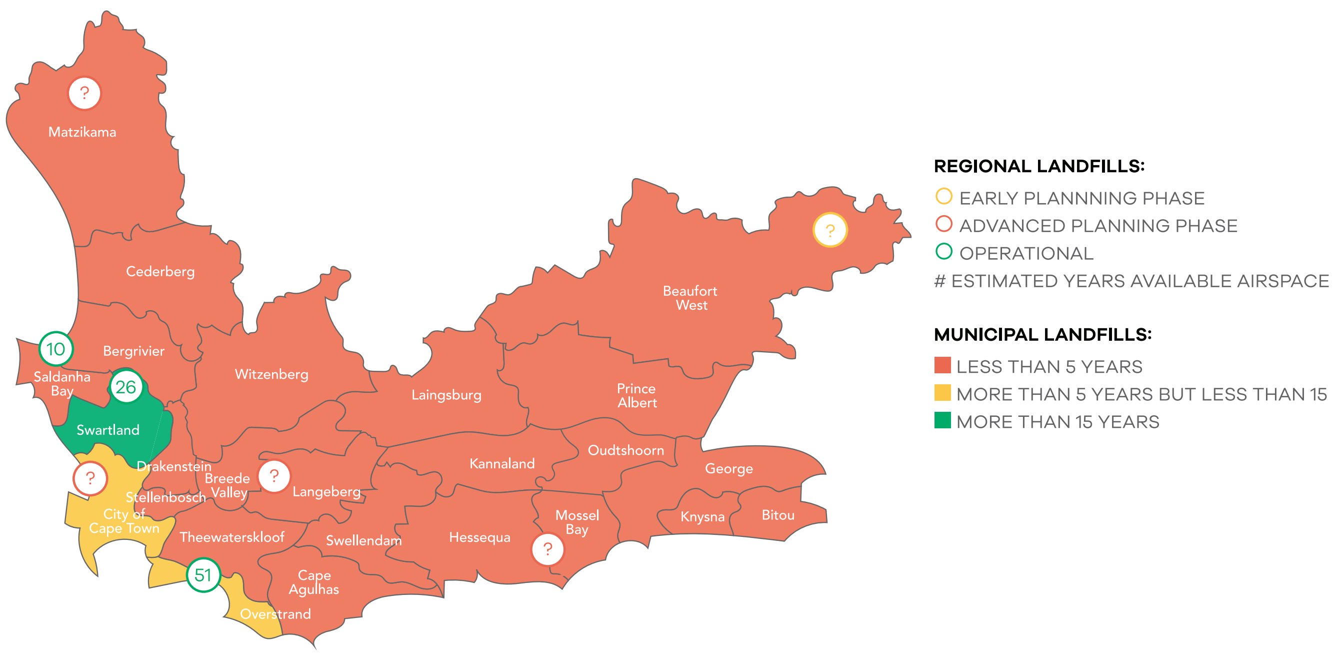

FIGURE 1 The current situation of landfills in Western Cape Municipalities (Greencape, 2022).

health" (Gerdes & Gunsilius, 2010). However, despite their contributions to recycling and environmental performance, waste reclaimers experience exploitation and stigmatization, and actual data on their performance are limited (Godfrey, 2021).

In the context of Cape Town, South Africa, the challenges surrounding waste management have been a focal point of various studies. For instance, Grant (2019) delved into the complexities of e-waste challenges in Cape Town, exploring opportunities for a green economy. Viljoen et al. (2014) conducted a value chain analysis on buyback centers in South Africa's recycling industry, shedding light on the opportunities and value-adding activities within the sector. Pérez et al. (2021) examined the discursive power of recycling, particularly in valuing plastic waste in Cape Town. Additionally, Barnes et al. (2022) highlighted the significance of buyback centers as key integration points between the formal and informal sectors in the waste economy of Cape Town.

Building upon the existing body of knowledge in Cape Town's waste management landscape, this study focuses on the Internet and Communication Technology (ICT)-enabled waste management system, specifically the Regenize Model, as a transformative solution for the informal recycling sector. The integration of digital technologies in waste management has the potential to address various types of waste, including household recyclables, industrial waste, and other forms of recyclable materials. By bridging the gap between formal and informal waste management practices, the Regenize model aims to enhance waste picker integration, resource recovery, and overall sustainability within the local waste management ecosystem. Through an exploration of the ICT-enabled waste reclaimer system in Cape Town, this study aims to contribute to the existing body of knowledge by addressing the knowledge gap in understanding the impact of digital technologies on waste management practices in the region. By leveraging insights from previous studies and highlighting the unique challenges and opportunities in Cape Town's waste management sector, this research seeks to provide valuable insights for enhancing waste management strategies and promoting sustainable practices in South Africa.

2 | INFORMAL WASTE RECYCLING IN SOUTH AFRICA

The role of the informal waste management sector in South Africa is crucial for several reasons. Informal waste pickers and recyclers play a significant role in diverting waste from landfills, contributing to recycling rates, and promoting a more sustainable approach to waste management. Informal waste reclaimers in Cape Town collect and reclaim recyclable waste to generate income and improve environmental protection by diverting large volumes of waste from landfills (GreenCape, 2021). In addition, informal waste reclaimers subsidize municipalities by providing alternative free collection services and reducing disposal costs (Godfrey et al., 2016). For example, Godfrey et al. (2016) reported that 80%–90% (by weight) of postconsumer paper and packaging was collected by waste reclaimers, saving municipalities between R309.2–R748.8 million in landfill airspace in 2014. These recycling achievements illustrate the significant role of the informal waste recycling sector, which has been very successful in bridging the service and value chain despite little-to-no integration (of the informal sector) into municipal waste management services (Godfrey & Oelofse, 2017). Informal waste reclaimer activities help reduce environmental pollution, conserve resources, and create economic opportunities for marginalized communities. Recognizing and supporting the informal waste sector is essential for achieving broader waste management goals and fostering a more inclusive and circular economy in Cape Town (GreenCape, 2021).

Currently, there are few traceable data on the essential role of waste reclaimers in collecting and transporting recyclable waste to buyback centers. Various studies have explored the tonnage of recyclable waste collected by waste reclaimers (DEA, 2018; Godfrey, 2021; Godfrey et al., 2016). However, similar to other developing countries, traceable and accurate waste data on the actual contribution of informal waste reclaimers are limited in South Africa (Gutberlet et al., 2017; Nahman & Godfrey, 2010). The research by Godfrey (2021) sourced the South African waste data of paper and recyclable packaging tonnages collected in 2012 and 2017 from industries (Packaging SA, 2018; Yadav & Patel, 2015). The waste data collected by informal waste reclaimers in South Africa are limited. However, Godfrey (2021) asserts that "none of the Producer Responsibility Organisations (PROs) was able to provide accurate figures on the percentage of paper and packaging collected by informal waste reclaimers."

Although their work is widely acknowledged in government and research for their environmental and social importance to the informal recycling sector, waste reclaimers are stigmatized, discriminated against and excluded from financial inclusion and health care benefits (Tirado-Soto & Zamberlan, 2013). As a result, waste reclaimers are exploited and not adequately remunerated for the services they provide from both middlemen and buyback centers. However, municipalities have established cooperatives and SMMEs to participate in recyclable collection since this is the most favored municipal approach for integrating waste reclaimers, even though research has shown that there is little success of the cooperative model in informal recycling in South Africa (Department of Trade and Industry, 2011; Satgar, 2007). Regarding the sustainability of cooperatives, Godfrey et al. (2016) asserted that "recycling cooperatives have a 92% mortality rate, one of the highest rates of failure for all cooperatives in any sector, nationally." Although municipalities have adopted various mechanisms to integrate waste reclaimers, these programs have been unsuccessful. Waste reclaimer integration in South Africa adopts charity-, developmental-, and human rights-based approaches (Samson et al., 2020). Nevertheless, these approaches have been based on poverty eradication and moving waste reclaimers from recyclable collection to other sectors, such as urban agriculture (Scheinberg et al., 2011). Furthermore, the integration process was based on the formal MSW system and excluded private sector involvement in these initiatives. Therefore, there is a need for a sustainable, efficient, and effective SWM approach through an ICT-waste reclaimer system that has the potential to contribute to an improved livelihood approach, inclusion, integration, and environmental sustainability using ICT-enabled digital platforms.

3 | ICT-ENABLED WASTE MANAGEMENT SYSTEMS

Emerging technologies and waste management digital platforms have transformed traditional municipal SWM into ICT-enabled waste management to achieve ecological objectives, necessitated by the increasing significance of technology in the fourth industrial revolution (4IR), where emerging ICT infrastructures and capabilities offered by computational infrastructure, the Internet of Things (IoT) and blockchain technology can be the foundation of an ICT-enabled waste reclaimer collection system (Bhubalan et al., 2022; Esmaeilian et al., 2018; Steenmans et al., 2021). Therefore, the ICT-enabled waste management system seems to be a promising solution for organized and intelligent waste recycling operations and integrating the informal sector into the formal recycling value chain in smart cities (Zanella et al., 2014). Furthermore, the emerging extended producer responsibility (EPR) system and local business innovation provide associated opportunities and new benefits for integrating waste reclaimers and environmental performance through the ICT-enabled waste reclaimer system.

The ICT-enabled waste reclaimer system is a model for recycling waste collection by informal waste pickers with the aid of the IoT, blockchain technology, and ICTs. Various models of ICT-enabled waste reclaimer systems, referred to as "internet-of-waste pickers," "intelligent collection," and "Internet^{+} recycling resources," have been identified mainly in Colombia, Brazil, and China (Xue et al., 2019; Govender, 2017 and Coelho et al., 2019). The ICT-enabled waste reclaimer system is a "decentralized and smart infrastructural system for the buyback and transfer of recyclable materials recovered from municipal waste streams in emerging economies" (Govender, 2017). In Brazil and China, the model enables users (householders, waste reclaimers, cooperatives, buyback centers, and ICT-waste collectors) to partake in the digital informal recycling market and value chain while enhancing efficiency in collecting recyclable materials (Coelho et al., 2019; Xue et al., 2019; Zhou et al., 2022). ICT-enabled waste reclaimer systems deploy digital waste management platforms and associated infrastructures to transform waste reclaimers' working conditions and informal networks.

In Europe, 87 models for ICT deployment in waste management were identified by de Souza Melaré et al. (2017), and nine of the models used intelligent collection. For example, 85 municipalities in Italy deployed ICT-enabled waste collection, which boosted the rate of recyclable collection by 85%, contributing to Italy's achievement of the European Union circular economy target (Rada et al., 2013). In Portugal, the intelligent collection system transformed household recycling behavior through incentives for participating in separation at sources and recycling (Rocha et al., 2019). However, most ICT-enabled waste management systems are in the initial trial or piloting phase in developing countries; hence, exploring their cost efficiency and operational costs might not be sufficient. Furthermore, previous studies on ICT-enabled waste management systems have focused on architecture and technological deployment within formal waste management systems but have overlooked their application in the informal recycling sector.

South Africa has been experiencing an increased deployment of ICTs and IoTs for collecting recyclable materials in the informal sector (DEFF, 2020; GreenCape, 2021). The ICT-enabled waste management systems in South Africa are in pilot phases and supported by multinational producer companies and as a business innovation project funded by a private ICT company that transformed itself into an ICT-enabled waste collector. Digital waste management platforms such as the WastePlan, the SAEWA E-Waste Alliance, the Glass Recycling Company (TGRC), Kudoti, Regenize, and BanQu play significant roles in waste management. The WastePlan utilizes digital tools to optimize waste collection routes and enhance recycling services, while the SAEWA E-Waste Alliance focuses on e-waste recycling with digital platforms for tracking activities. The TGRC manages glass waste with potential digital solutions. Kudoti, Regenize, and BanQu are also notable platforms in the South African waste management landscape, offering innovative approaches to waste collection, recycling, and tracking through digital technologies. These platforms exemplify the increasing adoption of digital solutions in waste management practices in South Africa, including Cape Town, to improve operational efficiency and promote sustainable waste recycling efforts.

ICT-enabled waste management systems can benefit the informal sector by addressing specific challenges faced by informal waste workers. These systems can streamline waste collection processes, provide access to market information, and facilitate fair compensation for services rendered. By using digital platforms, informal waste workers can overcome barriers such as a lack of capital, limited access to formal markets, and low levels of education. ICT-enabled waste management systems can empower informal waste workers to operate more efficiently, improve their livelihoods, and enhance their integration into the formal waste management value chain. In such ICT-enabled systems, various stakeholders play crucial roles. Informal waste pickers and recyclers collect recyclable materials from households, businesses, and public spaces. Formal waste management entities provide the necessary infrastructure, resources, and market access. ICT providers develop and maintain digital platforms for waste tracking, communication, and data analysis. Government agencies regulate and oversee waste management activities to ensure compliance and equitable practices. By empowering informal waste workers with ICT tools, the system becomes more efficient, transparent, and inclusive, bridging the gap between the formal and informal sectors. This leads to improved waste diversion, resource recovery, and livelihood opportunities for informal waste pickers in Cape Town.

4 | THEORETICAL FRAMEWORK

Sociotechnical transition theory serves as the theoretical foundation for this study to provide a comprehensive understanding of digital transformation within the informal waste management sector. This theory departs from previous approaches such as the social shaping of technology (Mackenzie & Wajcman, 1985) and structuration theory (Giddens et al., 1989), offering a holistic examination of the role of ICT in this context. The selection of this theory is justified by its relevance to the project's goals, particularly through the multilevel perspective (MLP), which differentiates between niches, regimes, and landscapes to provide a nuanced understanding of the interactions leading to digital transformation (Geels, 2002).

ICT-enabled waste management systems such as Regenize align with sociotechnical transition concepts, representing novel configurations within the informal sector. The theory addresses urbanization, resource depletion, and environmental challenges, viewing transitions as coevolutionary processes involving technology, citizens, policies, etc. (Smith et al., 2010). Within this theory, the MLP aids in understanding the digital transformation of the informal waste sector through ICT-enabled systems. This theory is fitting for analyzing the effect of the ICT-enabled reclaimer system on the informal recycling sector, aiming for an intelligent waste collection system and a programmable platform involving recycling stakeholders.

While the MLP is typically applied to formal sectors at the microlevels and macrolevels, its adaptation to the informal waste management sector represents a novel approach. By integrating insights from studies such as Diep et al. (2019) and Iyamu et al. (2022), which explore green infrastructure in informal settlements and municipal SWM transitions, respectively, this study extends the application of the MLP to the informal sector. The MLP incorporates concepts from various theories to offer a comprehensive framework comprising three analytical levels: niches, sociotechnical regimes, and sociotechnical landscapes (Geels, 2002). Niches represent spaces for innovators to develop technologies; regimes consist of networks, rules, and elements stabilizing the existing system; and landscapes encompass external trends influencing niches and regimes (Geels, 2002).

The trajectory of sociotechnical transitions involves four phases: pilot projects, technological innovation, diffusion, and institutionalization. Each phase involves key activities and struggles, often taking decades to complete. This framework is applied to analyze ICT-enabled waste management systems, considering the challenges and conflicts arising from interactions between niche innovations and existing regimes. The sociotechnical landscape of the study, influenced by the distinct contexts of Cape Town, plays a crucial role in shaping the implementation and outcomes of smart city projects. Odendaal (2021) argues that place-specific considerations, influenced by socioeconomic conditions, regulatory frameworks, and waste management landscapes, highlight the need for context-sensitive approaches to ICT-enabled waste management initiatives.

This emphasis on multistakeholder collaboration underscores the importance of addressing local waste management challenges for a more inclusive circular economy. Operationalizing the theory within the context of the study involves clarifying how technology aligns with the MLP framework. Technology, including ICT-enabled waste management systems, can be viewed as a niche innovation within the MLP, facilitating the transition towards more sustainable waste management practices (Geels, 2002). This study will observe and analyze how the integration of technology at the niche level influences interactions between waste pickers, households, ICT companies, and other stakeholders. By examining how technology shapes these interactions and contributes to the evolution of waste management practices within the informal sector, this study aims to enhance the operationalization of MLPs in the context of informal waste management.

5 | MATERIALS AND METHODS

An ICT-enabled waste reclaimer system was adopted for this study using a case study approach, namely, the Regenize/*Remali* project in Cape Town, to understand how digital transformation can contribute to waste reclaimer integration and boost recyclable collection. The object of the study is the effect of an ICT-enabled waste system in an informal waste recycling system. The ICT-enabled waste reclaimer system in Cape Town is an innovative initiative that integrates sustainability, education, and technology to promote recycling in Cape Town. The case study approach enabled the researcher to explore the processes and details of people's daily interactions with a system or artifacts (Walsham, 2006). Yu and Gibbs (2020) validated the relevance of the case study in exploring the process of technological innovation and science at the micro level to understand the smart city phenomenon. Finally, this study adopted interviews and data triangulation procedures (Kaman & Othman, 2016) to increase the credibility and dependability of the study.

Semi structured key informant interviews of purposively sampled respondents, complemented by the researcher's observations of the realities of digital transformation in the selected case studies, formed the primary data source. Various respondents in the ICT-enabled waste reclaimer system were interviewed to elicit subjective views on the transformative nature of the ICT-enabled waste management system. The researcher chose the key respondents due to their direct involvement in the project as active system designers or beneficiaries. The researcher interviewed a total of 22 respondents, including 9 who were waste reclaimers, 4 who were experts, 3 who represented waste reclaimer organizations, and 6 who were provincial government department officials. This distribution highlights the diverse composition of participants across the distinct categories, offering clear insight into the representation of respondents in the research study.

This study implemented comprehensive measures to address ethical considerations for vulnerable participants, specifically waste reclaimers in informal settlements. These measures included ensuring informed consent, maintaining confidentiality, respecting autonomy, and engaging with local communities to understand cultural norms (Diep et al., 2019; Iyamu et al., 2022). Continuous monitoring for emerging ethical issues was also prioritized. Thematic content analysis was used to extract themes on the ICT-enabled waste reclaimer system in Cape Town, focusing on waste reclaimer integration and waste diversion rates. Sociotechnical theory was applied to better understand how technology has transformed the informal recycling sector in Cape Town, promoting sustainability and inclusivity in smart city initiatives (Wilson et al., 2006).

6 | RESULTS

6.1 | Operation neighborhood-based scale: Regenize

The ICT-enabled waste reclaimer system in Cape Town is an innovative and interactive collection method referred to as a household-to-waste reclaimer ICT-enabled collection system. In this model, households register by creating a profile/account on the Regenize platform through a smartphone application (APPs) and log requests for the collection of recyclable materials in Bridgetown, Cape Town. The smartphone uses the GPS location of the household address and specifies the shortest route from the local hub or waste reclaimer to the household site. Similar to intelligent collection in China (Xue et al., 2019), during collection, waste reclaimers identify the household profile/account, submit detailed information about the waste streams, and weight and upload the images of recyclables collected on their Regenize profile. Once the data uploaded and later validated, the household receives a text message on their profile detailing the weight of recyclables, the amount of carbon emissions they have saved, and the *Remali* incentive equivalent to the recyclables they have traded. For example, one waste reclaimer noted, "Before using the Regenize platform, it was difficult to keep track of our collections and earnings. Now, everything is organized, and I feel more in control of my work. The platform has revolutionized our collection process, allowing us to efficiently cover a larger area and serve more households in less time." This quote illustrates the enhanced scale of operation and control reclaimers' experience using the Regenize platform.

6.2 | Provision of ICTs and associated infrastructure for informal waste pickers

ICT-enabled waste reclaimer systems intervene in the informal sector by providing technologies and other associated equipment to transform the current traditional informal recycling sector. Some of the interventions in the Regenize project that deserve mentioning are the provision of tricycles, smartphones, PPEs, hand scales, and storage containers (local hubs) for sorting and storing recyclable materials. The provision of technologies and associated equipment to waste reclaimers is similar to that of the Relix project in Brazil (Coelho et al., 2019). Another reclaimer stated, "the Regenize platform has reduced the time we spend sorting and transporting waste. We know exactly where to go and what to collect, thanks to the notifications we receive." Such testimonies highlight the operational efficiency gains from the system, reducing labour-intensive processes and increasing productivity. The interventions improved the working conditions of waste reclaimers in Cape Town and transformed their image in the communities in which they are operating. The provision of tricycles enabled waste reclaimers to collect more and transport their materials while improving their quality of life (Figure 2). Tricycles were given to waste reclaimers, which have the potential to change their image on streets because they use makeshift trolleys, which has caused congestion and accidents on roads.

FIGURE 2 Work conditions of waste reclaimers before and after the Regenize Project (Regenize, 2021).

FIGURE 3 The local hub in Bridgetown, Cape Town, for the Regenize Project (Regenize, 2021).

The provision of smartphones and local hubs in the ICT-enabled waste reclaimer system transformed the collection of materials into being systematic and efficient. Smartphones provide a daily list of households where waste reclaimers collect recyclables (Xue et al., 2019). This resulted in an organized and consistent collection of recyclables in the area. Digital platforms enable the systematic and consistent collection of recyclables through recorded daily collection schedules for households, suburbs, collection times, types, and amounts of waste collected and frequency, which becomes consistent and systematic. The infrastructure includes smartphones, apps, and tricycles equipped with GPS. These tools are vital for improving reclaimer productivity and safety. A reclaimer commented, "With the tricycle and GPS, I can navigate through the city easily and collect more waste without getting lost." In addition, smartphones enhance route optimization and empower informal waste reclaimers to schedule collections and improve their working conditions using data from ICT-enabled systems.

The project also intervened with the provision of storage containers designated as local hubs where waste reclaimers sort and store their recyclables before collection by the ICT-enabled waste collector. The local hubs are strategically located within the suburbs, reducing the long distance traveled by waste reclaimers to collect materials, thereby creating adequate time to sort the materials at the local hubs. In addition, local hubs have enabled waste reclaimers to collect more recycling by specializing in specific areas, increasing waste reclaimer visibility, and helping households become aware of and participate in recycling initiatives (Coelho et al., 2019). After sorting, the ICT-enabled waste collector (Regenize) collects recyclables for commercial buyback centers and recyclers (Figure 3). Additionally, local hubs prevent the illegal dumping of unwanted recyclables while sorting collected materials by waste reclaimers in open spaces and parks.

6.3 | Organized value chain with permanent transactions and traceable data

Several actors trade within the traditional informal recycling value chain with informal waste reclaimers at the lower end of the value chain. Since the informal value chain is unsystematic, waste reclaimers sell their materials to collectors, middlemen, or small informal buyback centers, which trade recyclables to commercial buyback centers and recyclers. The price of recyclable material increases as the amount of recyclable material increases in the value chain, and in each stage, the sorting of recyclable material meets the buyer's requirements. In this case, trading of recyclables takes place with each actor interacting, and since waste reclaimers are at the lower end of the value chain, they experience exploitation. In contrast to the traditional informal recycling value chain, the ICT-enabled waste reclaimer system has an organized value chain that includes households, waste reclaimers, registered buyback centers, ICT waste collectors, recyclers, and producers (Xue et al., 2019). The Regenize ICT-Waste Collector Company owns the sorting centers; they control and monitor the collection process from the household until the sorted materials are collected from the waste reclaimers and sold to the recycling companies. A reclaimer explained, "The app tells me which households have recyclables ready. I can collect them and directly sell them to the buyback center. It's all very streamlined now." This seamless flow of information and materials illustrates the efficiency of the new value chain. Thus, the digital transformation of the informal recycling sector through the application of ICT-enabled waste management digital platforms has incorporated households, ICT waste collector companies and producers previously excluded from the municipality-led integration process.

In the traditional informal recycling sector, neither the waste reclaimers nor the buyback center keeps accurate transaction records and statistical records of the waste quantities collected by waste reclaimers. Although recording is performed, the current technologies and systems in the informal recycling sector are paper-based, centralized and manual (MS Excel), making waste-related data easy to tamper with or alter from the system (Ahmad et al., 2021). Regenize system is developed to operate on blockchain technology, which offers the informal recycling sector an opportunity to facilitate payment transactions, communicate and keep detailed trading data available to all stakeholders in the value chain.

Detailed statistical information on the transactions, including the prices and quantity of recyclables, is provided at any moment and in real time. The system ensures transparency and accountability in transactions, with reclaimers receiving immediate notifications of payments. "Every transaction is recorded in the app, so I always know how much I've earned and when," shared a reclaimer. ICT-enabled reclaimer systems have transformed the informal recycling sector from cash-based to digital payment systems for waste pickers (Govender, 2017). The South African ICT-enabled waste reclaimer systems allow buyback centers to pay waste reclaimers through electronic payments such as "e-wallet and cash sent" linked to financial institutions through a mobile payment platform. Since the sector can now trade money and digital payments, this has increased recyclable trading. This electronic payment system includes waste reclaimers in the mainstream banking system.

6.4 | Tracking and monitoring of waste recyclable collection and diversion rates

The ICT-enabled waste reclaimer system has provided an opportunity for all the actors in the value chain to track waste material flow activities, enhance transparency in collection activities and guarantee that waste materials are collected quickly by legitimate waste reclaimers (França et al., 2020; Xue et al., 2019). The Regenize model of intelligent collection relies on household requests to collect recyclables, unlike fully developed ICT-enabled systems based on automated bin sensors. In South Africa, the data generated from ICT-enabled waste reclaimer systems are used for reporting purposes by manufacturers in compliance with EPR Regulations (DEFF, 2020). Because of data policies, the study managed to access Regenize data for recyclables collected in Bridgetown, a suburb in Cape Town. Between October 2018 and December 2021, Regenize diverted a total of 229 tonnes of recyclable material. This tracking system is crucial for monitoring performance and improving waste management practices. "The app's tracking feature helps us ensure that no waste goes uncollected, and waste reclaimers or households can report any issues immediately," explained one of the Regenize officials. Providing accurate and real-time data allows waste reclaimers to monitor and compare their collection rate against that of other private waste collectors to achieve the zero-waste goal in Cape Town. The ability to monitor and track waste reclaimer performance boosts waste diversion rates, resulting in municipalities meeting their annual recycling targets. The data enable industries, municipalities, and governments to determine the accurate contribution of waste reclaimers in diverting waste from landfills. In addition, these data from Regenize provide households, municipalities, and waste collectors with a cohesive, systemic approach to comprehending, and quantifying the contribution of waste pickers to the city recovery rate and carbon emission reduction.

The themes of scale of operation, ICT infrastructure, value chain, and tracking and monitoring were selected due to their critical roles in the successful integration of the ICT-enabled system. These themes emerged from a thorough thematic content analysis of the interview data, highlighting the pivotal aspects influencing the system's effectiveness and sustainability. Within the MLP framework, these themes correspond to different levels of sociotechnical transitions. The scale of operation pertains to the "landscape" level, representing broad socioeconomic and environmental impacts on diverse communities (Geels, 2002). ICT infrastructure aligns with the "regime" level, which is essential for enabling system functionality and improving operational efficiency within existing technological and organizational structures (Geels & Schot, 2007). The value chain is critical at the "niche" level, impacting economic transactions and data management and fostering innovations within the waste management ecosystem (Smith et al., 2010). Tracking and monitoring are pivotal for ensuring accountability, transparency, and continuous improvement across all levels of the MLP framework, driving systemic change (Rip & Kemp, 1998). The integration of the ICT-enabled waste management system has revolutionized informal waste management by enhancing efficiency, transparency, and economic opportunities for waste reclaimers. The selected themes provide a comprehensive framework for understanding these impacts, supported by rich qualitative data from our interviews. This new value chain and the broader implications of our findings underscore the transformative potential of ICT in urban waste management (Geels, 2002; Geels & Schot, 2007; Smith et al., 2010; Rip & Kemp, 1998).

7 | DISCUSSION

This study shows how the ICT-enabled waste reclaimer system has transformed the traditional informal recycling system. This system exhibits a robust organizational framework, surpassing traditional methods by enhancing infrastructure, organizing the value chain, facilitating data collection, ensuring smooth transitions, and enabling comprehensive tracking and monitoring of waste recyclable collection by all involved stakeholders (Doe et al., 2023). Furthermore, the technological artifacts and associated benefits afford the ICT-enabled waste reclaimer system the potential to integrate waste reclaimers into the formal municipal SWM system.

The Regenize company is implementing the ICT-enabled waste reclaimer system in Bridgetown, Cape Town. Two approaches to ICT-enabled integration have emerged in the literature: limited depth and collaborative integration (Xue et al., 2019). Regenize company's adoption of the limited depth integration approach, which focuses on experienced waste reclaimers, has proven efficacious. The provision of essential tools such as tricycles, smartphones, and personal protective equipment (PPE), coupled with training on ICT-enabled waste collection methods, addresses critical gaps in informal waste recycling systems (Munsamy, 2022). Furthermore, innovative solutions such as mobile payment platforms, render waste reclaimers, bankable, and foster social inclusion. Regenize exhibits similar benefits as China's Internet^{+} recycling resource, where waste reclaimers "can enjoy social insurance and welfare benefits from the ICT-enabled waste collector company" (Xue et al., 2019). The benefits of limited depth integration in the Regenize project are lacking in traditional informal waste recycling systems.

ICT-enabled waste reclaimer systems have enabled the intelligent collection of recyclables by waste reclaimers, thereby enhancing efficiency. The first aspect is the digitalization of paper-based data captured through the use of blockchain technology, which is an immutable ledge with all the information about transactions, waste streams, quantities of recyclables, the name of the waste picker, and the buyback center that has purchased the recyclables. Blockchain-driven data capture ensures transparency and immutability, while smartphone-based scheduling optimizes collection routes, reducing travel distances for waste reclaimers (Brown et al., 2019). Additionally, the introduction of cashless payment systems stimulates more trading of recyclables, reducing reliance on cash transactions. Thus, the ICT-enabled waste reclaimer system has the potential to create opportunities to promote social inclusion (Njoki & Wabwoba, 2013). Finally, the ICT-enabled waste reclaimer system allows for cashless payments via mobile application platforms, thereby increasing the trading of more recyclables, as the informal waste recycling sector no longer depends on cash payments.

Since the ICT-enabled waste reclaimer system was developed on blockchain technology, it can adopt cryptocurrency payments as incentives to motivate residents to participate in recycling and separation at source initiatives. Cryptocurrency incentives, such as those provided by *Remali*, further incentivize residents' participation in recycling initiatives, offering rewards that are redeemable in selected shops (Lidia et al., 2018). Similarly, in Argentina, citizens using the *JellyCoin* platform to participate in recycling initiatives are rewarded with *JellyCoin*, a redeemable virtual currency (Bhubalan et al., 2022; Steenmans et al., 2021). Incentives and rewards should not be only monetary but must consider other non-digital services such as PPE, separation at source refuse bags, and Council tax discounts.

The Regenize platform has broader implications, including improved residence and work status of foreign and illegal immigrant waste reclaimers, thereby enabling access to credit services, bank accounts, and mobile phones (Garcia et al., 2016). A blockchain ledger with a list of transaction records is used as proof of income, which is one of the requirements for informal workers when applying for a general work permit, Zimbabwe Exemption Permit (ZEP) or Lesotho Exemptions Permit (LEP). By regularizing their stay, waste reclaimers can now access credit services, open bank accounts, and mobile phone purchases through contracts. Regularizing waste pickers' status also facilitates access to municipal and government integration benefits.

In the evolving waste management landscape, ICT-enabled waste collector companies are emerging as key integration institutions, supplanting traditional buyback centers. This shift signifies a fundamental restructuring of the informal sector and recycling value chain, propelled by technological advancements and collaborative endeavors among various stakeholders (Taron et al., 2023). In the Regenize project, ICT-enabled waste collector companies are emerging and new institutions of waste reclaimer integration through the provision of infrastructure, technology, equipment, sorting spaces, and training waste reclaimers with aspects of ICT-enabled waste reclaimer systems. As a result, ICT-enabled waste collector companies are now replacing buyback centers as institutions of integration in the informal sector and recycling value chain.

ICT-enabled waste reclaimer systems in South Africa, exemplified by the Regenize model, have evolved within a complex framework involving technology and local networks (Geels, 2002). This study underscores the pivotal role of the Regenize model in enhancing waste reclaimer integration and resource recovery, aligning with the MLP framework. By prioritizing operational efficiency, transparency, and stakeholder engagement, the model offers valuable insights for stakeholders across government, academia, NGOs, and the private sector (Wang et al., 2021). Regenize has progressed to the phase in which stakeholders engage with the technology, embedding it in daily practices.

The key drivers behind these systems include government departments, waste reclaimers, academia, NGOs, and ICT companies. This network of innovators focuses on digital transformation in the informal waste sector. ICT-enabled waste reclaimer systems, which act as facilitators, continuously stimulate innovation in waste management through digital tools and end-user engagement. The MLP provides a conceptual lens for understanding the trajectory of ICT-enabled waste reclaimer systems. It delineates three analytical levels: niche, regime, and landscape. At the niche level, the systems operate as novel innovations with protection and support (Geels, 2002). However, existing waste management regimes, encompassing laws, regulations, user preferences, and market dynamics, pose challenges to their adoption. Struggles between innovators and established regimes involve economic, business, and political dimensions, affecting municipalities, waste reclaimer organizations, industries, academia, NGOs, policymakers, and other societal groups (Geels, 2002). Uncertainty persists regarding the systems' ability to overcome these challenges, as some technologies face setbacks in this dynamic sociotechnical landscape.

Finally, the research has demonstrated that waste reclaimers are not only crucial stakeholders but also data creators and system co-designers of ICT-enabled waste reclaimer systems. Waste reclaimers generate data in each phase of collection, transporting, and trading of materials at the buyback center or ICT-enabled waste collector. This data are key to designing policies, improving the efficiency of the collection of recyclable materials, and ensuring producers' compliance with EPR requirements. Furthermore, waste reclaimers are engaged in designing and developing platforms applicable to the informal recycling sector due to their knowledge of the recycling sector. However, the study acknowledges certain limitations, including potential resistance from some waste reclaimers, particularly concerning ownership, accessibility, and data presentation, which introduces conflicts and impedes further development. Further research is warranted to explore these dynamics and assess the long-term sustainability and scalability of ICT-enabled waste reclaimer systems within the MLP framework.

8 | CONCLUSION

The deployment of digital platforms in the informal recycling sector has led to the formulation of an ICT-enabled waste reclaimer system for the systematic, organized, and efficient collection of recyclables by waste reclaimers. In South Africa, the ICT-enabled waste reclaimer system emerged as a local innovation funded by multinational companies. ICT-enabled waste reclaimer systems can potentially optimize the collection of recyclable materials by adding the Internet of Things (IoT, ICTs, and blockchain technology) to traditional informal recycling systems. ICT-enabled waste reclaimer systems have augmented waste pickers' role in the recycling value chain through route optimization, organized value chains, permanent, and traceable transactions, and access to various payment modes through mobile platforms. Furthermore, the use of smartphones and daily schedule lists for collection has improved efficiency through reduced travel time and increased access to recyclables. The ICT-enabled waste reclaimer system incorporated households and the private sector, which were previously excluded from municipality-driven recycling and separation at source initiatives. Research has demonstrated that waste reclaimers are vital stakeholders in resource recovery, data co-creators, and system co-designers of ICT-enabled waste reclaimer systems. The provision of incentives to waste reclaimers and households boosted the recycling rate in Cape Town and transformed households' perceptions of recycling initiatives.

The ICT-enabled waste reclaimer system has the potential to track and monitor recyclable waste performance data and the actual contribution of waste reclaimers in the recycling value chain. Although the two ICT-enabled waste reclaimer systems are in their pilot phases, they have the potential to augment municipality-driven separation through source and recycling initiatives. Municipalities in South Africa must explore partnerships with ICT-enabled waste collectors to resuscitate the failed separation at source initiatives to achieve their annual recyclable collection and waste diversion target. In 2021, South Africa implemented the extended producer responsibility regulation to integrate waste reclaimers and establish annual recovery targets for industries. Thus, the ICT-enabled waste reclaimer system, through the gazetted EPR regulation, can provide efficient and optimum recyclable waste recycling and recovery in Cape Town.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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