PROCEDURES | INTERVENTIONS | GENERAL METHODOLOGY

Guide to municipal plastic waste management in Bangladesh

SCIP plastics

Sustainable Capacity building to reduce Irreversible Pollution by Plastics

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Sustainable Capacity building to reduce Irreversible Pollution by Plastics

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SCIP PLASTICS 360° VIRTUAL TOUR

Exploring plastic waste management in Bangladesh!

Starting at the Awareness Centre at KCC headquarters in Khulna, the interactive 360° virtual tour 'SCIP Plastics' showcases results from the SCIP Plastics project and provides a detailed and immersive overview of different research sites in the Khulna area and Mongla Port. From the Awareness Centre, the tour leads to different locations in the Khulna region, such as a plastic recycling shop, a secondary transfer station, the Rajbandh disposal site or a jute mill. Informative texts, photos and videos provide deeper insights and a broader understanding of the joint fieldwork and the SCIP Plastics project results.

The tour is accessible via any standard web browser through the QR code or link below. It is designed as a desktop application with limited mobile device functionality.

www.360-degree.education/SCIP_Plastics

INTRODUCTION

Across the globe, municipalities grapple with the growing challenge of managing solid waste in ways that protect public health, reduce environmental impact, and remain feasible with limited resources. Effective waste management has become an urgent priority for urban centres as cities face increased waste generation driven by population growth, rising economic activity, and changing consumer habits. Within this vast waste stream, plastic stands out – not only for its potential to harm ecosystems, health and other infrastructure systems but also for its ability to be recycled and repurposed. Yet, despite its promise, plastic remains one of the most mismanaged waste materials, especially in low-resource regions where efficient waste systems are difficult to sustain.

Bangladesh exemplifies these challenges on a complex scale. With its extensive waterways and densely populated urban areas, the country is vulnerable to severe consequences from mismanaged plastic waste. Though Bangladesh generates a relatively low amount of plastic waste per capita compared to high-income nations, it ranks among the top contributors to marine plastic pollution due to its dense population and proximity to the Bay of Bengal. Mismanaged waste often finds its way into rivers, channels, and the sea, clogging drainage systems, increasing flood risk and harming both aquatic and human life. Without effective interventions, this issue is expected to worsen as economic growth and urbanisation escalate waste production, adding pressure on municipalities to find sustainable solutions.

The need for a systematic and evidence-driven approach to waste management is more critical than ever. However, municipals in Bangladesh face significant hurdles, from inconsistent data to limited resources and outdated practices. Effective planning demands reliable information on waste composition, collection patterns, and disposal – information that is frequently unavailable or inconsistent. This knowledge gap hinders the design and implementation of effective waste management strategies, which are crucial for improving public health and minimising environmental damage.

This guide aims to bridge this gap by offering practical approaches to assess and reduce plastic waste emissions tailored to the unique challenges of Bangladesh. Targeted at municipal managers, planners, and young researchers, this resource presents approaches for data collection, waste analysis, and intervention design, supported by real-world examples from a recent research project focused on plastic pollution reduction. The guide's modular structure allows users to explore topics relevant to their specific needs, whether they involve system analyses, waste sampling, or operational strategies. By adopting these procedures, municipalities can more effectively navigate the complex landscape of waste management, fostering sustainable practices that prioritise both local conditions and long-term impact. Thus, this guide aims to empower decision-makers and researchers alike to take actionable steps toward a cleaner, healthier environment in Bangladesh.

ABOUT THE AUTHORS

This guide was written in 2024 by the authors of the international research project “Sustainable Capacity building to reduce Irreversible Pollution by Plastics” (SCIP Plastics). This joint research initiative supports the sustainable transformation of municipal waste management systems in Bangladesh. The project aims to build capacity through a waste management hub that brings together a broad alliance of universities, municipalities, institutes, political entities, and businesses.

The project consortium consists of two German partners, the Bauhaus-Universität Weimar (BUW) and the Institute for Social-Ecological Research (ISOE), and three partners from Bangladesh, the Khulna University of Engineering & Technology (KUET), the Chittagong University of Engineering & Technology (CUET), and the Khulna City Corporation (KCC).

In close cooperation with the KCC, various working groups investigated Secondary Transfer Stations and final disposal sites, as well as the private recycling sector in Khulna. Additionally, the project explored the potential for substituting plastics with jute products and a special case study at Mongla Port. The project also involved establishing a laboratory and collaboratively developing an Awareness Centre with KCC in the inner-city area.

https://www.scip-plastics.com

© Md Rafizul Islam

Professor Dr. Md Rafizul Islam

Since 2004, Professor Rafizul has contributed to research in organic soil characterisation, solid and plastic waste management, and landfill lysimeter technology.

Professor Rafizul’s international engagement in finding solutions for Bangladesh’s environmental challenges is evident in his role as the Academic Coordinator of the *EU Erasmus+ Programme* with the Bauhaus-Universität Weimar, Germany, since December 2020. This role is in addition to his other significant contributions: under the *Asia Pro Eco-II Programme* funded by the European Commission, he was a Research Associate, first in the *SoilTech* project (April 2006 to January 2007) and later in the *Safe & Sustainable Municipal Waste Management II (WasteSafe II) Project* (June 2008 to December 2009). In these projects, he collaborated with various international partners, including the *Asian Institute of Technology* in Thailand, the *Flemish Institute for Technological Research* (VITO) in Belgium and the Bauhaus-Universität Weimar in Germany. Professor Rafizul completed several research projects funded by Bangladesh’s University Grants Commission (UGC). He participated in research initiatives and international conferences across the globe, visiting countries such as Italy, Canada, Germany, Singapore, China and India.

Furthermore, Professor Rafizul worked as an expert in the consultancy team of the *Consultancy Research & Testing Services (*CRTS) Department of Civil Engineering, KUET. Professor Rafizul has authored 200 publications in Journals (56) and Conferences (144) and received several best paper awards at national and international conferences.

© Abir Ul Jabbar

Abir Ul Jabbar

Abir Ul Jabbar is the Chief Planning Officer of Khulna City Corporation, which operates under the Ministry of Local Government, Rural Development, and Cooperatives. He earned his Master of Urban & Regional Planning from Bangladesh University of Engineering & Technology (BUET) in 2004 and completed his Bachelor's degree in Urban and Rural Planning from Khulna University in 2000. In 2005, he was appointed Assistant Engineer (Planning) at Khulna City Corporation.

Throughout his career, he has gained extensive experience in various areas, including the preparation of project proposals, Master Plans, drainage network development, traffic management, waste management, city beautification, urban renewal, building control, preservation of water bodies, and the development of public spaces, parks, and slum improvement.

His first international project was the *Safe & Sustainable Municipal Waste Management Project* (Wastesafe) under the *Asia Pro Eco II Programme* of the European Commission in 2007. He served as the Assistant Coordinator for the City Region Development Project, which was supported by the Asian Development Bank, and as Assistant Engineer (Planning) for the Construction of the Sanitary Landfill project at Khulna City Corporation. He also held the position of Deputy Project Director for developing the heritage site of Khulna Shahid Meenar, Hadis Park, and its adjacent pond. Furthermore, he served as the Project Director for the project aimed at mitigating water logging and improving the environmental condition of Khulna City, funded by the *Bangladesh Climate Change Trust Fund* under the Ministry of Environment. He also directed the C*limate Change Adapted Urban Development Project*, funded by the German Development Bank (KfW). Additionally, he has served as the Point of Contact for the *Asia Resilient Cities* project, funded by USAID and supported by the Bangladesh Rural Advancement Committee (BRAC).

© Harry Kleespies

Heide Kerber, MA

Heide Kerber is a research scientist at the ISOE – Institute for Social-Ecological Research, where she is a member of the 'Coupled Infrastructures' and 'Water and Land Use' research units. Her work is grounded in the social sciences, with an emphasis on human geography and political science. She specialises in environmental governance, particularly integrated water resources management and water reuse, and has extensive experience addressing water pollution from marine litter and other anthropogenic pollutants.

Her research extends beyond Germany, reaching countries such as Bangladesh, Vietnam, and Namibia. She is actively involved in the *Prevent Waste Alliance*, an international initiative advocating for a circular economy, and participates in the *German Round Table on Marine Litter*.

Embracing a transdisciplinary approach, she integrates the perspectives and practical knowledge of social actors into her research. She views her work as a collaborative learning experience between science and society, aiming to link social solutions with scientific knowledge for ecologically and socially just transformations. Her research in Bangladesh, starting with the SCIP Plastics Project, is just the beginning of what she hopes will be a long-term research collaboration.

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Professor Dr.-Ing. Eckhard Kraft

Professor Dr-Ing Eckhard Kraft holds the chair of Resource Management at the Bauhaus-Universität Weimar and has a board membership in the Bauhaus-Institute for Infrastructure Solutions (b.is). His research focuses on biological treatment methods for domestic household waste, particularly the biodegradability of different materials. He is a member of the *Working Committee on Bio-based and biodegradable plastics* and the *DIN CERTCO Certification Committee on Biodegradable Materials*.

Professor Kraft's research focuses on theory but is deeply rooted in practical applications. He actively seeks interaction with practitioners and municipalities, recognising the importance of transferring scientific knowledge into applied practice. In his technical centre and laboratories, investigations go beyond small-scale experimentation to actually conducting and analysing biotechnological experiments in real-case scenarios. He is dedicated to developing and promoting applied solutions which can be effectively utilised in real-world settings. His commitment to global waste management solutions drives his research and is evident in his long-standing and ongoing collaborations with the Global South.

Since 2007, Professor Kraft has been working on research initiatives with KUET in Bangladesh, starting with implementing demonstration landfill sites and the collaborative foundation of the *WasteSafe International Conference*. Since then, he has guided the organisation of the WasteSafe Conference as a co-chair and has been a keen observer of the development of Bangladesh's waste management sector.

Professor Dr. Mst Farzana Rahman Zuthi

Professor Dr Mst Farzana Rahman Zuthi is a faculty member of the Department of Civil Engineering at Chittagong University of Engineering and Technology (CUET) in Bangladesh. Her expertise lies in environmental engineering, especially in water quality and treatment, sustainable solid waste (mainly plastic waste), and wastewater management. During her tenure as chair of the *Centre for Environmental Science and Engineering Research* (CESER) at CUET, she promoted knowledge development and awareness about sanitation and hygiene issues, emphasising gender-sensitive strategies for climate change adaptation.

Professor Zuthi has been actively collaborating with local and international organisations to effectively implement practical solutions for waste and water management. She demonstrates her leadership qualities as one of the master trainers and trainers at the *International Training Network* (ITN) of BUET. In this role, she not only imparts her knowledge but also serves as a mentor to students and young professionals, fostering their growth in the field. She focuses training on capacity building among municipal authorities and communities in the WASH sector for sustainable development. She is also involved with the *International Conference on Sustainable Waste Management and Circular Economy* to promote the circular economy in waste management and with NORPART, a collaboration programme between the University of Agder, Norway, and CUET that fosters international cooperation in education and research.

Professor Zuthi is a lifetime member of the Institute of Engineers, Bangladesh (IEB). Her research collaboration with CUET's Directorate of Research and Extension (DRE) reflects her unwavering commitment to addressing critical environmental issues in Bangladesh.

Bauhaus-Universität Weimar

CUET

PARTNERS

Political partners

Ministry of Environment, Forests and Climate Change (MoEFCC)
Department of Environment
Dhaka – 1207

University Grants Commission of Bangladesh (UGC)
Dhaka – 1207

Mayor's office Khulna
Khulna City Corporation (KCC)
Khulna – 9100

Mayor's office Mongla
Mongla Port Municipality (MPA)
Bagerhat – 9350

Nirala Janokallan Sanity at Ward no. 24
Community based organisation (CBO) Khulna – 9100

Implementing partner

Bangladesh Jute Association (BJA)
Unincorporated Association
Khulna – 9202

USING THIS GUIDE

The authors of this guide understand the waste management system of Bangladesh as a complex network of public, private and informal sector stakeholders. At the centre is the municipal authority. In our examples, this is generally the Khulna City Corporation (KCC). It is responsible for ensuring the collection and disposal of municipal solid waste, particularly from households and streets, roads and drains. The collection system is split into primary collection and secondary collection, where municipal collection activities mostly focus on the secondary collection. More details on the Bangladesh waste collection system are provided in the chapter *System description – Waste collection analysis.* Recycling activities are mostly left to the private sector and are often informally organised. First insights into this stakeholder network and recycling sector are presented in the chapters *System description – Stakeholder analysis* and *– Recycling value chain analysis.* This basic understanding of the waste management system informed the guide's structure and order of the chapters.

One of the key features of this guide is its modular structure, designed for flexible and convenient use. Each section is self-contained, providing short and concise information and practical examples on specific topics. Rather than being read from front to back, this guide encourages the reader to jump directly to the relevant chapter. The chapters are sorted into three main sections: *Procedures*, *Interventions* and *General methodology*. In the chapters *Procedures* and *Interventions*, **cross-references** appear in the margins of the page. They highlight interconnections, help with navigation, and guide the reader to useful background information in the final chapter, *General methodology.* The cross-references can point in both directions, i.e., refer to previous and subsequent chapters.

Additional resources that provide comprehensive information on specific subjects or are considered key literature in the field are either directly referenced in the text or listed under *Further reading.* Both *References* and *Further reading* appear in the margins of the respective chapter.

PROCEDURES

This first chapter outlines methods used to generate reliable data for waste management. It is divided into three sub-chapters that cover procedures for system description, waste analysis and sampling, and operation.

The first section, *System description*, focuses on descriptive procedures, identifying stakeholders, analysing their interactions, and modelling and measuring processes in waste collection and recycling while also presenting methods for developing business models and assessing environmental impact. The second section is dedicated to methods for evaluating the composition and characteristics of various waste streams, employing procedures such as sampling and sorting. The third section addresses practical operational procedures, including assessing and monitoring final disposal sites, understanding the role of the informal sector, and gauging public acceptance of waste management strategies. For each presented procedure, we tried to provide a real-life example illustrating how the procedure can be applied and what challenges were faced.

INTERVENTIONS

This chapter builds on the examples presented in the procedures, offering concrete interventions to address key challenges. It includes implementing business models, substituting plastic with local alternatives, and installing and operating a weighing platform at a disposal site. It also outlines strategies for managing mismanaged plastic waste at recycling shops, developing environmental management plans for final disposal sites, and promoting sustainable practices for the broader public and the waste management sector.

GENERAL METHODOLOGY

Although this chapter does not contain practical examples, it offers basic insights into planning approaches and scientific methodologies crucial for generating reliable data. Most chapters in *Procedures* and *Interventions* are based on the concepts presented here, making the chapter relevant and worthwhile to read, either before starting on the actual procedures and interventions or to quickly refresh existing knowledge in these fields. The chapter also aims to create a common understanding of central terms like system, representative sampling, material flow or social empirics.

As a final comment, we like to point out that this guide makes no claim to present all procedures and interventions necessary to tackle the plastic waste challenge. However, we see it as a "Getting Started" companion that assists in better understanding and making the first steps in sustainable plastic waste management.

1 PROCEDURES

SYSTEM DESCRIPTION

1.1 STAKEHOLDER ANALYSIS

Mapping roles and interests of stakeholders

BY H. KERBER AND L. SATTLEGGER

→CROSSREF:
- Waste collection analysis ▸p. 23
- Recycling value chain analysis ▸p. 30
- Social Business Model Canvas ▸p. 35
- Final disposal site assessment ▸p. 52
- Informal sector assessment ▸p. 64
- Social-empirical research methods ▸p. 105

Waste management depends on the interplay of various stakeholders and their practices, including municipal waste officers, formal and informal waste workers, business operators, such as those involved in recycling, and citizens. A stakeholder analysis (often also referred to as actor analysis) equips municipalities and policy-makers with essential insights into the roles, interests, and interactions of stakeholders to make informed decisions, design targeted interventions, evaluate the impacts of services or interventions, enhance communication strategies, and improve public service delivery.

Stakeholder analysis refers to the systematic examination and understanding of the stakeholders involved in a particular situation, event, or system. This method not only highlights the key players and their interests but also identifies gaps in communication and collaboration. The term 'stakeholder' here does not refer solely to individuals but encompasses any entity or group that has agency, influence, or a stake in the context being studied. A stakeholder analysis can be developed using literature studies, social-empirical data collection, or a combination of both.

An empirically based stakeholder analysis can include the following steps:

1. Goal and scope definition: Defining the objectives and boundaries of the study, specifying what aspects of stakeholder roles and interactions will be explored.
2. Identify relevant actor groups: Identifying and selecting relevant stakeholder groups through a literature review and/or expert interviews, e.g., households, municipal agencies, informal waste collectors, recycling shop owners, etc.
3. Design and conduct data collection: Develop methods such as surveys, interviews, or observations to gather qualitative and/or quantitative data.
4. Interpretation: Analysing and processing data according to the goal of the study, e.g., by creating a stakeholder map and/or report to summarise roles, practices and perceptions of relevant stakeholders.

Key advantages:

→ Identifying stakeholders: Identifying key stakeholders and understanding their interests is essential for effective decision-making and meaningful stakeholder engagement.

→ Comprehensive understanding: A stakeholder analysis enables anticipation and consideration of key factors, offering deep insight into the roles, relationships, and dynamics among various stakeholders within a system or context.

→ Anticipating behaviour: This allows for anticipating the behaviours and responses of different actors to interventions or changes in the system.

Key challenges and limitations:

→ Complexity and dynamics: Stakeholders and their relationships within systems can be highly complex and dynamic, making it challenging to capture and analyse all relevant interactions.

→ Data collection: Gathering comprehensive and reliable data on stakeholder roles, behaviours, and relationships can be resource-intensive and time-consuming, especially in diverse or large-scale systems.

→ Representation bias: Certain stakeholders or perspectives may be over-represented or under-represented in the analysis, leading to incomplete or biased conclusions.

→ Limited predictive power: While stakeholder analysis provides insights into current dynamics and sheds light on possible stakeholder responses, predicting future behaviours or outcomes with certainty can be challenging due to evolving circumstances

Example: Actor map of Khulna's municipal solid waste management system

We conducted a large social-empirical study that included all stakeholders associated with municipal waste management and plastic recycling in Khulna. First, we identified stakeholders through expert interviews, workshops, and a literature review. The relevant stakeholders for our analysis are individuals or groups actively engaged with materials classified as 'waste' within the waste management system, particularly through practices related to disposal, employment, or decision-making. This excludes, among others, stakeholders who only have an indirect influence on infrastructure planning.

We categorized them into the following groups: waste generators, waste collection and transportation workers (both formal and informal), treatment and cleaning workers, recycling business operators, and those directly responsible for waste management organizations, such as municipal officers and non-governmental organizations (see graphic).

Secondly, we defined four key categories of interest that structured our interview guidelines and subsequent analysis.

- **Practices:** Understanding how stakeholders act within the municipal solid waste management system – including their roles, motivations, required knowledge, and the tools they use – provides valuable insights into the system's current state.
- **Perceptions:** Examining how stakeholders view their roles, their societal standing, and past and future changes in waste management helps in understanding their current situation and in identifying risks and opportunities for transformation.
- **Chances:** Exploring stakeholders' aspirations and goals for transformation provides insight into potential opportunities.
- **Fears:** Evaluating perceived risks and potential negative consequences provides insights into (unintended) negative side-effects of transformative changes.

Third, a total of 90 semi-structured interviews were conducted with all relevant stakeholder groups, with each group comprising between five to 27 interviews.

The interview guidelines were structured around the key categories and tailored to each actor group and their specific roles in the waste management system. The interviews were conducted in Bangla, audio recorded, transcribed, and then translated into English for analysis.

Finally, we analysed the interviews using the qualitative data and text analysis software *MaxQDA*, which enabled us to create a stakeholder map (see Figure 1).

Using the stakeholders' descriptions of the status quo, we identified not only the existing connections but also four important interrelated practices that need to be considered for transformative changes in plastic waste management

- Household waste disposal and separation
- Door-to-door and Secondary Transfer Station (STS) collection and transportation
- Informal collection and sorting of recyclable plastic
- Acquisition of collected plastic by recycling shops

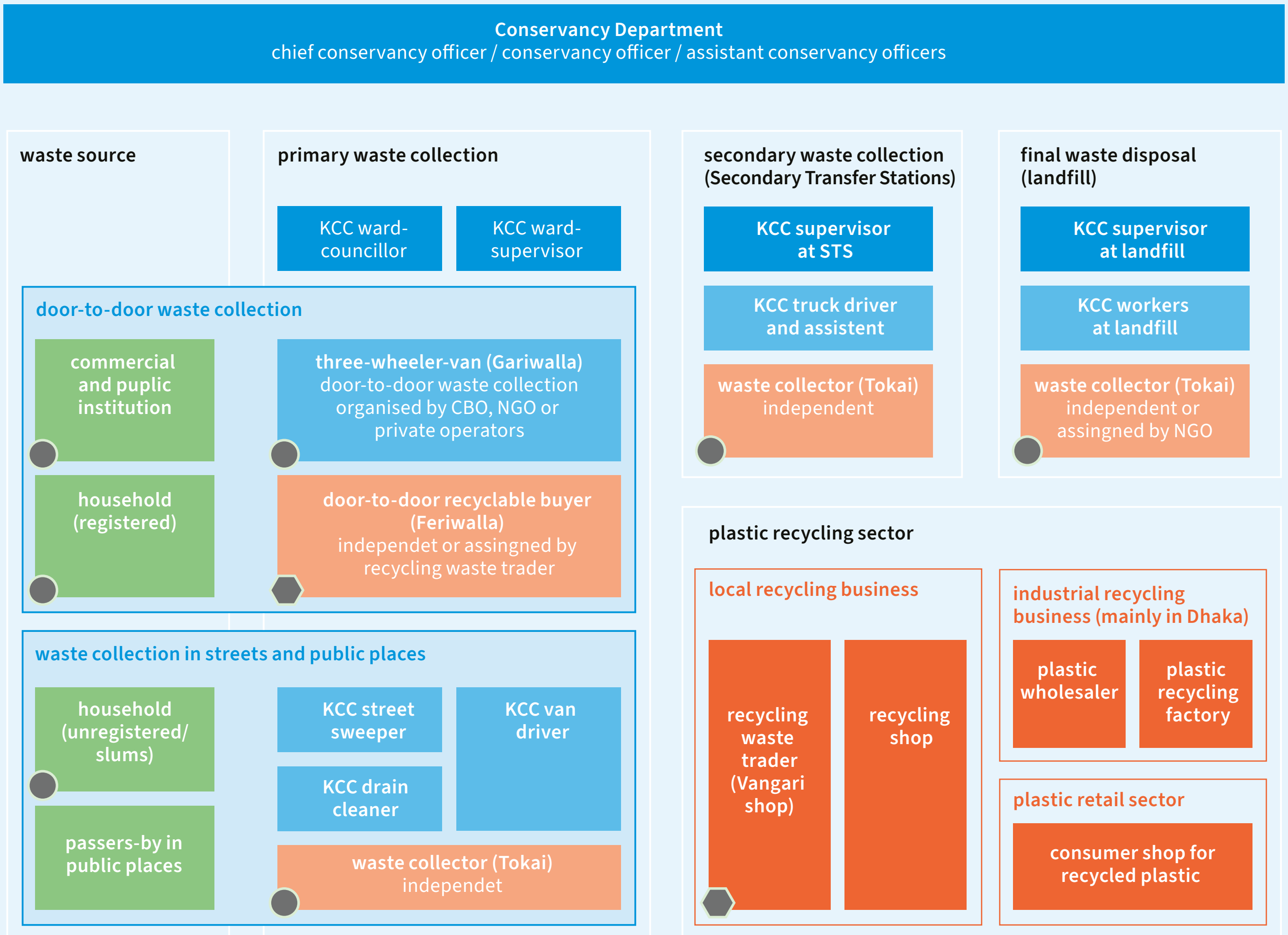

Figure 1: Characterisation of actors, including their roles and functions within the KCC waste management system.

summary of main actor groups:

- actors at waste source (household, commercial, public)
- organizational actors in waste management (public sector)
- waste workers in solid waste management (public sector)
- informal recycling sector
- plastic recycling business
- actors that collect recycleable plastics at source and sell it to intermediate waste traders like Feriwalla and Vangari shops
- actors that buy recycleable plastics from primary collectors and sell it to downstream actors in local recycling business

1.2 CONSTELLATION ANALYSIS

Visualising interactions for strategic improvement

BY J. PILLEN

A constellation analysis is a strategic tool to support municipal decision-makers in understanding and mapping the complex interactions within the waste management system. By visualising relationships among key elements such as stakeholders, infrastructures, material elements, and environmental components, this method facilitates the identification of critical issues and opportunities for improvement.

Municipalities can use this approach for:

- Visualising a waste management system and analysing existing barriers.
- Developing desirable and sustainable future visions, including options for reconfiguration of the current system.
- Bridging diverse scientific and non-scientific knowledge through participatory workshops.

The process of conducting a constellation analysis involves five steps:

- Defining the question: The process begins with a clearly defined question or problem, which helps determine the relevant elements and their boundaries within the constellation.
- Identifying elements: Elements in constellation analysis are categorised into four types:
  - **Actors:** Individuals or groups with agency in the system (e.g., organisations, institutions)
  - **Technical elements**: Artefacts or procedures (e.g., technologies, infrastructures)
  - **Natural elements**: Environmental components (e.g., resources, ecosystems)
  - **Symbolic elements**: Concepts, laws, ideologies (e.g., cultural norms, regulations)
- Mapping the constellation: This step involves creating a visual representation of the elements and their relationships. The relationships are depicted using lines or arrows to indicate types of interactions (e.g., conflicting, missing).
- Analysing and interpreting the constellation: The map is accompanied by a textual description that explains the functional principles and characteristics of the constellation. This narrative helps contextualise the visual data.
- Analysing processes of change: This involves examining how the constellation has evolved over time and predicting future changes. It includes identifying triggers for change and potential strategies for influencing future developments.

Key advantages of constellation analysis:

- Holistic understanding: Integrates multiple perspectives for a comprehensive analysis.
- Strategic planning: Facilitates the development of informed strategies for future innovation.
- Stakeholder engagement: Enhances communication and collaboration among diverse stakeholders.

Challenges and limitations of constellation analysis:

- Complexity: Mapping complex systems can be resource-intensive.
- Data challenges: Ensuring accurate and comprehensive data collection can be difficult.
- Representation bias: Certain elements or perspectives may be over- or underrepresented.

→CROSSREF:
· Stakeholder analysis ▸ *p. 14*

Example: Constellation analysis for the development of future visions for desirable and sustainable plastic waste management in Khulna

BY J. PILLEN

We conducted two constellation analysis workshops with 18 participants, comprising 13 operations-level practitioners, such as from the Khulna City Corporation (KCC), and five representatives from waste management-related NGOs. The participants, working in interdisciplinary groups, developed constellations representing the status quo and future visions, addressing four thematic problem complexes:

1. **Formal-informal sector integration:** Exploring synergies, overlaps and gaps in the interaction between formal and informal waste management services, including challenges stemming from low recognition and precarious working conditions of informal waste workers.
2. **Governance and coordination:** Exploring the interplay of different actor groups regarding communication, responsibilities, organisational structures and their alignment in municipal waste management service delivery.
3. **Public awareness:** Exploring citizens' knowledge and behaviour in waste handling.
4. **Operational efficiency and infrastructure:** Exploring waste management service delivery from a resource-based perspective, including manpower, technical equipment, and financial resources.

In the end, the stakeholders had developed one constellation for the status quo and one for a desirable future state for each of the four thematic complexes, resulting in four status quo and four future vision constellations. The status quo constellations highlight critical leverage points that hinder the flawless functioning of the system, while the future vision constellations depict how actors and elements could be aligned and connected for the system to function in a desirable way (see Figure 2 and Figure 3).

Building on the results of the constellation analysis workshops and the resulting future vision constellations, we conducted a second workshop applying the backcasting method. Backcasting is a planning method that starts with defining a desirable future outcome and then works backward to identify the steps necessary to achieve that future. As the first step of envisioning a desirable future state had been conducted in the constellation analysis workshops, we used the future vision constellations as a starting point for the development of specific options for action.

Participants were once again divided into four groups based on the thematic complexes described above. Each group developed action options to overcome the barriers identified in the first workshop.

Looking ahead and considering the four future vision constellations together, the visions depict a waste management system that is largely formalised and organised into clear structures, supported by comprehensive planning, strict law enforcement, and close coordination among government agencies, NGOs, and other stakeholders. Modern infrastructure and equipment will be in place, and the public will be actively involved.

A selection of measures for achieving such a vision was thoroughly detailed during the workshops, offering KCC guidance on the steps needed at various stages to reach the desired future state. For example, the proposed measures to enhance governance and coordination include establishing a central coordination committee chaired by the mayor, facilitating regular stakeholder meetings, creating a centralised online database accessible to the different actors involved in waste management, including an information platform for the public, and developing an integrated action plan.

Exemplary constellations of the current system and future vision for the thematic complex operational efficiency and infrastructure:

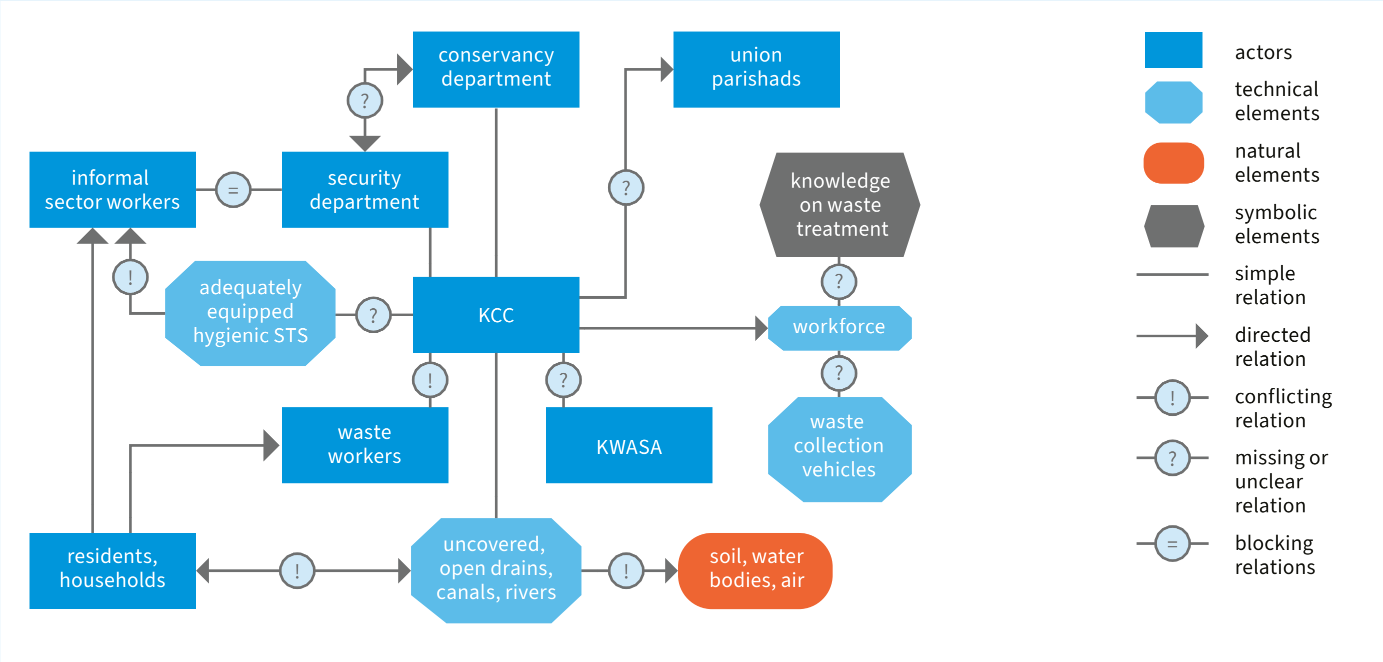

Figure 2: Current system constellation for the problem complex operational efficiency and infrastructure.

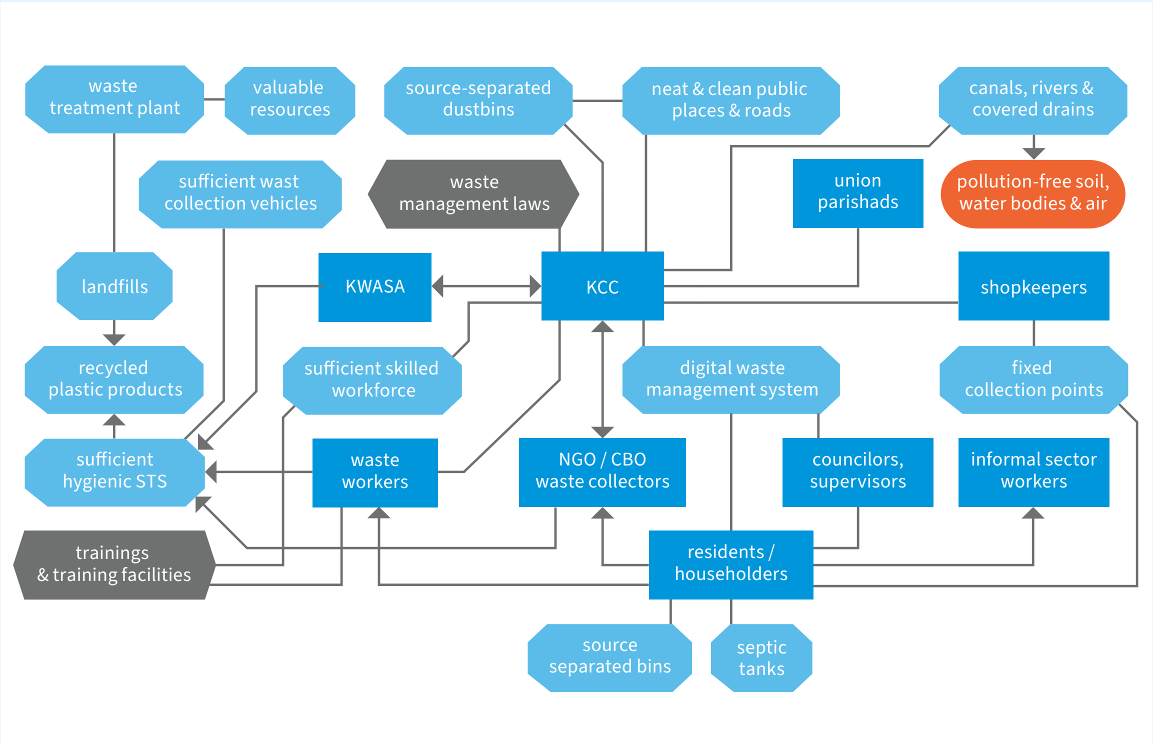

Figure 3: Future vision constellation for the problem complex operational efficiency and infrastructure.

Figure 4: Presentation of final constellations on formal-informal sector integration. Photo by Nahin Rahaman, 2023.

FURTHER READING

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1.3 PROCESS MODELLING IN WASTE MANAGEMENT

Using process modelling to visualise, communicate and optimise waste management processes

BY S. KÜHLEWINDT

The Business Process Model and Notation (BPMN) method helps municipalities optimise processes (e.g., waste collection), improve service delivery, and enhance transparency. BPMN is a standardised graphical tool for detailing business processes in workflows, using symbols such as events, tasks, and gateways. This approach is useful for municipalities managing complex operations involving multiple stakeholders or departments. It helps identify inefficiencies and bottlenecks, such as delays in permit approvals due to redundant steps or poor communication, allowing for streamlined operations and cost reduction.

To develop a BPMN model for a (municipal) process, the following steps are required:

1. Key tasks and stakeholders, such as citizens, departments, and external stakeholders, should be identified.
2. The process's start and end points, such as a citizen request and the final service provided, must be defined. BPMN elements like events (e.g., service request), activities (e.g., approval), and gateways (e.g., decision points) are to be used to outline the process flow.
3. Interactions between different stakeholders should be depicted.
4. The model must be reviewed and refined to ensure all relevant steps and exceptions are captured.

→CROSSREF:
- Stakeholder analysis ▸ *p. 14*
- Waste collection analysis ▸ *p. 23*
- Sampling of ship waste ▸ *p. 48*

FURTHER READING

Aagesen, G. and Krogstie, J. (2015). *Handbook on Business Process Management 1. Introduction, Methods, and Information Systems*. 2nd ed. 2015. Berlin, Heidelberg: Springer Berlin Heidelberg (International Handbooks on Information Systems).

Example: The process of waste collection from international ships at seaports

The International Convention for the Prevention of Pollution from Ships (MARPOL) ANNEX V regulates the prevention of pollution by waste from ships, prohibiting the discharge of most types of waste into the sea and establishing strict controls on the disposal of permitted substances. Bangladesh has acceded to the convention and is subject to its regulations. The provision of adequate waste reception facilities at ports to receive and properly dispose of ship-generated waste is, therefore, mandatory. Using the BPMN method, we depicted the waste collection process from international ships at the Chattogram and Mongla Ports. Through expert talks with the involved stakeholders, we clarified the tasks and the divided responsibilities, which were mapped out in a BPMN 2.0 diagram as presented in Figure 5.

We visualised the involved stakeholders and their tasks in the model, and the main steps of the process can be described as follows:

1. **Initiating the process:** The process begins when an international ship approaching the port requests permission to discharge waste. The request is typically made through shipping agents, who receive information through the shipping company.
2. **Vendor selection:** The shipping agents contact vendors who hold a 'Waste Cleaning License' issued by the Port Authority to arrange for waste collection. Vendors provide quotations, and the ship selects a vendor based on the best offer.
3. **Permission and waste collection:** The selected vendor is informed and goes to the ship, which is anchored in the port area, to collect the waste by ship.

4. **Waste reporting:** After collection, the vendor prepares a summary report detailing the amount of waste collected from each ship, categorised by type according to ANNEX V of the International Convention for the Prevention of Pollution from Ships (MARPOL). This summary is submitted to the Traffic Department of the Port Authority, which compiles the data from all international ships over a three-month period.

Key results:

- The bidding process from vendors holding the waste cleaning licence is a bottleneck in terms of sound collection and disposal practices.
- Despite the waste being separated on board, the collected solid waste is ultimately mixed again by the vendors and disposed of at municipal landfills.

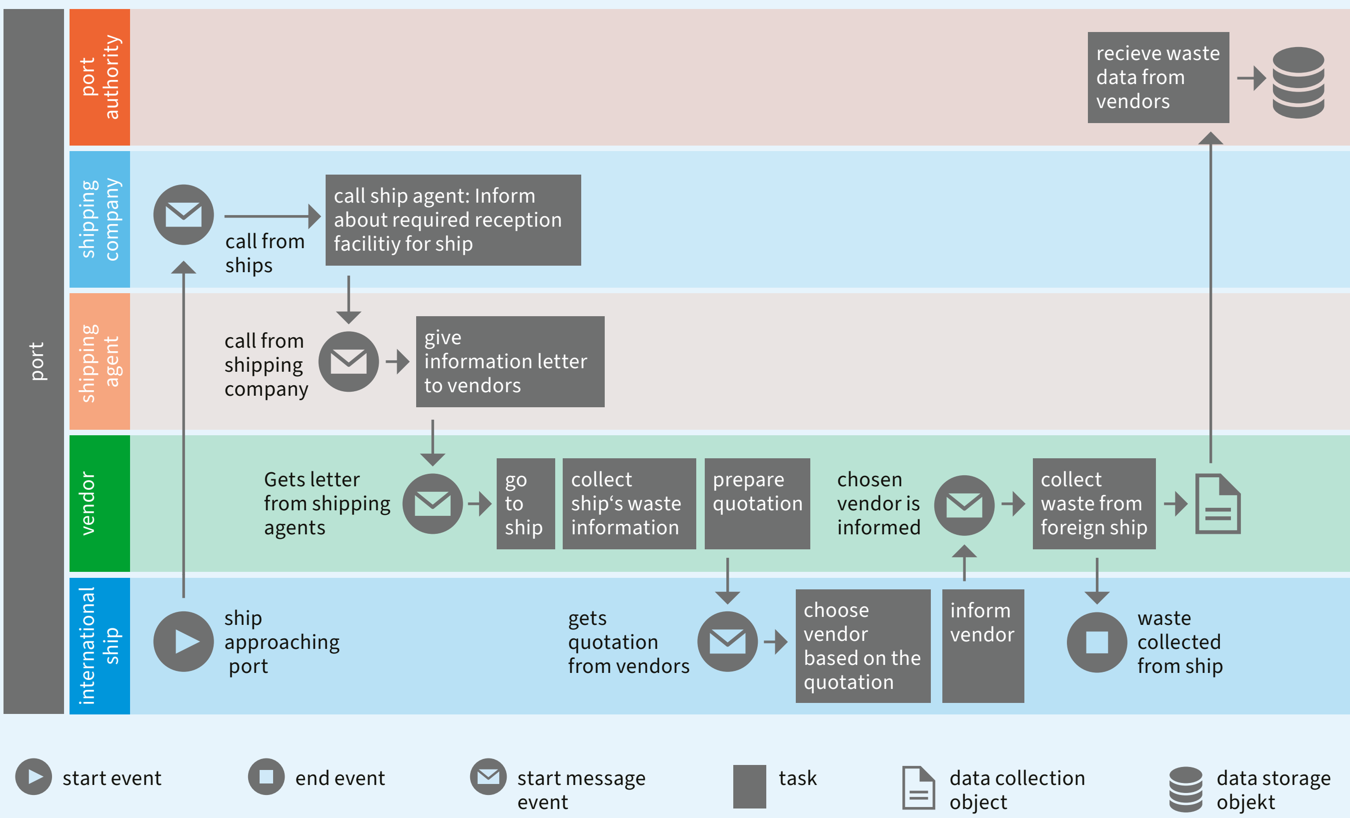


Figure 5: BPMN 2.0 model of waste collection from international ships at seaports.

1.4 WASTE COLLECTION ANALYSIS

From door to disposal site: Understanding how waste moves within the city

BY S. BERNER

A healthy and hygienic environment is the overall objective of municipal waste management, and waste collection services play a crucial role in achieving this goal. In the particular case of plastic waste management, the collection system must ensure that plastic waste is adequately contained along the collection process and, if possible, allow material recovery to foster recycling. A structured analysis of the collection system provides critical information on bottlenecks and consequent service gaps. Thus, the analysis of a municipal waste collection system aims to:

- Determine the status of collection vehicles and municipal infrastructure, e.g., transfer stations.
- Determine the collection service coverage and identify service gaps.
- Improve the efficiency of municipal infrastructure and vehicles.

In Bangladesh, municipal waste collection is generally split between primary and secondary (see Figure 6). Whereas secondary collection from transfer stations to the final disposal site is carried out by municipal staff and vehicles, the primary collection is mainly organised by non-governmental organisations (NGOs), community-based organisations (CBOs) and private service providers (often informal). Alternatively, households can drop off their waste at community bins. From here, municipal staff transports the waste to the transfer stations.

A systematic and transparent analysis of the overall formal waste management system requires the following steps:

1. Analysing municipal waste management chain to determine physical infrastructure elements, tools, and vehicles (see Figure 7). This includes quantifying collected waste.
2. Mapping physical infrastructure elements with permanent or semi-permanent character, such as Secondary Transfer Stations (STS).
3. Establishing a register of known door-to-door waste collection service providers.
4. Establishing a municipal waste collection vehicle register, including information on loading capacity and volume.
5. Using GPS trackers to determine collection routes and collection service coverage, mapping routes of waste collectors and waste trucks.
6. Identifying gaps and limitations of operational and technical aspects.

→CROSSREF:
- Stakeholder analysis ▸ p. 14
- Process modelling in waste management ▸ p. 21
- Weighing station at final disposal site ▸ p. 80
- System boundaries ▸ p. 96
- Waste characterisation ▸ p. 99

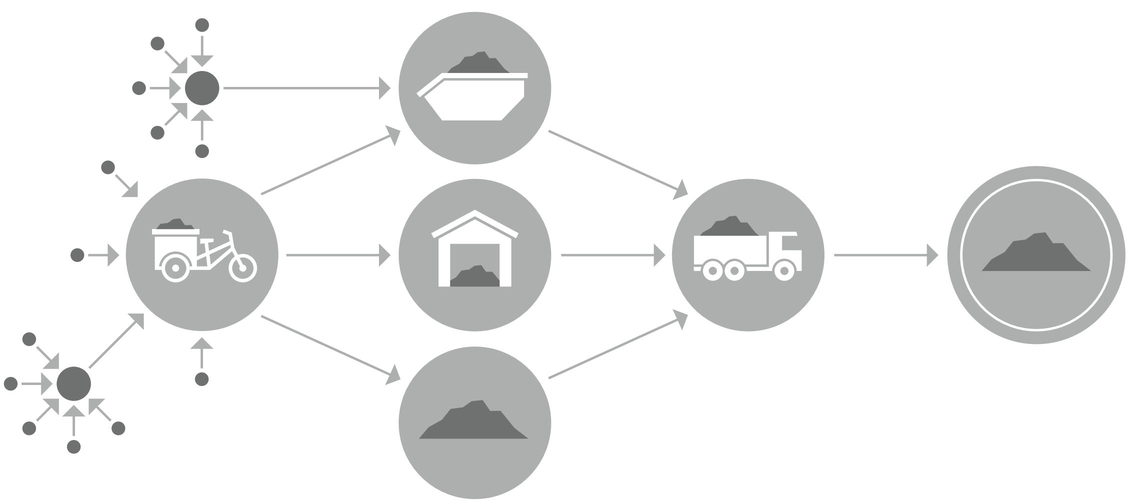


Figure 6: Two-stage formal waste collection system in Bangladesh.

BY S. BERNER

By following these six steps, the analysis compiles basic information that can be used to assess the collection system and develop a municipal waste management plan. During the respective surveys, special attention should be given to plastic handling and leakage.

Coffey and Coad (2010) provide a comprehensive overview of solid waste collection, particularly on collection vehicles.

waste management chain element	**waste generation**	**primary collection system** from point of generation to transfer station	**secondary collection system** from transfer station to final disposal site	**final disposal**
physical infrastructure elements	temporary **waste storage** at point of generation e.g. waste bins	**community bins**	**secondary transfer station** temporary waste storage	**final disposal site** permanent waste storage
vehicles and tools		**vehicles** rickshaw tricycles/van, handcarts (wheel barrows) **tools** brooms, shovels, hooks/forks, rakes	**vehicles** trucks, wheel loader **tools** shovels, brooms, rake	**vehicles** excavator, wheel loader **tools** shovels, brooms, rake

Figure 7: Municipal waste collection chain: Infrastructure elements, tools and vehicles.

REFERENCE

Coffey, M. and Coad, A. (2010). Collection of Municipal Solid Waste in Developing Countries, UN-HABITAT 2010. Available at: https://unhabitat.org/sites/default/files/2021/02/2010_collection-msw-developing-countries_un-habitat.pdf (Accessed 14 October 2024).

Example: Analysis of Khulna's waste collection system

BY S. BERNER

Following the municipal waste collection chain, we analysed physical infrastructure elements, tools, and vehicles used within the primary and secondary waste collection services of Khulna City Corporation (KCC).

We identified 11 NGOs and CBOs currently providing door-to-door collection services. Ten participated in a survey where waste collectors were monitored with a GPS tracker. The GPS data was mapped using a geographic information system (GIS). The analysis showed that only about 8 % of KCC is covered by formal door-to-door collection services. The number of informal service providers is unclear. Additionally, KCC provides around 1,200 community bins, which function as in-between households and STS and can be considered part of the primary waste collection system.

For secondary waste collection, KCC operates 38 waste collection trucks and 81 Secondary Transfer Stations, with seven in-house systems, 18 open systems, and 56 containers. Between 2022 and 2023, we surveyed and mapped all current and planned Secondary Transfer Stations (see map in Figure 8).

Thirteen of the 18 open STS are prone to waste and plastic losses into drains and the immediate environment (see Figures 10 and 11). They are roadside handover points but do not show any physical infrastructure elements.

The majority of the trucks deployed for waste collection are multi-purpose trucks not dedicated to waste transport (27 out of 38). Most of the trucks have low side panels, which limit the volume of waste that can be transported per trip. Table 1 provides an overview of the KCC secondary collection trucks.

The trucks were monitored with GPS trackers directly connected to the engine to ensure high-quality data and avoid tampering. By combining truck routes and STS locations, we could determine which type of truck collects waste from where, at what frequency, and along which route (see Figure 12). This data is critical when assessing vehicle utilisation and routing options for future planning.

Main conclusions from the analysis_

- When considering overall secondary collection capacities, the open transfer sites should be excluded since they do not have adequate waste containment measures.
- Door-to-door collection services are not well integrated into municipal processes. Monitoring, registering, and coordinating these services could be established on the ward level.
- Truck monitoring provides valuable information on waste collection routes. The data can be used to optimise routes or evaluate the impact of road conditions on waste collection services.
- Multi-purpose trucks are inadequate for waste transport. The low side panels are inadequate for waste transport. Due to the low density of waste (~500 kg/m3), volume capacity is quickly exceeded before the weight-based loading capacity is reached.
- Without reliable data on waste quantities delivered to the final disposal site, collection rates cannot be adequately evaluated.

Type of Vehicle	No. of Vehicle	Payload in metric tons	Volume in m^3	Purpose
Small Truck	18	3	3.68	Multi-purpose
Medium Truck	4	7	10.2	Multi-purpose
Large Truck	5	13	14.272	Mostly SWM*
Small Container Hauler	2	2.5	3.455	SWM*
Medium Container Hauler	2	4.5	5.465	SWM*
Large Container Hauler	2	5	6.173	SWM*
Compactor	5	–	–	SWM*

* SWM: Solid waste management

Table 1: KCC waste collection vehicle fleet (secondary collection), status December 2023.

BY S. BERNER

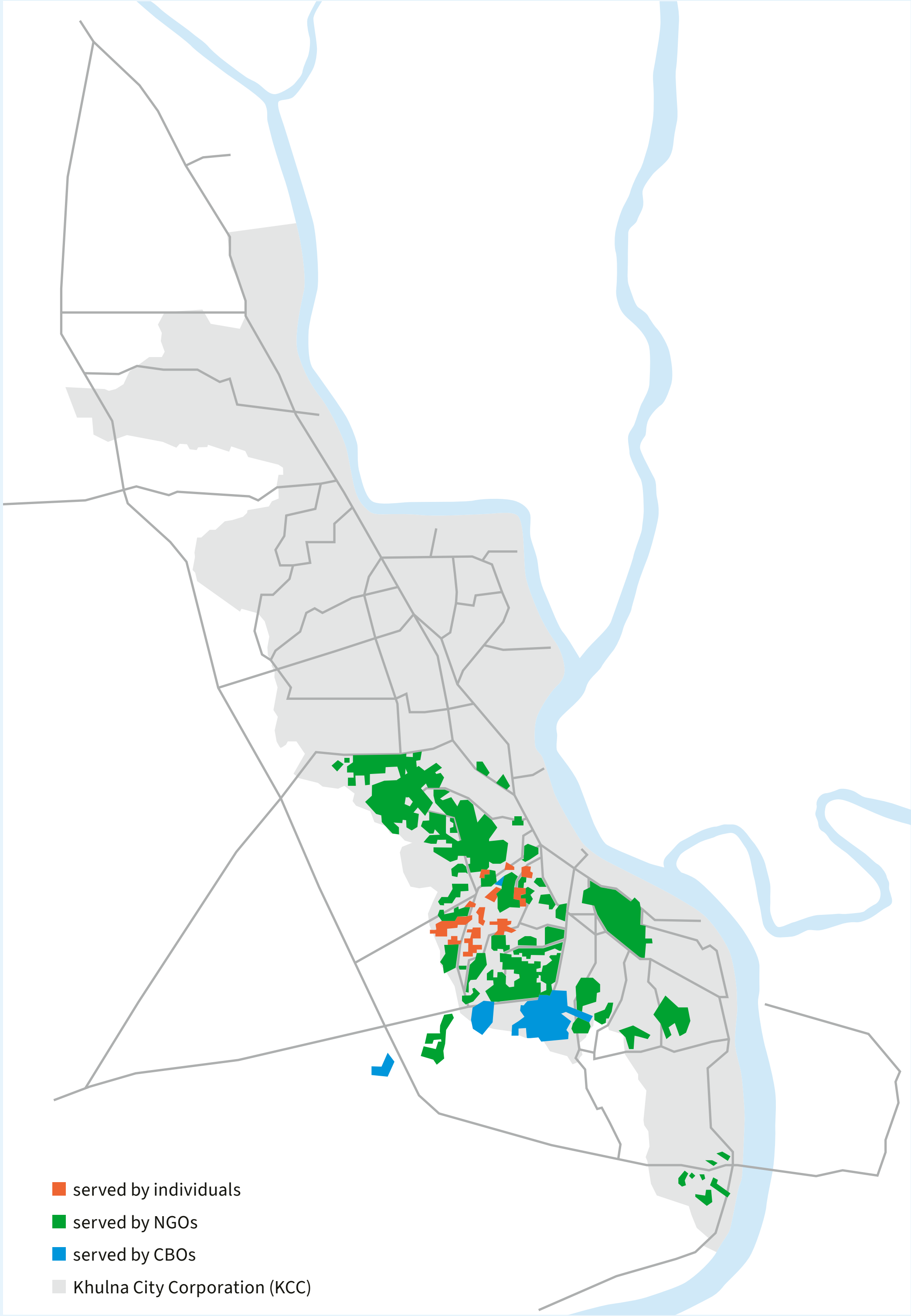


Figure 8: Map of primary collection service coverage in KCC as analysed in 2023.

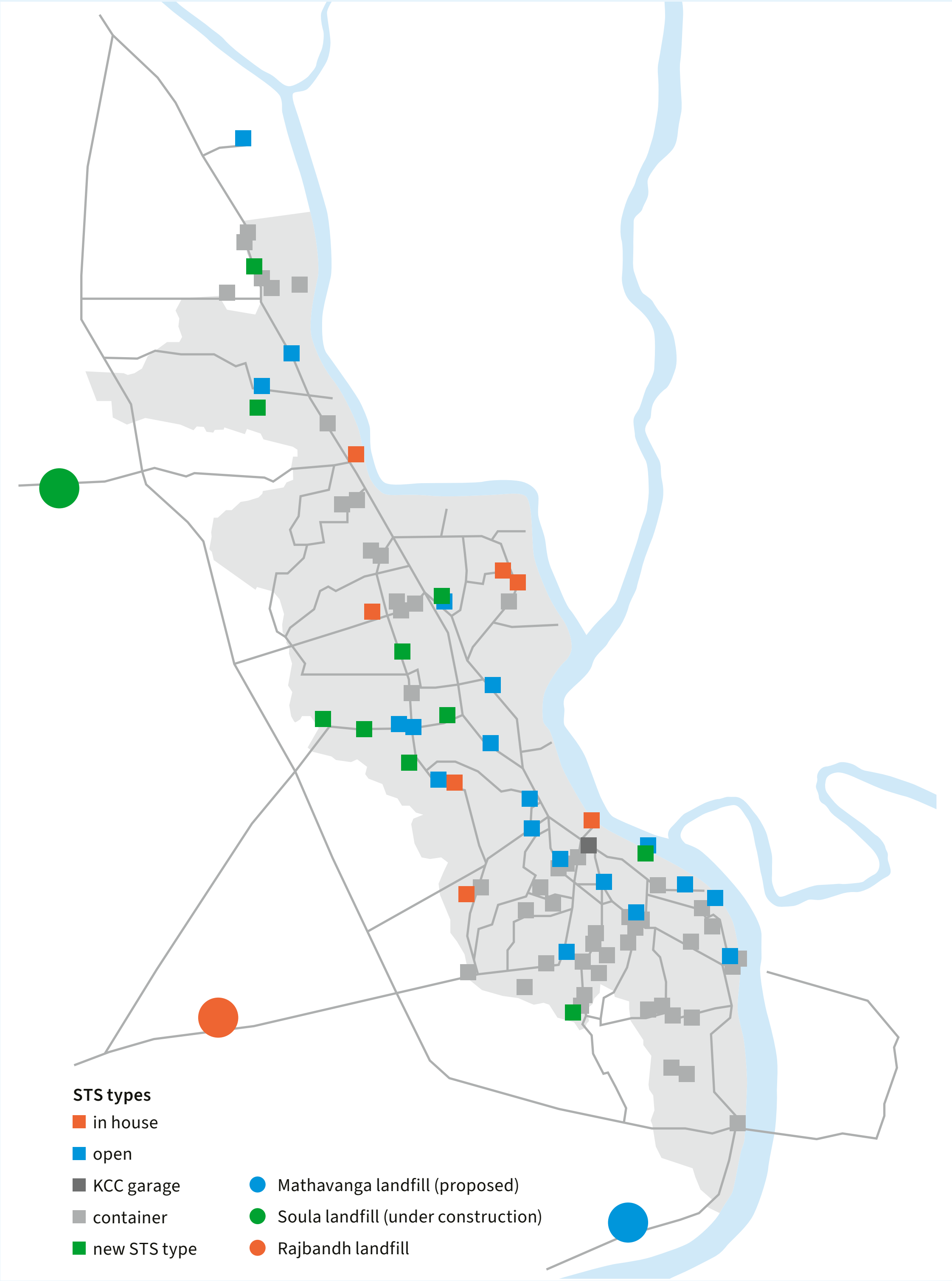


Figure 9: Map of waste management infrastructure in KCC as analysed in 2023.

Figure 10: Transfer point in Boyra area in KCC. Photo by Tariqul Islam, 2022.

Figure 11: Transfer point close to Badshamia clinic, KCC. Photo by Tariqul Islam, 2022.

BY S. BERNER

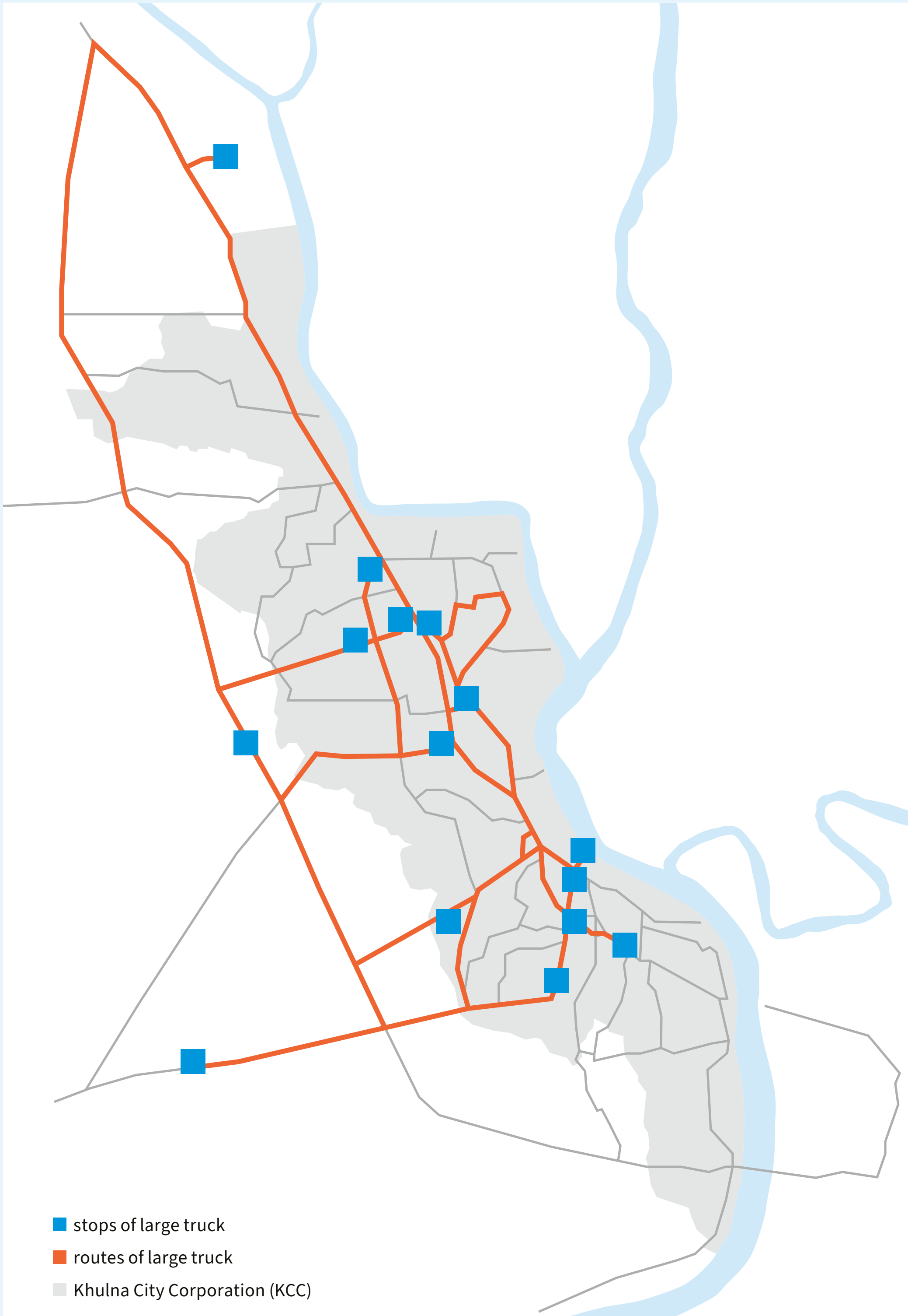


Figure 12: Routes of large KCC waste collection trucks as tracked in 2023.

1.5 RECYCLING VALUE CHAIN ANALYSIS

Examining the processes, stakeholders and economics involved in transforming waste into reusable resources

BY P. LORBER

→CROSSREF:
- Material flow analysis private recycling sector ▸p. 31
- Social Business Model Canvas ▸p. 35
- System boundaries ▸p. 96

A recycling value chain analysis (RVCA) can provide valuable insights into the current state of plastic waste management and recycling, helping to identify opportunities for improvement and potential interventions. It identifies and maps key stakeholders in the recycling process, from waste generators to recycling factories. Besides tracking the material flow, it analyses the added value at each step of the chain and is, therefore, particularly interesting for private actors in waste management.

As key benefits, the following aspects are mentioned:

- Comprehensive understanding: RVCA provides a holistic view of the recycling system, revealing interconnections between different actors and processes.
- Identification of bottlenecks: The analysis helps pinpoint constraints in the value chain, such as transportation costs, poor quality of recyclables, and lack of investment capacity.
- Economic insights: RVCA reveals the economic potential of recycling, showing how value is added at different stages and identifying opportunities for local economic development.
- Informal sector integration: It recognises the crucial role of the informal recycling sector.
- Policy support: The data gathered can inform policymakers about the current state of recycling and guide the development of targeted interventions.
- Environmental impact assessment: RVCA can help quantify the environmental benefits of recycling and identify areas for improvement in waste management practices.

The following list presents typical boundaries and limitations:

- Accurate and comprehensive data can be challenging, particularly in the informal sector.
- Temporal limitations are present, as the analysis provides a snapshot of the system at a specific time, which may not capture changes in material prices, seasonal variations or long-term trends.
- There are geographical constraints, as the study area may not encompass the entire value chain, with some processes occurring in distant locations such as port areas, export processing zones or other cities.
- Social and ethical considerations may arise, with issues such as child labour and poor working conditions being identified but requiring separate, in-depth analysis.

In a UNDP-funded project in a rural area of southeast Bangladesh, the RVCA disclosed transportation costs as the main impairment in the value chain. Precise interventions could be developed and presented to the recycling sector and relevant authorities (UNDP, 2019).

REFERENCE

UNDP (2019). *Recycling value chain analysis (RVCA) in Teknaf and Ukhia*. Sustainable Solutions To Solid Waste Project, Cox's Bazar, Bangladesh.

1.6 MATERIAL FLOW ANALYSIS: PRIVATE RECYCLING SECTOR

Quantifying the inflows and outflows of materials

BY P. LORBER

Material flow analysis (MFA) is a useful method used to study the flow of materials within a system, typically in a country, region, or specific industry. To analyse material flows, a simple input-output analysis can be performed. It focuses on quantifying the inflows and outflows of materials within an economy or industrial sector. It is also suitable for single factories and shops.

The following benefits can be emphasised when conducting an MFA in private businesses such as recycling shops (Goga et al., 2022):

- Identification of inefficiencies: By mapping the flow of materials, one can pinpoint areas where recycling material is lost or inefficiently processed, helping to identify potential improvements in the recycling process.
- Assessment of recycling capacity: MFA can reveal the current capacity of local recycling shops and highlight potential gaps between waste generation and recycling capabilities.
- Economic insights: MFA can provide information on the economic aspects of recycling, such as operational costs and potential revenues from recycled materials.
- Policy support: The data gathered through MFA can inform policymakers about the current state of plastic recycling and guide the development of targeted interventions to improve the system.
- Circular economy potential: MFA can help identify opportunities for implementing circular economy principles in the local context, such as closing material loops and reducing waste.

Nevertheless, material flow analyses carry some boundaries and limitations:

- Data availability and quality: Obtaining accurate and comprehensive data in informal or semi-formal recycling sectors can be challenging, potentially affecting the reliability of the analysis.
- Informal sector complexity: The presence of a significant informal recycling sector in Bangladesh may complicate the analysis, as these activities are often undocumented and difficult to quantify.
- Temporal limitations: MFA typically provides a snapshot of the system at a specific time, which may not capture seasonal variations or long-term trends.
- Technological differences: The analysis may be affected by variations in recycling technologies and practices among different local shops, making standardisation difficult.
- Dynamic market conditions: Rapid changes in the recycling market, such as fluctuations in material prices or demand, may not be fully captured in a static MFA.

→CROSSREF:
- Recycling value chain analysis ▸p. 30
- LCA on treatment options ▸p. 40
- Near-infrared plastic sorting ▸p. 46
- Collection of mismanaged plastic waste at recycling shops ▸p. 74
- System boundaries ▸p. 96
- Material flow analysis ▸p. 102

REFERENCE

Goga, T., Harding, K.G., Russo, V. and von Blottnitz, H. (2022). *What material flow analysis and Life Cycle Assessment reveal about plastic polymer production and recycling in South Africa*. South African Journal of Science.

BY P. LORBER

Example: Material flow analysis: Khulna's recycling sector

In Khulna City, a vital range of private plastic recycling shops has been established. The purpose of the MFA was to examine the material inputs required for the production of recycled plastic flakes, grains and subsequent output and waste products. We did not incorporate seasonal aspects and dynamic changes in material flows. Assuming that stocks are constant over time (e.g., one year) and no disposal options are offered, the process loss can easily be calculated as the difference between input and output materials (dark background).

The illustration shows an example of an MFA scheme at a local recycling shop, where PET bottles and mixed plastic waste are accepted as separate input streams. During sorting, valuable impurities are set aside and sold to other businesses. Actual data collection of the loss fraction might not reflect real data since certain light plastic fractions, e.g., PET bottle labels, can be seen burning on the spot. Other shredded material is lost while drying in an open area exposed to all types of weather.

From April to June 2023, five recycling shops received a total of 225 tonnes of plastic waste. The output of processed plastic material and other valuables was 169 tonnes for the same period. The remaining material flows contribute to the previous mass imbalance, meaning that stock accumulations, process losses, and both safe and unsafe disposal account for about 25 % of the materials handled at the analysed recycling shops.

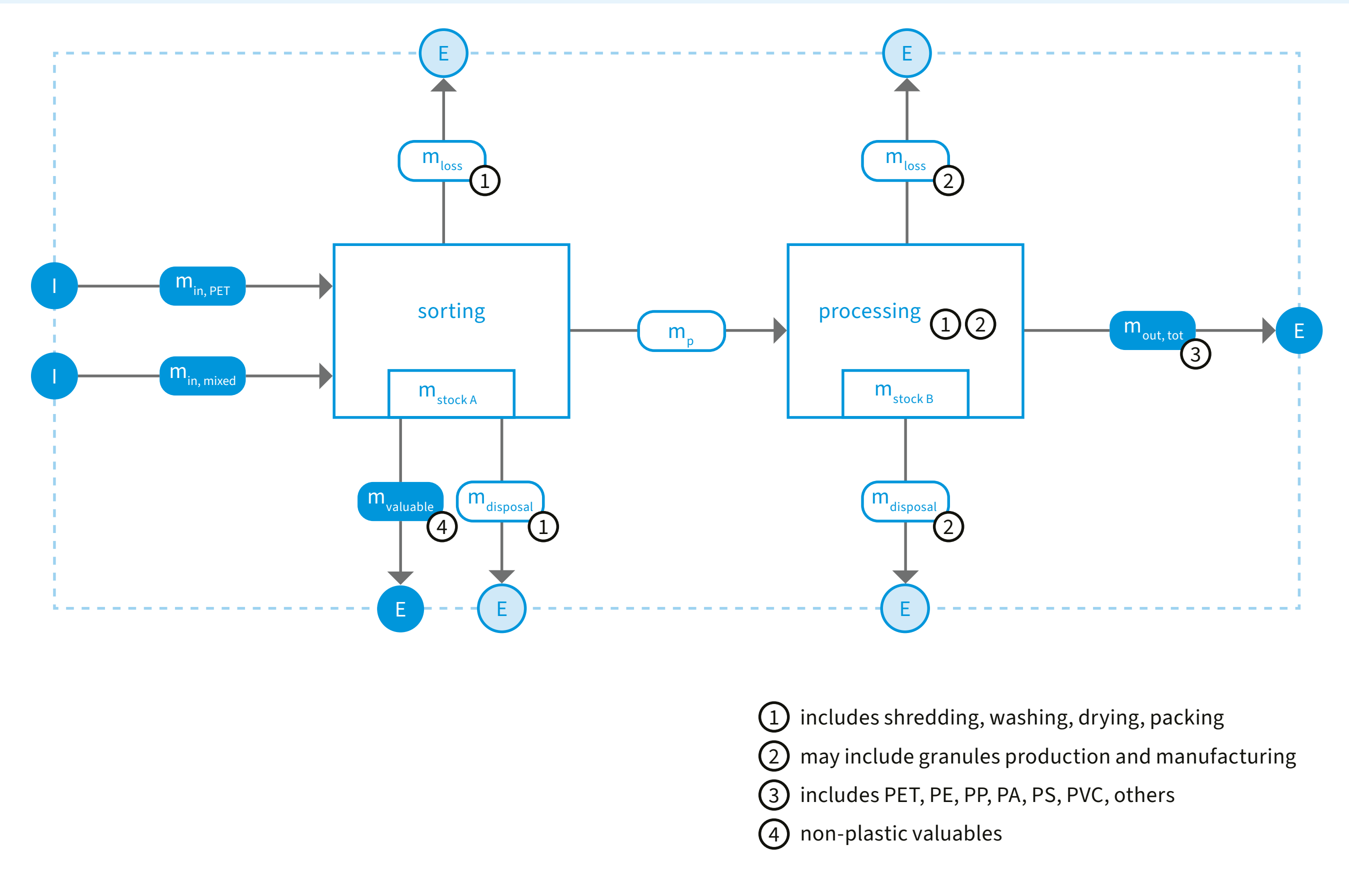


Figure 13: Framework of the MFA.

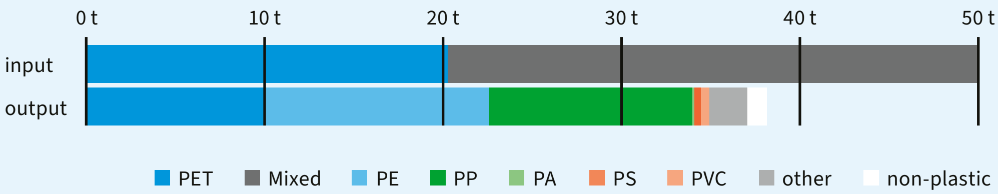


Figure 14: Example of an input-output imbalance at one of the recycling shops from April to June 2023.

BY P. LORBER

Figure 15: Manual waste sorting at a local recycling shop. Photo by Gregor Biastoch, 2022.

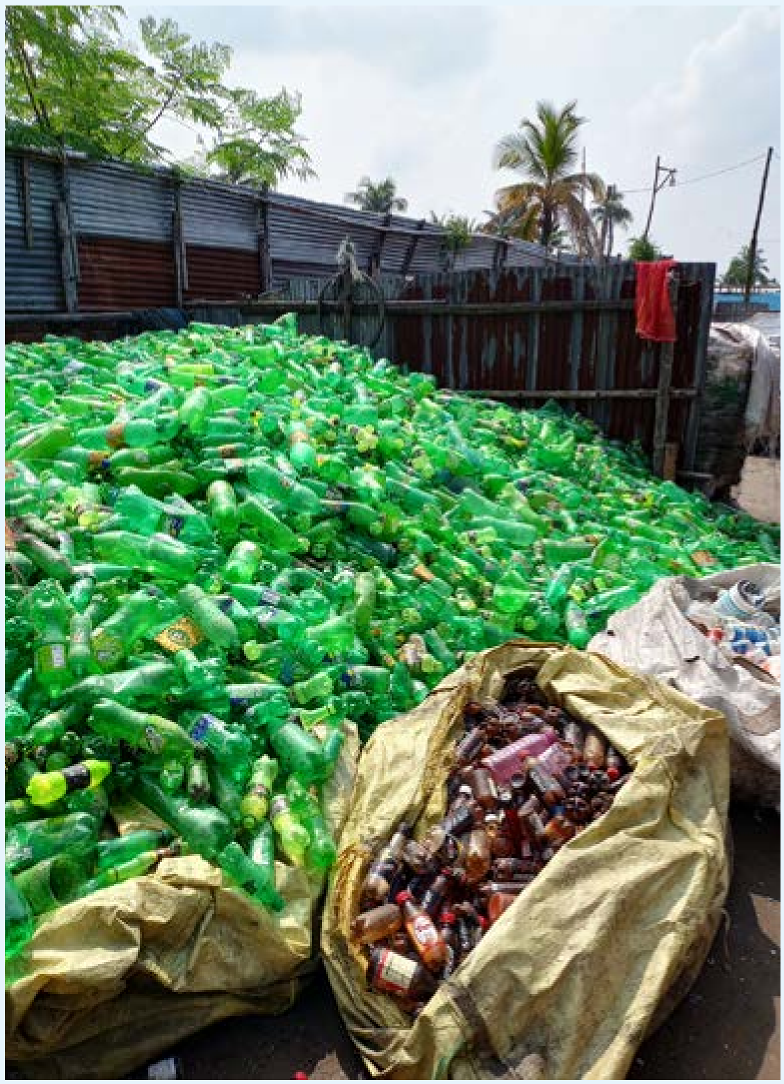


Figure 16: Coloured PET bottles at a local recycling shop. Photo by Lukas Sattlegger, 2022.

BY P. LORBER

Figure 17: Manual plastic separation by wind. Photo by Philipp Lorber, 2023.

Figure 18: Illegal dumping of PET bottle labels close to a recycling shop. Photo by Florian Wehking, 2023.

1.7 SOCIAL BUSINESS MODEL CANVAS

Identification of business models and partnerships for waste management with local experts

BY M. ROHRBACH

Business models play a crucial role in providing economically viable solutions that drive sustainable practices within the plastic waste management sector. Such solutions are essential for ensuring that waste management initiatives can be sustained over the long term, enabling organisations to invest in innovative technologies, social enterprises, and processes that enhance waste collection, as well as resource recovery.

The Business Model Canvas (BMC), introduced by Alexander Osterwalder (2010), serves as a powerful tool for developing and refining business models. This methodology provides a visual framework that outlines the key components of a business model, including value propositions, customer segments, revenue streams, and key activities.

The purpose of the Business Model Canvas is to facilitate a deeper understanding of how various elements of a business interact to create value. Therefore, it serves as a powerful tool for exploring new economic activities and making strategic decisions.

By now, there are many different canvas types, such as the Social Business Model Canvas (Annisa Rahamani Qastharin, 2015), which is an adaptation of the traditional Business Model Canvas with a focus on social value creation alongside financial sustainability. Unlike traditional businesses, which primarily focus on profit maximisation, social businesses prioritise their social mission and seek to create a positive impact in society. The Social Business Model Canvas has nine components:

1. **Social Innovation:** Identifies new products or services.
2. **Social Problem:** Addresses specific social or environmental issues, focusing on both social impact and market performance.
3. **Customer Segments:** Identifies the appropriate customer segments.
4. **Key Partners:** Identifies significant partners capable of supporting the social mission.
5. **Key Resources:** Lists essential resources for project implementation, including materials, knowledge, and time.
6. **Customer Relationships:** Outlines fundamental principles of customer communication.
7. **Channels:** Involves selecting and designing communication channels for external outreach.
8. **Cost Structure:** Lists all project-related costs and strategies for covering them.
9. **Revenue and Compensation Model:** Details expected contracts, revenue sources, and plans for income redistribution to sustain the project

Key advantages:

- → Supports the conceptual phase of business model design
- → Suitable for group formats
- → Simple to use
- → Suitable to identify possible partnerships, open questions or gaps in a business model and, therefore, clarify feasibility and develop strategies

Key challenges:

- → Canvas is strongly simplified and requires further steps.
- → A good overview is required to guide the group through the canvas.
- → Result depends on the participants filling out the canvas

→CROSSREF:
- Stakeholder analysis ▸ *p. 14*
- Recycling value chain analysis ▸ *p. 30*
- Informal sector assessment ▸ *p. 64*

FURTHER READING

There is a great deal of information online on how to use the Business Model Canvas, e.g., https://businessmakeover.eu/tools/business-model-canvas.

For the Social Business Model Canvas, e.g., the Business Model Toolbox can be used: https://bmtoolbox.net/tools/social-business-model-canvas/

Osterwalder, A., Pigneur, Y. and Clark, T. (2010). *Business Model Generation: A Handbook For Visionaries, Game Changers, and Challengers.* ISBN 9780470876411.

Qastharin, A.R. (2015). *Business Model Canvas for Social Enterprise.* In: The 7th Indonesia International Conference on Innovation, Entrepreneurship, and Small Business (IICIES 2015).

Example: A New Business Model for Recycling Shops

BY M. ROHRBACH

We developed a business model for the primary collection of mismanaged plastic waste in Khulna City, aimed at either disposing of it at the landfill or converting it into clean plastic flakes for energy production through pyrolysis. In this model, recycling shops are defined as the key operators. The business model was implemented as a pilot study to understand the suitability and robustness of the business model as a collection system for mismanaged plastic waste and the possibility of optimising the waste collection system in Khulna City. For continuous implementation of the business model, the question of funding needs to be clarified.

For filling out the The Social Business Model Canvas, we followed four steps:

- Preparation of group format: We select a small group of people with diverse backgrounds, such as integrated solid waste management, business management, and public funding; organise a meeting for a group discussion.
- Shared understanding: We introduced the aim and scope of the business model, along with the different sections of the canvas, to the participants.
- Filling in the canvas: We utilised sticky notes to populate the various sections of the canvas, highlighting any areas that raised open questions (e.g., funding). This approach allowed us to create multiple versions of the business model using several canvases before selecting the most suitable one.
- Follow-Up: After completing all sections, we concentrated on the open questions and identified strategies for addressing them to further develop a viable business model or business plan.

REFERENCE

Social Innovation Lab. (2013). Retrieved online, 11.09.2024 via: https://www.socialbusinessmodelcanvas.com/wp-content/uploads/Social-Business-Model-Canvas.png

Key resources

- Storage capacities
- Facilities for washing and shredding to produce clean plastic flakes*

What resources will you need to run your activities? People, finance, access?

Key activities

- Check waste quality and accept waste
- Pay money for mismanaged
- plastic waste to collectors
- Handling the material
- Invoicing with KCC
- Pre-treatment*

What programme and non-programme activities will your organisation be carrying out?

Type of intervention

- Service: facilitation of primary collection of mismanaged plastic waste by informal sector

What is the format of your intervention? Is it a workshop? A service? A product?

Segments

- Inhabitants of Khulna City
- KCC*

Beneficiary

Value proposition

- Improving living conditions in Khulna
- Prevention of marine plastic waste

Social value proposition

Impact measures
- Source of income for the informal sector
- Weight of collected waste

How will you show that you are creating (social) impact?

Partners and key stakeholders

- Waste workers from the informal sector
- KCC organising trucks for pick up of material
- Operator of the pyrolysis plant*
- KCC *

Who are the essential groups you will need to involve to deliver your programme? Do you need special access or permissions?

Channels

- Waste workers from the informal sector
- Trucks from KCC for transportation to the landfill
- Trucks from KCC to pick up clean
- plastic flakes*

How are you reaching your beneficiaries and customers?

Customer

- KCC (*)

Which people or organisations will pay to address this issue?

Customer value proposition

- Support for waste management in Khulna City
- Clean plastic flakes for production of fuel*

What do your customers want to get out of this initiative?

Cost structure

- Rent
- Wages for recycling shop workers handling waste
- Cost for purchasing mismanaged plastic waste from informal sector waste workers based on weight

What are your biggest expenditure areas? How do they change as you scale up?

Surplus

- Improvements in business operations

Where do you plan to invest your profits?

Revenue

- Payment from KCC for mismanaged plastic waste based on weight: 100 %
- Alternative: funding on a project or program basis
- Surcharge for producing clean plastic flakes*

Break down your revenue sources by %

* if energy production through pyrolysis is desired.

Figure 19: Social Business Model Canvas with guiding questions filled in for the Recycling Shop Model; structure from Business Model Toolbox (Social Innovation Lab, 2013)

1.8 LIFE CYCLE ASSESSMENT FOR PRODUCT COMPARISON

Evaluating and comparing the environmental impact of products across their life cycle

BY S. KÜHLEWINDT

→CROSSREF:
· Life Cycle Assessment ▸ *p. 38*
· Acceptance study ▸ *p. 67*
· Plastic substitution ▸ *p. 72*

Through a Life Cycle Assessment (LCA), the environmental impacts from raw material extraction to disposal are evaluated. Comparing products with LCA identifies options with lower environmental impacts, allowing for informed decisions. This method also improves transparency and helps communicate the environmental (dis-) advantages to producers and consumers. More details on LCA can be obtained from the chapter Life Cycle Assessment (general methodology).

Key advantages of LCA for product comparison:

- An LCA provides a holistic view of the environmental impacts of products, unlike other tools that focus on specific stages or impacts.
- An LCA enables the comparison of different product alternatives or design scenarios, allowing for informed decision-making.
- Multiple environmental impact categories can be evaluated through an LCA, such as climate change, resource depletion, and toxicity.

Challenges and limitations of LCA in product comparison:

- An LCA must be conducted for each product. For the results to be comparable, special attention must be paid to the definition of the functional unit.
- The level of detail and processes considered in each LCA depends on the system boundaries selected. Allocating material, energy flows, and waste streams across multiple products or processes within the system boundaries is a complex task.
- Results of the LCA mainly rely on the quality of the Life Cycle Inventory. Therefore, data collection, access to existing databases and the verification of existing data in databases must be considered thoroughly.
- Conduction of an LCA can be a time and resource-intensive task if a certain level of detail should be reached in the assessment.

BY S. KÜHLEWINDT

Example: LCA – Comparison of a jute bag with an LDPE bag

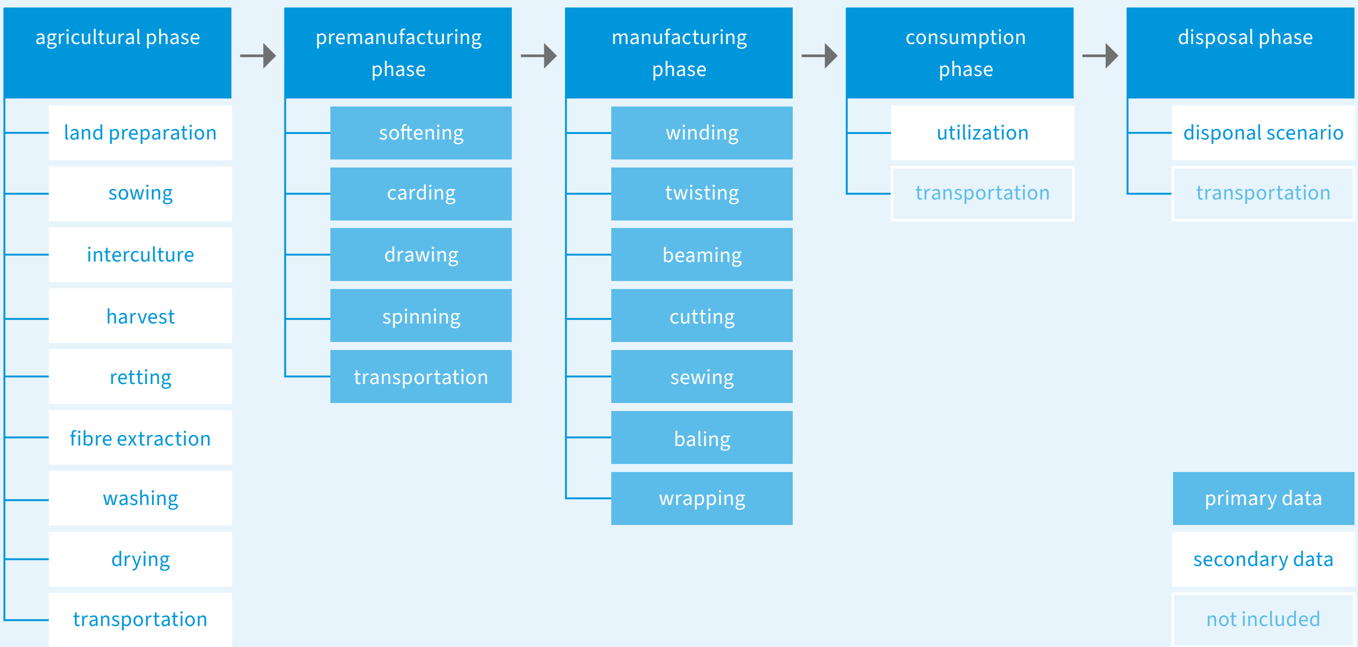
To compare the environmental impact of a jute bag with an LDPE bag, we conducted a comparative LCA. We used openLCA software and the ecoinvent database as supportive tools. The system boundaries were set from the extraction of raw materials (cradle) to their disposal (grave). For both products, we considered the process steps of raw material extraction, manufacturing, transportation, consumption, and disposal. Figure 20 provides an overview of the processes included, as well as data classification for the jute bag in the LCA. We chose the functional unit as the number of bags necessary to carry a person's annual groceries in Bangladesh. Given the same bag size, the product weight for the required bags differs annually due to the varying materials.

In one impact category, we found that a 100 g jute bag emits approximately ten times more CO2 than a 10 g plastic bag. Based on our LCA results, for the jute bag to achieve an ecological benefit compared to the LDPE bag, it must be reused at least ten times. This reuse factor is crucial, as single-use plastic bags have a much lower environmental burden in several impact categories due to their lightweight nature. However, it is important to note that our current analysis does not account for factors such as littering and the long-term environmental persistence of the materials. If these aspects could be included in the calculations – which is currently not possible due to data limitations – the results might differ significantly, potentially favouring the jute bag more.

Key messages:

- → The LDPE bag outperforms the jute bag in 17 out of 18 considered impact categories.
- → A minimum of 10 uses is required for a jute bag to outperform single-use plastic bags in terms of environmental impact.
- → None of the impact categories sufficiently assess the environmental impact of littering or the long-term persistence of materials in the environment. These factors could influence the overall ecological balance between the two products.

Figure 20: Processes overview of the jute bag life cycle for the LCA, including data classification.



1.9 LIFE CYCLE ASSESSMENT ON TREATMENT OPTIONS

Evaluating and comparing the environmental impact of waste treatment options

BY P. LORBER

→CROSSREF:
- Material flow analysis private recycling sector ‣ *p. 31*
- Life Cycle Assessment ‣ *p. 38*
- Final disposal site assessment system ‣ *p. 52*

One of the goals of an LCA is to detect possible ecological risks and weak points and to identify potential for optimisation. The assessment improves technical transparency and helps communicate the environmental (dis-)advantages to stakeholders and decision-makers. More details on LCA can be obtained from the chapter Life Cycle Assessment (general methodology).

Regarding solid waste management, LCA allows tailor-made statements on the efficiency and environmental impacts of waste treatment options. The focus here is on the Life Cycle Impact Assessment (LCIA) as part of the LCA framework. The LCIA breaks down emissions and resource extractions into a limited number of environmental impact categories and scores (Hauschild and Huijbregts, 2015). One such LCIA method is *ReCiPe 2016*, consisting of 17 impact categories (Huijbregts et al., 2016), as shown below. For the evaluation of treatment and disposal options for solid waste, the dark-coloured categories are particularly helpful:

The characterisation factor for the category climate change is the global warming potential (GWP). It is presented in the metric measure of carbon dioxide equivalent or CO2 equivalent, abbreviated as CO2-eq. It allows a comparison of emissions from various greenhouse gases on the basis of their global warming potential by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential.

The quality of such an assessment is strongly dependent on a profound life cycle inventory, meaning the activity of accumulating sound data on emissions during every single step of a treatment process. These steps might include collection, storage, treatment, transportation, and final disposal of waste material.

REFERENCE

Hauschild, M.Z. and Huijbregts, M.A.J. (eds.) (2015). *Life Cycle Impact Assessment.*, Springer, https://doi.org/10.1007/978-94-017-9744-3.

Huijbregts, M.A.J., Steinmann, Z., Elshout, P., Stam, G., Verones, F., Vieira, M., Zijp, M., Hollander, A. and Zelm, R. (2016). *ReCiPe 2016 A harmonised life cycle impact assessment method at midpoint and endpoint level Report I: Characterization.* RIVM Report 2016-0104.

Climate change	Ozone depletion	Ionising radiation	Fine particulate matter formation	
Photochemical oxidant formation: terrestrial ecosystems	Photochemical oxidant formation: human health	Terrestrial acidification	Freshwater eutrophication	
Human toxicity: cancer	Human toxicity: non-cancer	Terrestrial ecotoxicity	Freshwater ecotoxicity	
Marine ecotoxicity	Land use	Water use	Mineral resource scarcity	Fossil resource scarcity

Figure 21: LCIA impact categories. Dark coloured: Categories especially useful for the evaluation of treatment and disposal options.

Example: LCA on waste treatment options

BY P. LORBER

Our interviews and observations have shown that many recycling shops in Khulna City dispose of their process waste improperly in nearby locations such as roadsides, backyards, water streams, drains and green spaces. The purpose of our LCA was to visualise and evaluate treatment options for identified process waste from the local plastic recycling sector. The results act as a decision tool for municipal bodies to further develop public solid waste management activities.

The software in use was the open-source tool *openLCA v2.0*. The data comes from the database *ecoinvent 3.9.1 Cutoff UNIT Regionalized*, released in December 2022. We considered the following treatment options provided by the software: Open burning, open dump, unsanitary landfill and sanitary landfill. Although the different disposal options are not clearly defined in the software, we assumed that an unsanitary landfill is similar to a controlled open landfill, as described in the chapter Final disposal site assessment.

The open burning of polyethylene (PE), as an example waste material, would release 3.17 kg of CO2 equivalent, whereas disposed at a sanitary landfill, it would only release 0.15 kg of CO2 equivalent. Unsurprisingly, open burning is the treatment option with the highest global warming potential. Open burning also has the worst impact on particular matter formation, human cancerogenic toxicity, terrestrial ecotoxicity and acidification. For a better understanding of the relationship between the treatment options, we put the results in a visual and relative manner in the figure below.

The LCA calculations solely examined the impact of various disposal options for a number of plastic waste fractions. The origin and earlier use of materials, as well as the transportation to disposal sites, could not be taken into consideration. The system boundary was limited to the disposal and treatment process. For reasons of comparability, the functional unit of the LCA is set to one kilogram (1 kg). The temporal course is not considered.

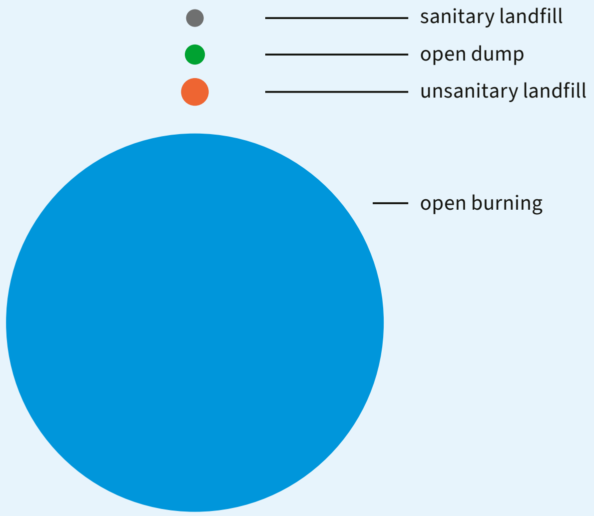


Figure 22: The global warming potential of different treatment options of PE waste shown in relative size.

1.10 HOUSEHOLD WASTE ANALYSIS

Everything starts here: Assessing the main contributor to municipal solid waste.

BY S. BERNER

→CROSSREF:
- Near-infrared plastic sorting ▸p. 46
- Representative sampling ▸p. 97
- Waste characterisation ▸p. 99
- Material flow analysis ▸p. 102

Knowing how much waste households generate and what materials the waste contains is critical for designing an adequate municipal solid waste management system with sufficient local waste storage, efficient material recovery schemes, collection logistics and appropriate final disposal sites.

Household waste analysis is a complex task due to the diverse nature of municipal waste. It allows us to determine waste generation per capita and day, total waste generation per day, and waste composition. Municipal waste can be categorised into dry and wet waste, organic and inorganic materials, and inert and putrescible materials. Its particle sizes vary, ranging from meters (e.g., old mattresses or furniture) to millimetres (e.g., ash or dust). This heterogeneity makes sampling challenging.

At the same time, waste generation is different across all households. There is a well-established correlation between household income, waste generation and waste composition. Generally, increasing income results in rising per capita waste generation and an increasing plastic waste fraction due to the consumption of packaged goods. For sound data, the waste sample must be large enough to mitigate bias due to heterogeneity, and sampling must consider income structures. Therefore, a random stratified sampling approach is recommended, which comprises the following five steps:

Step 1: Classifying wards according to income structures into different categories and randomly selecting one ward per category. If there is no data on income structure, one can use an intermediate parameter such as housing structure and survey the selected wards to determine the actual income distribution.

Step 2: Determining the sample size in selected wards, aiming for 1 % of the weekly generated waste based on an assumed per capita generation rate. This means determining how many households must be included in the sample to meet the required size.

Step 3: Collecting and analysing samples from selected households in each income group over seven days. The actual waste characterisation process is described in the chapter general methodology: Waste characterisation. Near-infrared analysis can provide a more detailed characterisation of the plastic waste fraction.

Step 4: Compiling the first results, i.e., the per capita waste generation rate and waste composition in each income group.

Step 5: Extrapolating results from selected wards, first at the ward level and then the entire city. The average per capita waste generation rate in each income group is multiplied by the number of people in each income group, resulting in the daily waste generation rate in each income group. The sum of these generation rates is the total waste generation rate of the ward. The income distribution, average per capita waste generation rates and waste composition of the different income groups are transferred from the selected ward to the other wards within the same category.

With the resulting dataset, it is possible to determine how much waste is generated in each city and each ward. In addition, one can calculate expected material flows from each ward, e.g., how much plastic materials or biowaste are generated. This can help to develop material-specific collection, treatment, and disposal schemes, such as waste-to-energy or composting.

FURTHER READING

Bidlingmaier, W and Müsken, A. (2017). Analysis of Waste Composition and Characterisation of Wastelines. Orbit Science, Available at: https://www.orbit-online.net/index.php/literature/analytical-methods (Accessed 10 October 2024).

BY S. BERNER

Example: Household waste analysis in KCC

According to the Water and Sanitation Master Plan for Khulna City (KWASA, 2022), KCC has a population of 1,238,129 people in 31 wards. The most recent information on income structures in the different wards is the UNDP Poverty Score, assessed in 2019. The higher the score, the higher the perceived poverty and the lower the affluence level in the different wards.

Step 1: Based on this information, the 31 KCC wards were classified into nine categories. One ward was randomly selected from each category. To reliably determine the income distribution, 275 households were surveyed in each of the nine selected wards. The resulting income distribution comprised five classes: low, lower middle, middle, higher middle, and high.

Step 2: Based on an assumed waste generation rate of 15 tonnes per day and ward, the 1% weight-based sample of the weekly generated waste amounts to 1,050 kg (see also chapter Representative sampling). With an average household size of 5 people, 75 households should create this amount of waste over one week. Therefore, 15 households per income group were randomly selected for sampling.

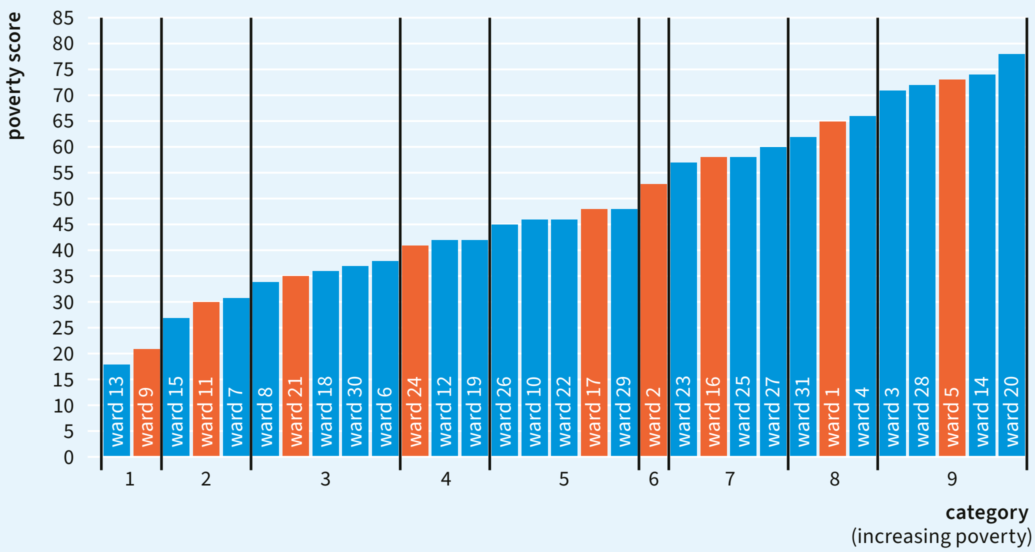


Figure 23: KCC wards sorted by UNDP Poverty Score from 2022 (a low poverty score indicates higher income and low perceived poverty, and a high poverty score indicates lower income and high perceived poverty).

Income groups

high	> 40.000 BDT
higher middle	30.000 – 40.000 BDT
middle	20.000 – 30.000 BDT
lower middle	10.000 – 20.000 BDT
low	< 10.000 BDT

Figure 24: Income groups used for household waste survey.

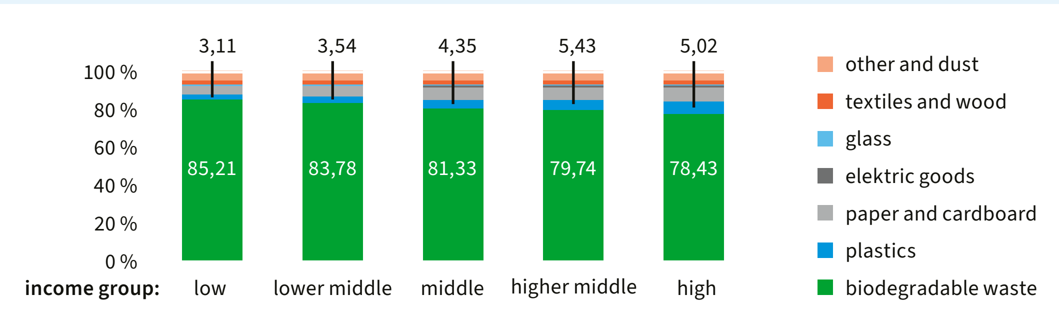


Figure 25: Waste composition by income group in KCC, based on a survey in 2022/2023.

BY S. BERNER

Waste generation rate [(kg/(cap·d)] **in ward category and income group**

Category	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	Average	SD
Ward	9	11	21	24	17	2	16	1	5		
Low	0.47	0.46	0.37	0.32	0.37	0.31	0.36	0.28	0.30	0.358	0.063
Lower Middle	0.41	0.42	0.40	0.38	0.45	0.36	0.45	0.34	0.36	0.395	0.039
Middle	0.59	0.58	0.53	0.45	0.51	0.44	0.51	0.40	0.42	0.493	0.066
Higher Middle	0.73	0.67	0.59	0.52	0.71	0.56	0.69	0.49	0.52	0.609	0.087
High	0.75	0.68	0.75	0.61	0.78	0.67	0.78	0.56	0.58	0.683	0.081

Table 2: Waste generation rate in the nine ward categories and five income groups based on a survey in 2022/2023.

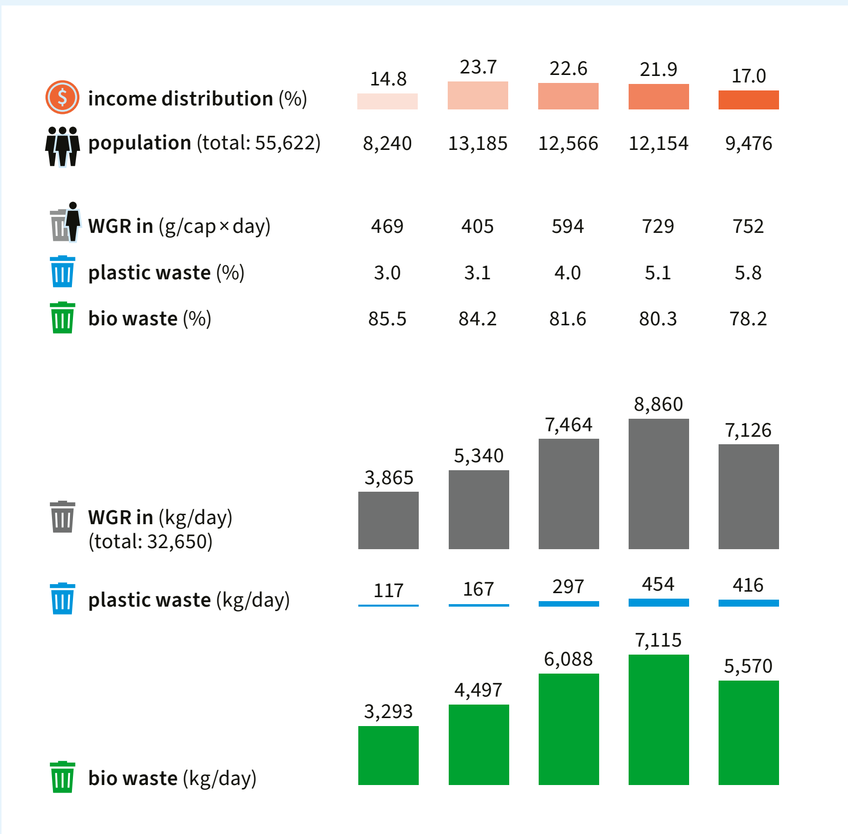


Figure 26: Waste generation and composition in KCC Ward No. 9 based on a survey in 2022/2023.

Step 3: With 75 households in nine selected wards, waste samples from 675 households were analysed, and the average daily waste generation rate (WGR) and waste composition were determined.

Step 4: In the nine selected wards, the average WGR ranges from 280 g/(cap*d) in low-income to 780 g/(cap*d) in high-income households. The biodegradable waste fraction decreased from 85.21 % in low-income households to 78.43 % in high-income households. Respectively, the plastic waste fraction increased from 3.11 % to 5.92 %.

Step 5: The results were extrapolated with the income distribution to the ward level. For example, in Category 1, income distribution, respective WGR in income groups, and waste composition data were transferred from Ward 9 to Ward 13.

After compiling datasets for all wards, the total waste generation rate for KCC was calculated, and based on available population data, it amounted to 610 tonnes per day, including 503 tonnes of biodegradable waste and ca. 29 tonnes of plastic waste.

Lessons learnt

- **Population numbers matter!** Absolute waste generation rates are only as reliable as the underlying population data. A high-quality, representative sampling campaign cannot compensate for unreliable secondary data, such as population numbers.
- Data verification: The results must be verified with waste collection quantities, which are optimally obtained at a weighing facility at the final disposal site.
- Data management: Representative sampling campaigns quickly result in large datasets. In this campaign, sampling from 675 households for seven days generated 4,725 individual data points. Resources must be available for sound data management, including comprehensive data documentation to ensure high data quality and transparency.

1.11 NEAR-INFRARED PLASTIC SORTING

Plastic sorting based on their chemical composition

BY G. BIASTOCH

→CROSSREF:
- Household waste analysis ▸ p. 42
- Waste generation of ships ▸ p. 50

Plastics are typically sorted based on visual characteristics and human experience, which can lead to misidentifications since not all types of plastics can easily be distinguished this way. A technical solution to this problem is near-infrared (NIR) spectroscopy, which can accurately identify the chemical composition of plastics, eliminating doubts in the identification process.

NIR spectroscopy utilises wavelengths of 700–2,500 nm, which are longer than those of visible light (400–780 nm) and invisible to the human eye. When plastics are exposed to near-infrared light, each different type of plastic reflects a unique spectrum, creating a distinct fingerprint. The transmission spectrum of the sample is measured and compared to a database to determine its chemical composition. This method can distinguish between various plastics, including polyethylene terephthalate (PET), high-density polyethylene (HDPE), polyvinyl chloride (PVC), low-density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS).

The main advantage of NIR spectroscopy is that it is a non-destructive technique, leaving the sample unaffected and intact. However, there are some limitations:

- Dirt and moisture: Samples must be free of dirt and completely dry, as water and dirt can alter the reflected spectrum.
- Black materials: Regardless of their composition, black-coloured plastics absorb the entire spectrum and cannot be identified using NIR spectroscopy.
- Composite materials: If materials are made of a blend of different plastics, the NIR spectroscope cannot recognise each component of blends correctly.

The use of NIR spectroscopy is technically ready and state-of-the-art in fully automated industrial-scale sorting systems. Large-scale material recovery facilities are operated with conveyor belts; plastics are scanned and sorted by air classifiers within fractions of a second. However, manual measurements are also common, for example, for quality control in production or sorting batches of material.

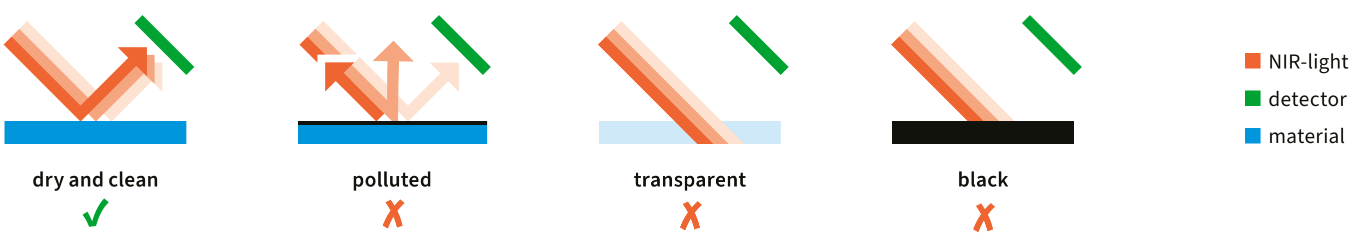


Figure 27: NIR light sample interaction.

BY G. BIASTOCH

Example: Comparing local polymer distinctions with NIR results

As part of a grab sampling process to verify the visual sorting of local categories in a recycling shop, we took a random sample of 45 items using a handheld NIR device. This compact tool offers the advantage of on-site measurements when paired with a mobile phone app.

Among the 45 items tested, we identified 28 as belonging to the most common plastic categories, PA and PE. Additionally, transparent plastics such as polymethyl methacrylate (PMMA), also known as acrylic glass, and styrene-acrylonitrile resin (SAN) were identified. Crucially, PVC was also recognised and appropriately labelled. This process confirmed that the local categories used in the recycling shop could reliably match their respective plastic categories.

Key result/ lesson learnt:

- Our example demonstrates that near-infrared plastic sorting can enhance local sorting practices in private recycling companies, improving product purity and quality while also increasing occupational safety.

Figure 28 a, b and c: Handheld NIR spectroscope. Photos by Gregor Biastoch, 2024.

The local name of the sample	Plastic-type
drum china, gastric, hawa red, high brush, blue/harpic/ parachute, pepsodent, mukh mojo orange, pipe alu, mukh chapa blue, pran, technique/cChuri	PE
chair cutting green, gastric doba, grain blue, karat fruit, PET bottle label, PP milk (dudh), PP water (pani), RFL blu	PP
PET green, PET kotka white, PET tiger, PET white	PET
pipe chara, pipe hard PVC, pipe water (pani)	PVC
polyamide (nylon), abs hard black	PA
opaque, transport hard	PS
ivory	PMMA
pani hard	SAN
CD hard black, lota, sandal, shoe average bata	others

Table 3: Overview local names of samples and plastic-type.

1.12 SAMPLING OF SHIP WASTE

The first step in understanding waste generation on board

BY S. KÜHLEWINDT

→CROSSREF:
· Process-modelling in waste management ▸p. 21
· Waste generation of ships ▸p. 50
· Representative sampling ▸p. 97
· Waste characterisation ▸p. 99

Research on waste sampling from ships has been surprisingly scarce, yet the need for sampling waste from specific sources is recognised as crucial for shaping the future of maritime infrastructure. The groundwork for designing effective reception facilities and planning adequate collection and treatment capacities must be laid accordingly. Characterisation of waste material composition typically consists of three phases:

1. Sampling of the waste (see also general methodology: Representative sampling)
2. Sorting the waste into material fractions (see also general methodology: Waste characterisation)
3. Handling, interpretation and application of the obtained data

Different sampling methods are available for household waste analysis. In the absence of best practices on how to sample waste generated on board ships, this procedure provides some general recommendations on how to sample ship waste in port areas:

Which waste types to sample? The relevant waste types, such as inorganic solid waste, should first be identified/defined based on the main objective. Criteria for selection are then set based on factors like the waste's composition, volume, and environmental impact. The sampling process is designed to ensure that a representative range of waste types and quantities is captured for accurate and practical data.

Where and how can the ships be reached? Ship locations within the port area may vary. Ideally, ships should be anchored, with a specific number of ships accessible within a limited time frame. As ports are restricted areas, it is essential to involve and inform the port authority during the planning process. Contact details for the ship crew should be obtained, and potential limited accessibility due to poor network coverage, especially if the ship travels to the deep sea, should be considered. The necessary logistics for sampling should be planned accordingly.

For how many days should waste be collected? Ships constantly arrive and depart from the port area. It is essential to define a specific period during which waste should be collected on board. Challenges may arise if a ship leaves the port area within the designated period. Household waste samples are typically taken for a week, and flexibility is required with regard to defined collection periods from ships.

Where is the waste collected? Bins or bags suitable for on-board storage during the collection process must be provided. The process of reaching ships and collecting samples may be complicated by tidal conditions, ships anchored in rivers or at sea, and the use of ladders as the only means to board. The prevailing conditions should be considered, and life jackets, in addition to standard safety equipment, must be provided for sample collectors.

Is additional information required? If more information beyond data on waste generation and composition is needed, conducting a survey should be considered. For instance, the current waste disposal practices of crew members could be examined.

Example: Sampling of local ship waste at Chattogram and Mongla Ports

BY S. KÜHLEWINDT

Figure 29: Sample collection process from local ships in Chattogram Port. Photo by Trisa Das, 2023.

Figure 30: Local ships anchored in the Mongla Port area. Photo by Gregor Biastoch, 2022.

In our study, we introduced a waste sampling methodology designed for the efficient and comparable characterisation of inorganic solid waste from local ships. We applied this methodology to waste collected from local ships at the two main seaport areas in Bangladesh: Chattogram Port and Mongla Port. To ensure a representative data set, we aimed to collect waste from 1 % of the approximately 7,000 registered local ships in Bangladesh. Prior to our study, there was no data available on waste generation from local ships in Bangladesh, nor any sampling studies from local ships existed. Our overall goal was to estimate the amount of plastic waste entering waterways and, ultimately, the marine environment from these ships. Consequently, we focused our sample collection on inorganic solid waste generated on the ships.

Our aim with this focus was to:

→ Increase the willingness of crew members to collect waste over a specified period by excluding the organic fraction, considering the challenges of the humid and warm climate and the limited space on board.

→ Minimise the complexity of instructing crew members on which waste should be collected, recognising that individual understanding and perceptions of what constitutes plastic waste can vary.

In total, we randomly selected the crews of 240 ships within the two port areas. Surveys were conducted, and bags were distributed to collect the waste samples. The ships were reached by boat. Out of a total of 240 ship crews, we collected 80 inorganic solid waste samples after a period of 3–8 days. We sealed and labelled each bag before sorting the samples into predefined fractions and size categories at the waste lab facilities of KUET and CUET. Results from the waste characterisation and waste generation can be found in the following procedure: Waste generation of ships.

The key findings of the sampling procedure have led us to formulate general recommendations with regard to location, access to the ships, safety precautions, and collection period, as presented above.

1.13 WASTE GENERATION OF SHIPS

From deck to disposal: Quantifying waste generation

BY S. KÜHLEWINDT

→CROSSREF:
- Near-infrared plastic sorting ▸p. 46
- Sampling of ship waste ▸p. 48

Waste produced by ships poses a significant environmental challenge, primarily due to the variety of waste generated during maritime activities. Ships are responsible for creating multiple types of waste, including sewage, solid waste, hazardous materials and ballast water. Proper waste characterisation is essential as it allows for the identification of the types and amounts of waste generated, facilitating the development of effective waste management strategies.

On-board solid waste is comprised of diverse materials such as food scraps, plastics, paper, cardboard, glass, metals, and packaging. These wastes arise from various shipboard activities, including food preparation, maintenance, and crew-related tasks. Improper disposal of waste, particularly plastic, when it is dumped into the ocean, contributes to marine debris, exacerbating the global issue of marine litter. This debris poses risks to marine life through ingestion and entanglement, and it can also impact human health and local economies. To address these concerns, the International Maritime Organization (IMO) has implemented regulations under MARPOL Annex V, which restricts the discharge of most solid waste into the sea. Ultimately, it is the responsibility of each country to draft local laws, take appropriate measures and monitor compliance with existing laws.

Effective waste management on ships necessitates the establishment of onboard waste separation systems and appropriate storage facilities to reduce waste disposal in water bodies. Tackling the challenges associated with solid waste management on ships is vital for safeguarding the marine environment from the threat of pollution, and it does not end on board. Properly designed reception facilities at ports, as well as waste treatment plants, are required to guarantee treatment and safe disposal options for the waste on land.

Example: Plastic waste generation on local ships at Chattogram and Mongla Ports

BY S. KÜHLEWINDT

Following the approach described in the procedure Sampling of ship waste, we quantified the plastic waste generation of local ships using 38 inorganic solid waste samples collected at Chattogram Port and 42 samples from Mongla Port. In both study areas, standard operating procedures helped to ensure that the same procedure was followed and the manually sorted waste fractions were separated and weighted accordingly. To calculate the daily waste generation rate for each crew member, we used the data obtained from the survey. We found that the average crew size at Chattogram Port was 13 members, while at Mongla Port, it was nine members.

The weighted average of plastic waste generated on local ships in Chattogram Port results in 3.16 g per crew member and day. At Chattogram Port, the daily average of active local ships within the port area lies at 1,281, resulting in a plastic waste generation from local ships of 52.6 kg per day. Meanwhile, over at Mongla Port, with fewer ships – about 224 active local vessels on an average day – the total plastic waste generation is lower but still significant. Here, it was found that each crew member produced slightly more plastic waste, averaging 4.26 g per day, which totals an average of 8.5 kilograms of plastic waste generated on local ships daily.

These numbers highlight the unseen impact of ship activity, showing how even small amounts of waste can accumulate into something much larger when scaled up to the total number of ships active in a distinct area.

As there are no reception facilities to be used for the local ships, nor a collection system in place or treatment plants available for the waste generated, all waste is currently dumped. Our survey findings reveal the common disposal practices for plastic waste from local ships at Chattogram Port, illustrated in Figure 31.

Given the fact that 75 % of plastic waste currently ends up in the surrounding water bodies and the deep sea, this results in nearly 40 kilograms of plastic being thrown overboard every day. To visualise the plastic waste generation of local ships at Chattogram Port, we created a material flow diagram, represented in Figure 32. In conclusion, our study estimated that implementing a waste collection system for local ships at Mongla and Chattogram Port could prevent an average of 17.5 tonnes of plastic waste from entering the Bay of Bengal yearly.

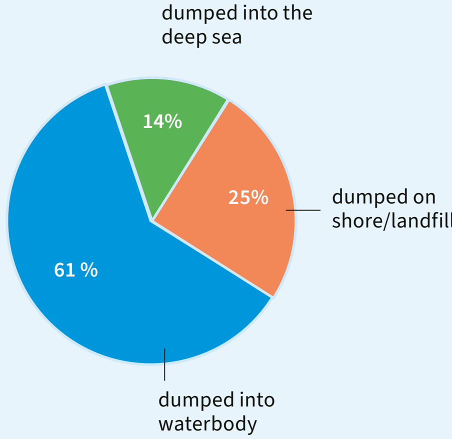


Figure 31: Disposal practices for plastic waste from local ships at Chattogram Port.

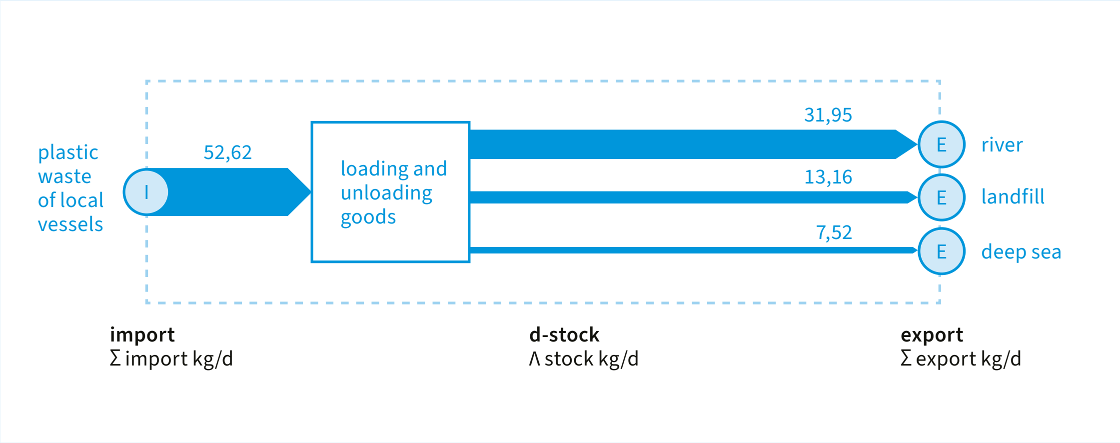


Figure 32: Material flow diagram of plastic waste from local ships at Chattogram Port.

1.14 FINAL DISPOSAL SITE ASSESSMENT SYSTEM

Creating a baseline to decide the future of disposal sites

BY S. BERNER

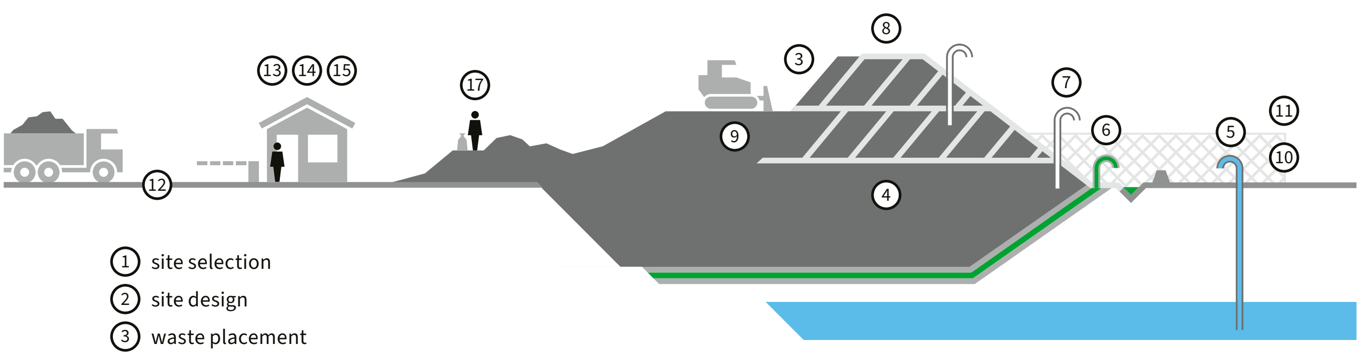
→CROSSREF:
- Stakeholder analysis ‣ p. 14
- Waste collection analysis ‣ p. 23
- Life Cycle Assessment on treatment options ‣ p. 40
- Drone monitoring of final disposal site ‣ p. 60
- Final disposal site environmental management plan ‣ p. 77
- Weighing station at final disposal site ‣ p. 80
- Training for informal waste workers ‣ p. 84

Landfilling is often the most cost-effective way to dispose of municipal solid waste. However, dump sites can pose risks to human health and the environment. Before deciding on improvements or site closure, a structured assessment provides a baseline for intervention by creating a fact-based and transparent understanding of the disposal site's current state and possible target scenarios. There is no official assessment or landfill classification system available in Bangladesh. Following findings by EPTISA (2010) and Idris et al. (2004) and integrating requirements of the 2021 Solid Waste Management Rules of Bangladesh, a pilot assessment system that evaluates disposal sites and their operations within 17 categories (see also Figure 33) was developed and tailored to conditions in Bangladesh.

The assessment system acknowledges that disposal sites are not in a fixed state but can be transformed.

- → The lowest state is an open-crude dump site that does not fulfil sanitary landfill criteria.
- → Open-controlled sites already show minimal engineered elements and operational interventions.
- → The target scenario for landfilling is a sanitary landfill with qualified staff and standard treatment, monitoring, and containment systems, minimising risks to the environment.

Observations from site visits, including photographic evidence and findings from interviews with relevant stakeholders, are documented for each category and compiled in an assessment report. The site assessment findings are then summarised for each category in tabular form and compared to the assessment guideline (see Table 4).



1. site selection
2. site design
3. waste placement
4. biological process
5. water management
6. leachate management
7. landfill gas management
8. cover
9. compaction
10. fencing
11. containment and vector control
12. access road and interior roads
13. records (inclusive weighbridge and site office)
14. waste acceptance
15. staff and equipment
16. site closure
17. waste picking

Figure 33: Final disposal site with assessment categories.

BY S. BERNER

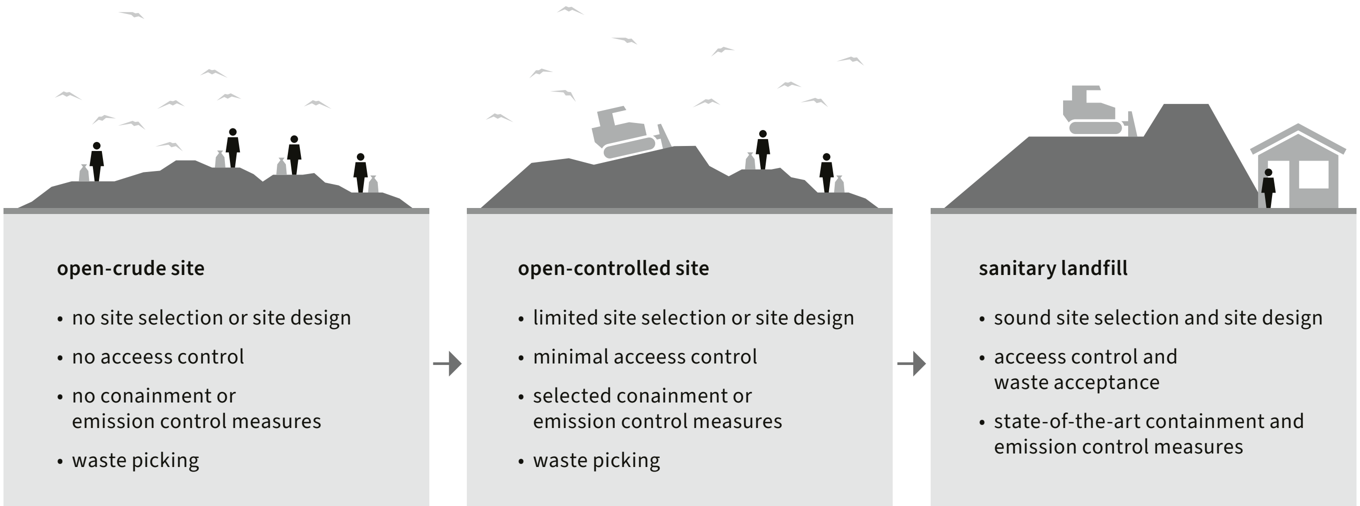


Figure 34: Different stages or types of disposal sites.

Category	Characteristics of disposal site type			
	Open-crude	**Open-controlled**	**Sanitary, basic**	**Sanitary, advanced**
(12) Access road and interior roads	No access or interior roads (0 points)	Maintained access road (2 points)	Surfaced primary access road: Access roads and internal roads should be paved (SWMR 2021) (4 points)	Surfaced primary access road and maintained secondary and tertiary haul roads. (6 points)

Table 4: Excerpt of the assessment guideline for Category (12): Access roads and interior roads.

A scoring system from zero points to six points in each category is introduced to improve comparability and progress tracking. An open-crude site would score zero points across all categories, a basic sanitary landfill would score four points in each category, and an advanced site would score six points in selected categories; for example, if the site comprises laboratory facilities and employs highly qualified staff (see also Table 2). In-between scenarios can be credited with odd scores. A waste management expert or site engineer assigns the respective scores using the assessment guideline.

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EPTISA (2010). *Waste Governance – ENPI East – Landfill Operations Guidance Manual*. European Neighbourhood Partnership Instrument (Eastern Region). October 2010. Copyright © 2010 by EuropeAid.

Idris, A., Inanc, B., Hassan, M.N. (2004). *Overview of waste disposal and landfills/dumps in Asian countries*. J Mater Cycles Waste Manag (2004) 6:104–110 © Springer-Verlag 2004. https://doi.org/10.1007/s10163-004-0117-y.

Solid Waste Management Rules (2021). Government of the People's Republic of Bangladesh: Ministry of Environment, Forest and Climate Change. 09 December 2021.

Example: Assessing Rajbandh disposal site, Khulna City

BY S. BERNER

All municipal solid waste collected from Khulna City is taken to the Rajbandh open dump site. In 2022, we assessed the Rajbandh disposal site by applying the previously developed assessment system with 17 assessment categories. In most categories, the site showed the characteristics of an open-crude dump site. However, in the five areas, the site is already in line with an open controlled site, and we could award two points for each (see Table). We observed very basic infrastructure elements in the areas of fencing, containment, and roads and assigned one point for each. For example, there is an existing access road. However, the road is a simple dirt road without a regular maintenance scheme or reinforcements, so it becomes impassable after heavy rain.

Overall, the Rajbandh site achieved a score of 15. In comparison, a controlled site would receive a total score of 26 and a basic sanitary site a score of 68.

Rajbandh key facts:

- Est. daily waste intake: 300–600 tonnes/day
- Area: 78,320 m^2
- Location: approx. 7 km east of the Khulna City centre
- Operated by KCC Conservancy Department
- In use since approx. 2010

Key findings:

- The assessment system helped to identify areas of intervention at the site and provided a comprehensive overview of physical structures at the site and operational processes. It provides the baseline for the site's further development and transformation into an open-controlled site.
- The Rajbandh site is an open-crude dump that already operates within a basic operational framework and shows aspects of an open-controlled site.
- Rainwater run-off mixes with leachate. Observations at the site indicate that surface water run-off drives plastic emissions. Plastic and leachate leak from the site into the surrounding ponds, highlighting the lack of proper site containment measures.
- Waste picking activities are limited to around 20 informal waste workers at the site.

After carefully considering the results of the assessment, we prioritised interventions in three areas:

- Lack of waste quantity data: We need reliable data on waste intake to evaluate the site's lifespan and capacity and plan waste placement and covers. A weighing facility must be installed.
- Site containment and emission control: Appropriate containment measures for plastic and leachate emissions must be designed and implemented to avoid further contamination of the surrounding environment.
- Improvement of working conditions at the site: Municipal staff and informal workers must receive proper occupational health and safety training and should have access to adequate sanitation facilities.

No	Category	Main findings	Score				
			O	**R**	**C**	**Sb**	**Sa**
1	Site selection	There is no transparent site selection process; the site was selected based on land availability and the vicinity of Khulna City.	0	1	2	4	6
2	Site design	There is no documentation of site design or site preparation.	0	0	0	4	6
3	Waste placement	The site manager oversees waste placement; the active waste dumping zone is moved from section to section.	0	2	2	4	4
4	Biological process	Thin spreading of waste, promoting aerobic degradation and reducing landfill gas build-up.	0	2	2	4	4
5	Water management	There is no active rainwater or groundwater management or containment in place.	0	0	2	4	6
6	Leachate management	No leachate management; leachate and rainwater mix in ponds on site.	0	0	0	4	6
7	Landfill gas management	No gas collection.	0	0	0	4	6
8	Cover	No covers are applied.	0	0	2	4	6
9	Compaction	A compactor (bulldozer) is used to spread, shift and compact waste.	0	2	2	4	4
10	Fencing	Temporary fencing was put in place to monitor wind-blown litter from the site.	0	1	2	4	4
11	Containment and vector control	No vermin or pest control; a low embankment and a bamboo fence are in place.	0	1	2	4	4
12	Access road and interior roads	An unimproved dirt road gives access; interior roads are simple dirt tracks; roads are repaired with construction waste.	0	1	2	4	6
13	Record keeping	There is essential record keeping with handwritten logbooks, no digital records, and no weighbridge.	0	2	2	4	4
14	Waste Acceptance	All waste is accepted; no weighbridge.	0	0	0	4	6
15	Staff and equipment	Two site supervisors, one bulldozer driver, and three guards are on site; a work shed and a record/tool storage room are present, and there are no sanitary facilities.	0	2	2	4	6
16	Site closure	There is no site closure plan in place.	0	0	2	4	4
17	Waste picking	12 to 20 informal waste workers are on site and are known by the site staff; an agreement with 2 NGOs to sort medical waste is in place.	0	1	2	4	4
	Maximal score		**0**	**15**	**26**	**68**	**92**

Table 5: Assessment summary of Rajbandh disposal site and score system (O: Open-crude, R: Rajbandh, C: Controlled, Sb: basic Sanitary, Sa: advanced Sanitary Site).

Figure 35: Waste pickers at the Rajbandh open dump site. Photo by Senta Berner, 2022.

Figure 36: Waste dumping from the truck. Photo by Md Nahid Hasan, 2022.

Figure 37: Levelling of dumped waste by bulldozers. Photo by Senta Berner, 2022.

BY S. BERNER

Figure 38: Drainage line excavated on top of the waste pile. Photo by Senta Berner, 2023.

Figure 39: Drainage line forming towards the access road. Photo by Senta Berner, 2022.

BY S. BERNER

Figure 40: Leachate and run-off accumulation along the western boundary. Photo by Senta Berner, 2023.

Figure 41: Monitoring fence and earthen embankment at Rajbandh site. Photo by Senta Berner, 2023.

Figure 42: On-site workshop and office shed. Photo by Senta Berner, 2023.

1.15 DRONE MONITORING OF THE FINAL DISPOSAL SITE

Gauging site stability and emission risks from the above

BY S. BERNER

→CROSSREF:
· Final disposal site environmental management plan ▸p. 77
· Weighing station at the final disposal site ▸p. 80

Final disposal sites require careful monitoring. Any problems in the containment of the sites might lead to severe environmental contamination in the surrounding areas. In the case of open dump sites, parts of the site might not be safely accessible. Drone images can be a helpful tool to assess the site's stability and emission risks. In particular, drone images can assist in determining the following parameters:

- Extent of waste body, leachate ponds/ run-off leachate accumulation
- Distance between waste body and boundary
- Location of active waste zone
- Location of any ongoing construction
- Vegetation on waste body
- Erosion-prone areas
- Landfill fires and burnt areas
- Current state of construction sites to improve the site

As with any other monitoring activities, drone surveys should follow a standard protocol to facilitate comparing images, including a monitoring plan and proper documentation of each monitoring event. The following steps are recommended:

1. Establishing a monitoring plan detailing the objective of the monitoring and the parameters to be surveyed.
2. Developing standardised monitoring procedures and datasheets documenting the videos and images and the time, date and altitude taken.
3. Optionally, manipulating images with photo editing software, e.g., stitching images together.
4. Georeferencing and loading images into a GIS programme (e.g., ArcGIS or Google Earth).
5. Mapping relevant parameters (e.g., the extent of the waste body).

Weekly or monthly drone images can illustrate the change in the waste body or leachate accumulation over time and containment problems.

Drone model in use: **DJI Air 2S**

- Weight: 595 g + 198 g battery
- Size: 183 × 253 × 77 mm (length × width × height)
- Camera resolution: 20 MP (photos), max. 5.4K (video)
- Max. flight height a. NN: 5000m

Figure 43: DJI Mavic Air 2 drone in flight. Photo by C.Stadler/Bwag, 2021 under licence CC BY-SA 4.0.

Example: Drone monitoring at the Rajbandh disposal site

BY S. BERNER

Since 2023, we have frequently taken images with a DJI Air 2S of the Rajbandh open dump site. We used the photos to monitor the overall site development and document the construction of a weighing station and sanitation facilities.

The first drone image of the Rajbandh open dump site was taken in March 2023. We determined the following parameters:

- Cross-hatched area: designated waste disposal area
- Black-hatched area: active work zone in March 2023
- Dotted area (yellow outline): historically contaminated area (based on older satellite images)
- Blue-hatched area: accumulation zones for leachate and surface water run-off
- Boundaries: walls (SE and E), fences (W and N) and open (S and NE)

Subsequent images illustrate the expanding waste body. In particular, the images taken in April 2024 show how close the waste body encroaches on the site's northern fence line. These images inform the ongoing assessment of the disposal site's operations.

The drone was also used to document the construction progress of the weighing station and the sanitation facilities on the Rajbandh site.

Key findings:

- Drone images are a valuable tool to illustrate changes at a final disposal site, especially during the rainy season when the waste body becomes unstable and difficult to monitor from the ground.
- The current waste placement scheme spreads the waste body more and more towards the northern and western boundary. A likely result is an increased plastic emission across these boundaries.

Figure 44: Expanse of Rajbandh disposal site in March 2023. Photo by Florian Wehking, annotations by Senta Berner 2023.

BY S. BERNER

Figure 45: Comparison of the northern boundary of the Rajbandh disposal site in April 2024 (top) and March 2023 (bottom). Photos by Noor Alam (top) and Florian Wehking (bottom).

Figure 46: Weighing station under construction in the entrance area of the Rajbandh site. Photo by Noor Alam, 2024.

Figure 47: Sanitation facilities under construction at the Rajbandh site. Photo by Saptarshi Mondal, 2024.

1.16 INFORMAL SECTOR ASSESSMENT

Understanding services and needs of informal waste workers

BY H. KERBER AND L. SATTLEGGER

→CROSSREF:
- Stakeholder analysis ▸ *p. 14*
- Social Business Model Canvas ▸ *p. 35*
- Final disposal site assessment system ▸ *p. 52*
- Training for informal waste workers ▸ *p. 84*
- Establishing an Awareness Centre ▸ *p. 87*

Municipal plastic waste management and recycling in Bangladesh depend significantly on informal waste workers. Informal means that these workers have no contract, no regular income, rather simple equipment to work with, little recognition and high vulnerability (Gunsilius et al., 2011). An assessment of the informal sector can help municipalities and policymakers grasp the contributions and challenges of informal waste workers.

An informal sector assessment enables informed decision-making, effective policy formulation, improvements of informal working conditions, support for integrating informal workers into formalised employment structures, and exploration of resource recovery and recycling opportunities in collaboration with the informal sector. It provides an overview of the relevant working conditions and needs within the informal waste sector, characterised by individuals who collect, separate, classify, and sell solid waste as a means of subsistence or supplemental income. Such assessments can be based on quantitative data (statistical data and surveys), qualitative data (interviews), or a combination of both. Municipalities can use the findings to develop a comprehensive understanding of the informal waste sector's structure, operations, and contributions.

The International Labour Organization (ILO 2021) names four core components of an informal sector assessment:

1. Assessment of the informal economy: Extent, characteristics and nature of the informal economy
2. Factors and causes: Identification of the main drivers of informality and incentives for formalisation
3. Mapping of actors and coordination mechanism(s) in place, if any
4. Identification and assessment of current policy approaches to reduce decent work deficits in the informal economy and facilitate the transition to formality

Key advantages:

- → Empirical insight: It provides a factual understanding of working conditions, needs, and operations within the informal sector.
- → Voice for informal actors: It can give informal workers a platform to express their concerns and needs, fostering inclusion in policymaking.

Key challenges and limitations:

- → Data availability and quality: Obtaining accurate and comprehensive data from informal sectors can be challenging due to their decentralised and informal nature.
- → Bias and representation: There may be biases in the data collected, as certain groups within the informal sector may be under-represented or overlooked.
- → Risks of unintended consequences: Interventions that relate to formalisation or changing conditions of informal work must be carefully assessed in their consequences, considering opportunities but also risks for (different groups of) informal workers.

REFERENCE

Gunsilius, E., Spies, S. and García-Cortés, S. (eds.) (2011). *Recovering resources, creating opportunities – Integrating the informal sector into solid waste Management*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Sector Project Recycling Partnerships. Eschborn, Germany. Available at: https://www.giz.de/en/downloads/giz2011-en-recycling-partnerships-informal-sector-final-report.pdf (Accessed 14 October 2024).

ILO (International Labour Organization) (2021). *Diagnosis of informality: Methodological note*. International Labour Organization. Geneva, Switzerland. Available at: https://www.ilo.org/sites/default/files/wcmsp5/groups/public/@ed_protect/@protrav/@travail/documents/briefingnote/wcms_832476.pdf (Accessed 14 October 2024).

Example: Informal sector assessment – Case study Khulna

BY H. KERBER AND L. SATTLEGGER

The informal waste economy is crucial for plastic recycling in Khulna and interrelates with municipal waste management structures. We conducted an informal sector assessment to identify the conditions and needs of informal waste workers in Khulna. The assessment was based on a social-empirical study that included qualitative, semi-structured interviews with relevant stakeholders operating within the informal waste economy. The analysis is structured around key criteria defining informal work: lack of formal contracts, irregular income, use of basic equipment, limited recognition, and high vulnerability.

Table 5 provides an overview of different groups of workers regarding an overall assessment of their vulnerability. It was synthesised from the individual ratings of the interview partners and includes the following categories:

- Income (amount and stability)
- Form of organisation (independent, group-based, contracted, etc.)
- Subjective perceptions of risks and vulnerabilities
- Tools used for work, including safety equipment
- Recognition and acknowledgement by others

We then summarised these categories to generate an overall assessment of vulnerability. Highly vulnerable actor groups from the informal sector are waste pickers at landfills, waste pickers at Secondary Transfer Stations (STS) and waste collectors on streets and in public places.

Key messages:

- Khulna’s informal sector is diverse in roles, perspectives and vulnerabilities. Hence, the needs of informal waste workers are not uniform. When planning interventions, this diversity must be considered.
- Vulnerable groups, in particular, should be prioritised for support, and their needs must be considered in all efforts aimed at achieving a sustainable transformation of plastic waste management in Khulna.

	Income (TK/ month)	Income (range, regularity)	Form of organisation	Perceptions of risks	Equipment & tools	Recognition & treatment	Assessment of vulnerability
Landfill waste picker	6000–9000	Income varies; difficult to secure livelihood	Work independently, in informal group or with NGO	Health risks: accidents, injuries due to sharp and hazardous waste, illness mostly during rainy season	Spade & hook for picking, vans and waste sacks for transportation; boots, gloves, masks for safety	Overall positive experience, despite low social status	High vulnerability; high priority for support
STS waste picker	5000–20000	Income varies; difficult to secure livelihood	Usually work independently and alone	Health risks: injuries, dehydration during ramdan; Financial risks: stolen equipment	Iron rod, shovel, and bucket for waste collection; most do not use safety equipment, some use gloves and masks	Ambivilant experience; often good relationship with KCC staff	High vulnerability; high priority for support
Waste collector at streets	3000–9000	Income varies; difficult to secure livelihood without other income sources	Usually work independently and alone	Health risks: injuries; Financial risks: collected items get stolen	Often no use of safety equipment, e.g. lack of money	Ambivilant experiences; partially physical assaults	High vulnerability; high priority for support
Vangari shops	12000–40000	High income variety by shop size	Usually work independently, some with employees or family members; some belong to an association	Health risks: injuries due to heavy items, respiratory problems; Financial risks: loss of money and equipment, dishonest staff	Drill machine, weighing machine; some use gloves, eye glasses and masks for certain works	Ambivilant experience; some feel underestimated; generally respectful with KCC and neighbours	Lower vulnerabiltiy: higher income, status and degree of organisation
Ferriwala	12000–30000	Income varies; most cover basic costs, but irregularities cause issues	Usually work independently; some cooperate with moneylenders or vangari shops	Health risks: injuries due to heavy items or harmful substances; generally low risk perception	Some use masks and gloves	Ambivilant experience; some face disrespect and social stigma, mostly respectful with related actors	Lower vulnerabiltiy: higher income, status and degree of organisation
Recycling shop worker	9000–15000	Most cover basic costs, but irregularities, such as illness, can cause issues	Employed by factory owners (often no formal contracts)	Health risks: injuries, accidents with heavy machines, respiratory problems, allergy	Normally use boots, mask and gloves, sometimes helmet and glasses	Overall positive experience, but occasional disputes between factory owner and employees	Lower vulnerabiltiy: usually in employment relationsship, but often no formal contract

The informal sector assessment is based on a content analysis of interviews with relevant actors working in the informal waste economy (social-empirical study). The analysis of interviews is structured along central criteria for informal work based on the following definition of the German Development Cooperation (GIZ): „Informal means that they have no contract, no regular income, rather simple equipment to work with, little recognition and high vulnerability” (GIZ 2011).
GIZ 2011: https://www.giz.de/en/downloads/giz2011-en-recycling-partnerships-informal-sector-final-report.pdf

Table 6: Informal sector assessment for waste management in Khulna.

1.17 ACCEPTANCE STUDY

Understanding what people think about alternatives to plastic

Switching to eco-friendly materials, such as those that are biodegradable, instead of plastic can be a game-changer in tackling plastic waste. While assessing the environmental impact of these materials through Life Cycle Assessment is crucial, it is equally important to understand public acceptance towards adopting them.

An acceptance study can reveal whether people are ready to embrace eco-friendly materials, such as jute bags. Municipalities can benefit from these insights in creating municipal sustainability strategies, supporting local entrepreneurs, running awareness campaigns, and developing tailored policies. This ensures municipal actions align with community needs and aspirations.

An acceptance study is a research process aimed at understanding users' attitudes, opinions, and behaviours regarding the adoption and use of products made from different materials. Various methods are available to determine acceptance, including social empirical methods, which gather data on users' experiences, preferences, concerns, and intentions. In addition to collecting original data, it is also possible to review existing literature through a literature review.

Key steps include:

- Defining objectives: Establish clear goals for evaluating the acceptance of the product (e.g., bags made from jute or cotton, cups and straws made from bamboo or steel), including overall consumer acceptance, identifying barriers to use, and understanding specific preferences for materials and designs.
- Identifying the target audience: Select participants for the study based on demographic criteria (e.g., age, income), geographic factors (e.g., urban vs. rural areas), or psycho-graphic traits (e.g., environmental awareness, lifestyle choices) to ensure diverse perspectives on the alternative product under study.
- Developing research instruments: Create tools such as surveys, interview guides, and focus group discussion prompts, or outline a literature review approach that focuses on existing research regarding acceptance and usage.
- Collecting data: Conduct empirical research through surveys, interviews, or group discussions to gather insights on consumer attitudes toward the product or perform a literature review to compile existing knowledge and trends.
- Analysing data: Use qualitative or quantitative methods to analyse the collected data, identifying patterns and trends related to product acceptance.
- Interpreting findings: Evaluate the level of acceptance for the product and determine the key factors influencing consumer attitudes, such as environmental concerns, cost, usability, and aesthetic appeal.

→CROSSREF:
- Life Cycle Assessment for product comparison ▸ *p. 38*
- Plastic substitution ▸ *p. 72*

BY H. KERBER AND L. SATTLEGGER

BY H. KERBER AND L. SATTLEGGER

Important aspects regarding the data collection approach:

- Conducting a qualitative study provides detailed insights into opinions, attitudes, and behaviours, revealing aspects often missed by quantitative methods. However, these findings may not be broadly representative.
- In contrast, a quantitative study uses large, random samples to generate data that is more representative and generalisable. While such surveys can identify gaps between knowledge and behaviour, qualitative studies are essential for understanding and addressing these gaps by explaining why they exist.
- Literature reviews can provide a general overview of how materials, such as jute, are accepted in various regions, such as Europe, America, and Asia, or how other materials, such as bamboo or cotton, are received in a specific region. However, the results from these studies may not align with the local context and thus may have limited applicability.

Acceptance alone does not necessarily lead to behaviour change, as change typically requires more than just positive attitudes toward a product or practice. An effective acceptance study should, therefore, also examine capability (skills, knowledge, and resources), opportunity (external factors), and motivation (internal processes) – three critical factors identified in the Behaviour Change Wheel Framework. According to this framework, behaviour occurs through an interaction between these elements, making the COM-B behaviour model a valuable tool for describing, designing, and evaluating strategies for behaviour change (Michie et al. 2014).

FURTHER READING:

Michie S, Atkins L, West R. (2014) The Behaviour Change Wheel: A Guide to Designing Interventions. London: Silverback Publishing

Example: Acceptance study of jute bags as a supplement for plastic shopping bags in Khulna

BY H. KERBER AND L. SATTLEGGER

In Bangladesh, the legal transition from plastic to jute as a more eco-friendly alternative is already underway. This shift is supported by the deep cultural significance of jute and its long history of cultivation in the Ganges Delta region. Jute fibre presents a viable alternative to plastic, particularly in packaging transported goods. However, challenges remain in the implementation, and this change has yet to be fully reflected in user behaviour.

In an acceptance study, we explored users' attitudes toward jute products and empirically assessed the practicality of using jute bags as a substitute for plastic bags among Khulna's citizens.

We used two methods for our acceptance study:

Literature review
In a literature review, we synthesised current research on the acceptance of sustainable alternatives to plastic, with a particular focus on jute products and the factors influencing eco-friendly behaviour.

Key results from the literature review are:
Users who already use jute and other plastic alternative products cite the following key benefits:
- → Attractive design
- → Eco-friendliness
- → Made of local material

Users who already use jute and other plastic alternative products cite the following key drawbacks:
- → Higher price
- → Limited availability, e.g., in stores
- → Limited range of products
- → Often less durable than plastic products
- → Lack of trust in product quality

Focus group study
We conducted six focus group discussions, each with six to eight participants and a duration of 90 minutes, to explore user experiences with the acceptance of jute bags. We selected participants using various socio-demographic criteria (see Table 7). Prior to the discussions, we provided each participant with a jute bag (see Figure 48) for a three-week testing phase.

The discussion covered the following topics:
- → Experience using jute bag
- → Acceptance and preferences
- → Motivation and barriers
- → Sustainability and future implementation

Figure 48: Jute bag

Income group high < 40.000 BDT	Income group middle 20.000–40.000 BDT	Income group low 10.000–20.000 BDT
female age 20–55 years different houshold sizes		
male age 20–55 years different houshold sizes		
General characteristics: mainly responsible for shopping or regularly at least 1–2 time a week involved in shopping		

Table 7:
Participants profile


MAP

2 INTERVENTIONS

2.1 PLASTIC SUBSTITUTION

Cutting plastic use by embracing local substitutes

BY S. KÜHLEWINDT

→CROSSREF:
- Life Cycle Assessment for product comparison ▸ *p. 38*
- Acceptance study ▸ *p. 67*
- Social-empirical research methods ▸ *p. 105*

Switching from plastic to products made from alternative materials can promote better consumption practices and help prevent plastic pollution. Exploring historical materials and recent advancements in biodegradable options can reveal effective local alternatives.

Below, you can find a 5-step plan to consider when planning to substitute a plastic product:

1. **Assess the plastic product:** Identify the purpose and requirements of the product.
2. **Research potential alternative materials:**
   - Identify locally available alternative materials (e.g., natural fibres) that can fulfil the same function.
   - Compare the physical and chemical properties of these materials against the plastic product's requirements.
3. **Evaluate the environmental and economic impact**
   - Assess the lifespan, durability, and limitations of these alternatives and analyse the environmental impact (e.g., conduct a Life Cycle Assessment to compare the environmental impacts; *see Procedure: LCA for product comparison*).
   - Analyse the cost implications of switching to the alternative material, including production costs, potential savings, and long-term economic benefits.
4. **Prototype and testing**
   - Create prototypes and ensure they meet the necessary standards and requirements identified in Step 1.
5. **Implementation and monitoring**
   - Plan a phased implementation for the alternative product to replace the plastic product. Establish a monitoring system to track the use, performance and environmental impact of the new product. Make necessary adjustments and improvements based on the collected data.

BY S. KÜHLEWINDT

Example: Jute bag distribution on the KUET campus

Jute bags were considered a theoretical alternative to plastic bags only on the KUET and CUET campuses due to their unavailability, despite the long history of Bangladesh in jute production. During our study, we found that plastic bags were exclusively distributed in all existing shops and the canteen. To facilitate the substitution of plastic bags, we created a conceptual design for a campus test phase. Since plastic bags are currently given out for free, we proposed a subsidy scheme to lower the price of the jute bag alternative. Additionally, we planned events to distribute free jute bags, aiming to enhance their availability, visibility, and usage on campus.

Key messages:

- **Existing infrastructure should be utilised:** We included campus shop owners in the planning process and aimed to use existing sources of plastic products to display and distribute the jute bag alternative effectively.
- **Motivation for use should be encouraged:** We proposed using gamification and rewards to make the transition to jute bags more engaging and to encourage behaviour change.

In case of a successful implementation on campus, we can expect:

- Effective provision of a sustainable alternative to plastic bags
- Stabilisation of plastic bag waste generation and reduction in littering on campus
- Insights into how to encourage multiple uses of bags and promote behaviour change
- Recommendations for the successful introduction of a permanent campus system, with potential for off-campus adoption

Figure 49: Dyed jute at a local production site. Photo by Gregor Biastoch, 2022.

2.2 COLLECTION OF MISMANAGED PLASTIC WASTE

Incorporating mismanaged plastic waste into solid waste management

BY P. LORBER AND M. ROHRBACH

→CROSSREF:
- Material flow analysis private recycling sector ▸p. 31
- Social Business Model Canvas ▸p. 35

However, the largest source is likely non-valuable plastic waste found in the streets – also referred to as mismanaged plastic waste.

An approach to address this issue is to integrate local recycling shops into the solid waste management process. Although these shops operate as private and independent actors, they are, in many respects, well-suited to assist the municipal body with solid waste management. Local recycling shops have access to necessary assets and possess a valuable network of waste collectors specialised in gathering certain waste fractions.

These prerequisites make it technically straightforward for local recycling shops to begin supporting municipalities in their collection and treatment efforts. However, successful collaboration also requires mutual willingness from both private and municipal actors. Additionally, ensuring fair compensation for the recycling shops' services is essential, which requires municipal funding. The collection of mismanaged plastic waste reduces costs for cleaning drainage systems and mosquito control. Those cash flows can be redirected to cover the cost of the collection of mismanaged plastic waste via recycling shops.

Collaborations that incorporate formal recognition and controlled formalisation stand a strong chance of achieving sustainability in improvements of waste collection and supporting marginalised groups from the informal sector without the need to build up new institutions for this collection service.

This approach can work either as an exclusive system, allowing only shop-affiliated informal waste collectors and sellers to drop off materials, or as a more open system that, e.g., includes registered waste collectors and sellers from across the city. The municipality can arrange direct transportation to a final disposal site or treatment facility such as a pyrolysis plant. However, it is also possible to contract a private company to manage the transportation process on its behalf.

Example: Collection of mismanaged plastic waste through recycling shops

Khulna City has a vibrant and well-established network of recycling shops. In 2022, we identified over 35 active plastic recycling businesses in the area, each supported by a substantial number of informal waste suppliers (collectors) throughout the city.

In July 2024, we initialised a pilot project with four local recycling shop owners who were willing to offer their waste suppliers the opportunity to include mismanaged plastic waste into their collection routine. Determining appropriate compensation for the shop owners was an important prerequisite, and we agreed on the recommendation of 30 to 40 Taka per kilogram of mismanaged plastic waste. We experienced a successful implementation of the extended collection routine accompanied by detailed documentation and data acquisition. The compiled material was then transferred to the final disposal site via local transport.

Figure 50: Impression of the collection of mismanaged plastic waste through recycling shops. Photo by Abdullah al Hasan, 2024.

Figure 51: Mismanaged plastic waste collected by local waste collectors. Photo by Tanvir Ahmed, 2024.

Figure 52: Mismanaged plastic waste collected by local waste collectors. Photo by Tanvir Ahmed, 2024.

Figure 53: Collected material dumped at the local disposal site. Photo by Tanvir Ahmed, 2024.

2.3 FINAL DISPOSAL SITE ENVIRONMENTAL MANAGEMENT PLAN

Making landfilling a successful and environmentally sound disposal solution

BY S. BERNER

The environmental management plan of a final disposal site is a comprehensive document designed to outline the measures, procedures, and practices for minimising the environmental impact of landfill operations. The plan is crucial for ensuring compliance with regulatory standards, protecting the environment, and maintaining public health and safety. It details the site's engineered elements and respective operational activities and provides the framework for monitoring processes and reporting. Furthermore, it ensures proper day-to-day and long-term operation and provides guidelines and protocols for the site staff.

The environmental management plan addresses six sections:

1. Introduction and regulatory framework
2. Site description and listing of all engineered (physical) current and planned structures
3. Management plans (operation, maintenance and monitoring) of all engineered structures, e.g., leachate management plan, surface and groundwater management plan
4. Informal waste worker strategy
5. Site closure plan
6. Emergency response and contingency plan

Additional sections could describe reporting of monitoring results, staff training and capacity building, environmental impact assessment, or review processes. It is important to ensure that every physical structure has operational procedures, maintenance protocols, and a monitoring scheme. The disposal site environmental plan is a living document that is continuously updated to ensure that the latest adjustments to operational procedures are transparently described and that the respective data documentation is available.

→CROSSREF:
- Final disposal site assessment system ▸ *p. 52*
- Drone monitoring of final disposal site ▸ *p. 60*
- Weighing station at the final disposal site ▸ *p. 80*

FURTHER READING

EPTISA (2010). *Waste Governance – ENPI East – Landfill Operations Guidance Manual.* European Neighbourhood Partnership Instrument (Eastern Region). October 2010. Copyright © 2010 by EuropeAid

Example: Environmental management plan for Rajbandh open disposal site

BY S. BERNER

The first environmental management plan for KCC's open disposal site at Rajbandh was developed based on the 'Final disposal site assessment'. The results in each of the seventeen assessment categories directly inform the sections 'Site description', 'Management plans', 'Informal waste worker strategy', and 'Site closure plan' of the environmental management plan. In addition, the plan describes the current regulatory setup and outlines the existing emergency response. The following table shows how the Final Disposal Site Assessment results are transferred into the environmental management plan.

No	Category	Details	Section
0		Details of Operator: Name and Address of Operator and Site (G)	1, 2
1	Site selection	(no documentation available)	2
2	Site design	Site Description: Boundaries and topography, local meteorology (G) Site capacity: Waste sources and estimation of site lifespan and maximum capacity (E) Site preparation and provision of services (O) Description of the operations (O) Phasing of filling (O)	2
3	Waste placement	Waste placement procedures and preparation of active disposal area (e.g., berms, slope stabilisation) (E, O)	3
4	Biological process	Description of the operations to ensure the process. (O)	3
5	Water management	Surface water control measures, ditches, road drains, etc. (E) Control measures (E) Monitoring and maintenance procedures (O)	3
6	Leachate management	Leachate drainage, collection, and treatment (E) Control measures (E) Monitoring and maintenance procedures (O)	3
7	Landfill gas management	Landfill gas abatement method, collection, and flaring (E) Monitoring and maintenance procedures (O)	3
8	Cover	Cover requirements: Final capping and intermittent covers to reduce emissions. (E, O)	3
9	Compaction	Compaction requirements and procedures (E, O)	3
10	Fencing	Fencing, gates, and other security (E) Regular maintenance and control to ensure accessibility of fence line (O) Access control and waste acceptance procedures (O)	3

BY S. BERNER

Key challenges:

Enforcing new operating procedures that oppose current procedures: A current challenge is to ensure a buffer zone between the waste body and the fence line in order to implement containment measures. The drone monitoring documents the increasing encroachment of the boundary areas.

Producing reliable data on waste intake: The recently constructed weighing station will record the first reliable waste quantities. Long-term monitoring and recording will provide a sound database to determine the site's capacity and lifespan correctly.

Acquisition of funding to implement measures determined in the environmental management plan. Decision-makers must know that any final disposal site requires continuous funding to operate and control properly. Even if the site is closed, funding is necessary to ensure aftercare and environmental monitoring.

No	Category	Details	Section
11	Containment and vector control	Containment details, e.g., catch fences, berms (E) Monitoring points for landfill gas, leachate, surface water, and groundwater. (E) Measures for the control of environmental nuisances (E) Litter abatement methods and procedures (O) Noise and dust abatement (O) Measures to deal with vermin and other pests (O) Monitoring of site containment using drones (O)	3
12	Access road and interior roads	Maintenance of access roads and secondary site roads (E, O)	3
13	Record keeping	Templates and form; Data management plan. (O)	3
14	Waste acceptance	Types of waste accepted: Acceptance and monitoring and record-keeping procedure. (O) Quantities of waste accepted: Minimal record requirements. (O)	3
15	Staff and equipment	Offices, fuel stores, etc. Wheel cleaning infrastructure, site weighbridge Site opening and operating times (O). Equipment to be utilised (O). Site personnel, including duties, qualifications, and responsibilities (O) Operational and safety rules (including safety statement) and emergency procedures (O).	3
16	Site closure	Final capacity and expected operational period of the facility Final contours and topography of the site Restoration plan Phases for closure and restoration of completed areas Aftercare monitoring and other control measures Maintenance programme for the aftercare phase	4
17	Waste picking	Management of informal waste-picking	5

Table 8: Content of the Environmental Management Plan with general (G), operational (O) and engineering (E) measures.

2.4 WEIGHING STATION AT THE FINAL DISPOSAL SITE

All waste will go through here!

BY S. BERNER

→CROSSREF:
- Waste collection analysis ▸ *p. 23*
- Final disposal site assessment system ▸ *p. 52*
- Final disposal site environmental management plan ▸ *p. 77*

One of the most effective and critical parts of solid waste management infrastructure is a weighing facility at the entrance of the final disposal site.

With a weighing station, we can determine:
1. The waste quantity delivered to the final disposal site.
2. The officially collected waste quantity. This quantity should equal the delivered waste quantity.
3. The efficiency of the waste management system. The efficiency is evaluated by comparing collected and disposed waste quantities with estimated generated quantities.

Sanitary landfills come equipped with a weighing facility, generally in the form of a calibrated weighbridge. Staff record the weights of incoming and outgoing trucks, and the weight difference is noted as the delivered waste quantity.

A permanent weighbridge is potentially costly and requires a stable underground or respective subgrade preparation. This might not be feasible for open dump sites with unclear site conditions. A temporary weighing facility, which requires a concrete platform with ramps and a mobile truck scale, could be an attractive alternative. This setup allows spot checks, providing better oversight of waste quantities.

BY S. BERNER

Example: Temporary weighing facility at the Rajbandh site

At the entrance of the Rajbandh site, we identified a suitable area for a concrete platform. To avoid mud and waterlogging, the platform should be higher than the level of the access road.

Figure 54: Weighing station under construction (final curing). Photo by Sourav Saha, 2024.

BY S. BERNER

A depression in the platform allows the correct and solid placement of the truck scale's weighing pads.

A mobile truck scale by Dini Argeo (model WWSERF) allows us to weigh up to 20 tonnes axle-weight. The pads are placed on the weighing platform at the beginning of the weighing campaign and removed and stored away at the end of each day.

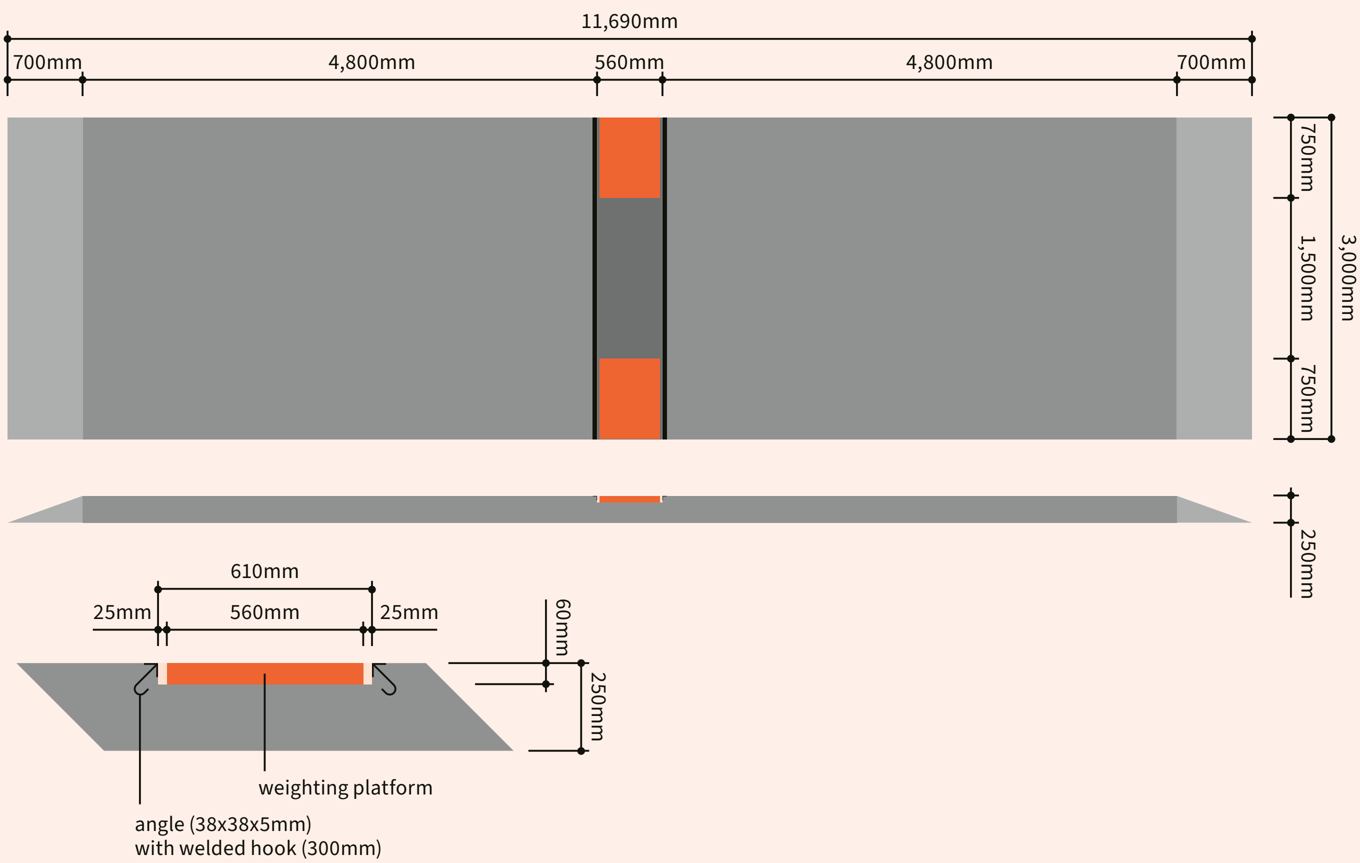

Figure 55: Technical drawing of the weighing platform.

Figure 56: Mobile truck scale: indicator case and two weighing pads. Photo by Noor Alam, 2024.

Lessons learnt:

- Initially, the platform did not reach road level. During the rainy season, mud started to spread onto the platform. Consequently, the platform was raised.
- Communication with truck drivers is critical. Each truck driver needs to be informed about the weighing procedures. Their buy-in is essential for the success of the truck monitoring.
- First weighing results indicate that, up to now, waste quantities have been exaggerated. Municipal mixed solid waste often has a lower density than expected. Without a scale, accurate assumptions are problematic.

The installation of this weighing facility improves the general performance at the site and moves it closer towards an open controlled site.

Dimension of each pad	750 mm × 561 mm × 58 mm
Loading surface	750 mm × 450 mm
Weight of each pad	28 kg
Capacity of each pad	Ten metric tons
Power supply	Internal rechargeable battery
Battery life	40 h (approximately)

2.5 TRAINING FOR INFORMAL WASTE WORKERS

Approaching informal workers and taking the first steps in improving working conditions

BY S. BERNER

→CROSSREF:
- Final disposal site assessment system ▸ p. 52
- Informal sector assessment ▸ p. 64
- Social-empirical research methods ▸ p. 105

Based on the actor's map and informal sector assessment, we identified the risk of injury as a central theme in informal waste workers' concerns. Whereas integrating informal workers into municipal service structures and formalising their work is a complex process as various interests and viewpoints must be aligned, mitigating work-related risks is crucial. It could also be the first step in a long-term transition or integration.

An immediate intervention is the appropriate training of waste workers on occupational health and safety measures, particularly the benefits and proper use of personal protection equipment and first aid instructions. For this, the following steps help to organise the training:

1. Establish contact with informal workers and identify a spokesperson.
2. Interview workers to determine how they are grouped (identify different status groups) and understand their needs, including literacy level and information on previous schooling or training.
3. Design an appropriate training programme that fits the needs of the workers.
4. Provide a safe and comfortable training location.
5. Recompense workers for lost income.
6. Conduct training.
7. Provide personal protection equipment to ensure safe working conditions.
8. If possible, conduct a post-assessment to establish training effectiveness.

In summary, occupational health and safety (OHS) training offers a practical, hands-on approach to engaging informal workers and addressing their immediate needs without neglecting systemic and long-term issues. A municipal Awareness Centre can serve as a contact point for OHS training and address any concerns informal waste workers may have.

FURTHER READING

The International Labour Organization (ILO) provides an extensive library of documents that can assist in developing tailor-made OHS training. Relevant documents can be accessed here: https://www.ilo.org/resource/occupational-safety-and-health-informal-economy.

Example: OHS training with informal waste workers from Rajbandh final disposal site

BY S. BERNER

At the Rajbandh final disposal site of KCC, twenty informal waste workers recover valuable materials from incoming waste. An initial assessment showed that most waste workers suffer frequent injuries due to lacking personal protective equipment (PPE).

In 2023, we carried out occupational health and safety training, including a first aid course and distributed personal protective equipment at the KCC Awareness Centre. The post-assessment revealed that the frequency of injuries with sharp objects could be reduced if workers used protective equipment, such as shoes and gloves. However, the lack of sanitation and resting facilities at the Rajbandh disposal site remained an ongoing challenge. With the overall refurbishment of the disposal site in 2024, a new sanitation block, a resting area and a training facility are under construction to improve working conditions for municipal staff and informal workers. The new facilities also ensure the continuous presence of staff at the disposal site, which might encourage waste workers to wear their protection equipment and replace any damaged or broken PPE.

Figure 57: Training session on OHS: Risks of injuries faced by the waste workers. Photo by Md. Mobashar Hossain, 2023.

Figure 58: First aid instructions. Photo by Md. Mobashar Hossain, 2023.

Figure 59: Conclusion of training. Photo by Md. Mobashar Hossain, 2023.

2.6 ESTABLISHING AN AWARENESS CENTRE

Encouraging environmental behaviour through education

BY H. KERBER AND S. BERNER

Environmental awareness means grasping why protecting our environment is crucial and recognising how our actions affect it. Education for sustainable development equips people with the knowledge, values, and skills needed to make informed decisions and take meaningful action.

To turn knowledge into action, it is essential to move from passive learning to active engagement. This means promoting clear communication and inspiring everyone to adopt environmentally friendly behaviours. Environmental Awareness Centres (EACs) or Visitor Education Centres (VECs) play a key role in this process. They educate the public and stakeholders, deepen understanding, and inspire active participation in addressing environmental issues.

An Awareness Centre is often part of governmental institutions, such as regional or municipal departments, offices, or agencies, commonly focused on urban planning, natural resources, or biodiversity conservation. This means that these centres are financed through public budgets, i.e., taxes. However, there are also centres that are jointly managed and financed by governmental institutions, Non-Governmental Organizations (NGOs), and companies. Naturally, it is also possible for NGOs, non-profit associations or foundations to establish such centres, which would then, for example, be financed through membership fees, support associations, donations or public funding.

Key function:

- Providing opportunities for people to acquire the knowledge, values, attitudes, commitment, and skills needed to investigate issues, solve problems, and protect and improve the environment

Key approach:

- Using environmental communication as a positive influence on stakeholder involvement

Key activities:

- **Educational programmes:** Offering workshops, seminars, and courses on environmental topics for various audiences, including schools, communities, and businesses
- **Public outreach:** Engaging with the community through events, campaigns, and social media to raise awareness and encourage environmentally friendly practices
- **Resource centre:** Conducting research on local and global environmental issues and advocating for policy changes and sustainable practices
- **Volunteer programmes:** Coordinating volunteer activities such as clean-ups, upcycling projects, fun games, and event days
- **Collaboration:** Partnering with stakeholders to enhance environmental communication and foster a positive influence on stakeholder involvement

→CROSSREF:
- Stakeholder analysis ▸ p. 14
- Informal sector assessment ▸ p. 64
- Training for informal waste workers ▸ p. 84
- Social-empirical research methods ▸ p. 105

BY H. KERBER AND S. BERNER

Example: Khulna's Centre for Plastic Pollution Awareness

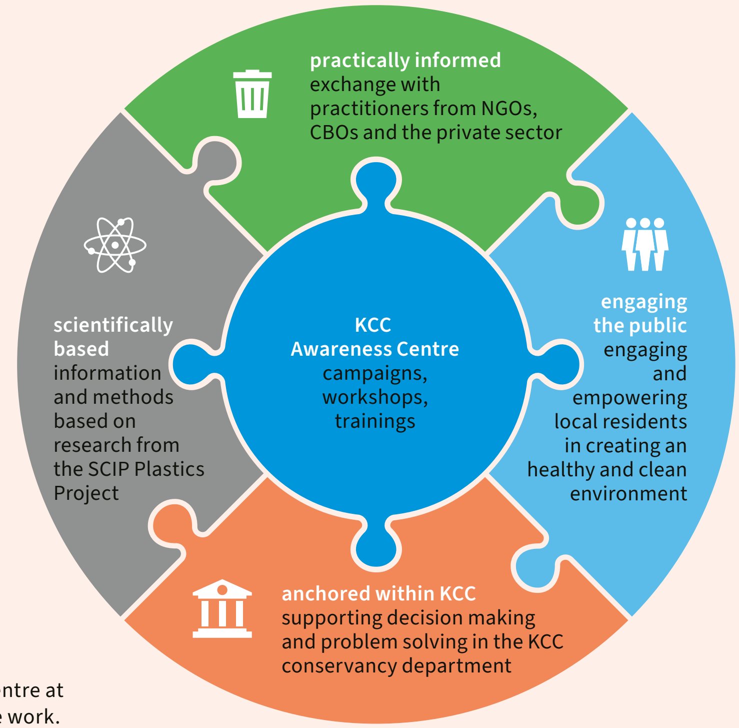

Figure 60:
Awareness Centre at KCC – How we work.

As part of the SCIP Plastics research project, we established an Awareness Centre at Khulna City Corporation (KCC) in the heart of Khulna in March 2022. Four SCIP Plastics employees, with expertise in environmental engineering, social and humanities studies, and graphic design, actively run the centre, supported by additional SCIP researchers from Bangladesh and Germany.

The centre's vision and mission:
Promote awareness and knowledge of sustainable plastic waste management practices among waste management practitioners, experts, and citizens, especially in Khulna and the surrounding region.

The goal is to empower stakeholders and disseminate SCIP Plastics' research outcomes by raising awareness and facilitating mutual learning, thereby contributing to effective waste management practices. The centre bridges research activities, municipal services, and local residents, translating research findings into actionable insights and providing a platform for stakeholder engagement.

Main activities:

- **Educational programmes:** Conduct workshops and training based on SCIP Plastics' scientific results with KCC personnel, waste workers, recycling shop owners, ward councillors, NGOs, CBOs, and others.
- **Public outreach:** Engaging with the community through campaigns, events (such as open days), and social media (Facebook).
- **Resource centre:** Supporting the SCIP Plastic Team in knowledge transfer beyond scientific activities.

Main products:

- Toolbox for awareness programmes and knowledge transfer
- Information material, e.g., leaflets, information booklets
- Training Manual for Occupational Health and Safety Training, especially for informal waste workers

Lessons learnt:

- Promoting new waste management behaviours requires engaging the public, waste workers, and municipal stakeholders, with efforts aligned to existing infrastructure. Awareness raising can support changes, such as waste separation at the source, but must be well-integrated into infrastructure development to prevent rejection of new systems.
- Effective awareness-raising requires strong collaboration with political and administrative actors, ensuring their active support and engagement.
- Awareness raising is a specific skill that requires capacity development in order to be effectively carried out.

Figure 61: Co-design workshop on plastic substitution campaigns. Photo by KUET, 2024.

Figure 62: Meeting with recycling shop owners. Photo by KUET, 2023.

BY H. KERBER AND S. BERNER

Figure 63: Workshop on source separation. Photo by Heide Kerber, 2023.

Figure 64: Open Day. Photo by KUET, 2024.

Figure 65: Workshop with conservancy supervisors. Photo by KUET, 2023.

2.7 CAPACITY BUILDING: PHYSICAL CONSOLIDATION

Pooling and consolidating knowledge enhances the success of local implementation.

BY G. BIASTOCH

→CROSSREF:
· Establishing an Awareness Centre ▸p. 87

Responsibilities and accountabilities in the waste management chain require consultation and agreement among various professions, extending beyond just municipal boundaries. Without proper coordination between stakeholders, many initiatives and projects are at risk of failure. Effective concepts and solutions must be developed and implemented in collaboration with local experts.

Waste management is a global challenge, with national and international working groups, specialised conferences, and exchange platforms rapidly evolving in this field. It is crucial to consolidate resources in a physical space where local expertise – such as companies, associations, political bodies, and consultants – can come together to develop effective strategies. The advantages of a local collaborative approach include pooling capacities for assessing state-of-the-art technologies and planning tools. Sharing experiences also aids in procurement, tendering, and commissioning research institutions. Local collaboration facilitates training programmes and partnerships with expert committees from business, politics, and science.

A centralised local point of contact for waste management experts and relevant planning offices enhances the anchoring of strategies and ensures consistent results. Having a fixed contact point simplifies decision-making and participation processes with external experts. Over time, such consolidation increases visibility, attracting skilled professionals and fostering advanced qualifications for engineers and planners.

Example: Consolidation of Knowledge Transfer Hub in Khulna

On November 9, 2023, Khulna University of Engineering & Technology (KUET) inaugurated a newly built research hub on its campus, in which we moved in as the first dedicated waste management centre known as the Knowledge Transfer Hub. The premises include a waste laboratory, meeting rooms, and workspaces for researchers and employees. By bringing together local expertise to conduct analyses and investigations, the hub offers numerous opportunities for the municipality. Members are integrating their academic programmes with practical, hands-on collaboration, enabling the initiation, control, monitoring, and evaluation of waste management measures.

Our hub also serves as a platform for promoting and disseminating results at national conferences and to a broader audience. Managed by a board of directors that includes permanent municipal representation, it acts as a vital contact point for waste management experts. This includes facilitating meetings, commissioning assessments, and providing advice, such as for the KCC master plan for waste management. The physical consolidation of waste management expertise within the Knowledge Transfer Hub offers decision-makers a centralised resource to address their needs effectively.

Figure 66: Research hub building – Aerial image. Photo by KUET, 2024.

Figure 67: Research hub building – Meeting room. Photo by KUET, 2024.

Figure 68: Research hub building – Waste laboratory. Photo by Noor Alam, 2024.

Figure 69: Research hub building – entrance area to hub offices and laboratory. Photo by KUET, 2024.

3 GENERAL METHODOLOGY

3.1 SYSTEM BOUNDARIES

Simplifying complex relations to a minimum allows measurement and modelling.

BY G. BIASTOCH

Municipal waste management often means navigating through complex tasks with shared responsibilities, where focusing on relevant information and key elements is crucial. By understanding and applying the concept of system boundaries, the complex web of relationships can be simplified: Address specific key elements directly, solve problems without diversion and measure material flows only where necessary.

Municipal waste management connects various disciplines and departments, such as planning, conservancy, and transport, with regulations and interdependencies extending from national policies to community-level actions. Even seemingly straightforward tasks or regulations are often embedded in a complex context of factors and responsibilities. The concept of applying system boundaries originates from a 'system thinking' approach, limiting processes to a minimum while fully capturing a system (Anderson and Johnson, 1997). Boundaries help planners define the scope of their work, ensuring clarity and focus. Systems can be technical, social or natural. System boundaries are as simple as possible and as complex as necessary.

The first step in planning is to define the planning task as clearly and precisely as possible, framing the scope and focusing only on relevant aspects. This principle applies to various procedures outlined in this guidebook, such as stakeholder analysis, material flow analysis, Life Cycle Assessment, or waste characterisation. The question or task from which the system and its limits are derived must be formulated very clearly and precisely. These system boundaries are defined by several dimensions, such as spatial, temporal, regulatory, and functional units, as follows:

- → **Geographical boundaries:** What are the physical boundaries?
- → **Area type:** What type of area is considered (residential, commercial, agricultural, industrial, etc.)?
- → **Stakeholders:** Which stakeholders are considered?
- → **Functional units:** What functional units are investigated (material, money, energy flow, regulations, directives)?
- → **Time frame:** What is the study time frame (days, weeks, years)?
- → **Points of intersection:** What are the points of intersection with boundaries outside the system?

In practice, it is crucial to clearly describe not only what lies within the system boundaries but also what lies outside of them. Delineating what is not included in the study helps to better interpret the results. A graphical overview can be particularly useful for organising the elements and focusing on the essentials. Everything within the frame, represented by a dashed box, is considered, while everything outside is deliberately excluded. This is a typical form of visual representation, for example, in material flow analysis.

REFERENCE

Anderson, V. and Johnson, L. (1997). *System Thinking Basics from Concepts to Causal Loops*, Oegasus Communication, Inc. Waltham, ISBN: 1-883823-12-9.

3.2 REPRESENTATIVE SAMPLING

Establishing a sound database for infrastructure development and investments

BY S. BERNER

Solid waste management deals with complex systems, large numbers of people, and large quantities of mixed materials. Data on waste characteristics and material quantities or people's perceptions and behaviours directly inform decisions linked to significant investments. For example, what waste separation scheme is acceptable to residents, how many and what type of waste collection vehicles are needed, or what is the necessary size of the local landfill site? To avoid bad investments, decisions must be based on investigations using representative samples that accurately mirror the investigated characteristics of the total population. For example, when analysing the composition of mixed municipal waste in a city, the waste sample should reflect the composition (percentage of organic waste, plastic waste, etc.) of all the waste generated.

Thus, a representative sample shows the following characteristics.

- → It is large enough to minimise errors.
- → It is based on a transparent sampling method that minimises bias by favouring randomised sampling.
- → It mirrors the investigated characteristics in their proportions and diversity.
- → It shows a high confidence level. The confidence level is a statistical measure quantifying the degree of certainty or confidence that a sample accurately represents the true population parameter. It is often given in percentage, e.g., a 90 % confidence level suggests that there is a 90 % probability that the sample shows the true population parameter.

In waste management, the (statistical) parent populations could be people living within a specified system or specific waste quantity produced.

Practical steps to determine a representative sample size are:

- → **Conducting a pilot study** to gather preliminary data to estimate variability (variance, standard deviation) and proportions within your target population.
- → **Using stratification** to segment the population into meaningful strata and calculate sample sizes for each stratum. The household waste analysis provides a typical example of a stratified sampling approach in waste management.
- → **Choosing the desired confidence level and margin of error** to determine the acceptable precision for the investigation.
- → **Applying statistical formulas** (e.g., Cochran's formula) to calculate the sample size.
- → **Adjust for finite populations and resource constraints**.

A statistical formula that can assist in calculating sample size for surveys is Cochran's formula (for finite populations)

$$n = \frac{\frac{Z^2 p(1-p)}{e^2}}{1 + \frac{Z^2 p(1-p) - e^2}{e^2 N}}$$

Equation 1
n: sample size (being determined)
N: population size;
p: proportion in the target population estimated to have characteristics being measured
e: acceptable error
Z: standard deviation at a given confidence level (z = 1.645 at 90 % confidence level)

An online sample size calculator is available, for example, from the Australian Bureau of Statistics (2024).

Although a similar approach can be applied for mixed municipal waste quantification and characterisation, general practitioners' guidelines state that a 1 % sample, based on wet weight, of the weekly (7-day) generated waste within a study area provides a sufficient sample size for representative sampling (e.g., in Bidlingmaier and Müsken, 2017). In case of an average waste generation rate of 500 g per capita and day and a population of one million people, the weekly waste generation would amount to 3,500 tonnes. Thus, the resulting representative sample should comprise 35 tonnes.

BY S. BERNER

It is important to note that representative samples can be challenging to obtain, especially for large or diverse populations, and it may be easy to forgo representative sampling and choose a convenience sampling approach where samples are selected based on their easy accessibility, proximity, or convenience to the researcher. For example, a survey that only encompasses people living in housing right next to the street but ignores all second-row buildings because they are more challenging to access is biased, no longer random, and thus no longer representative. If the samples are used to extrapolate characteristics from the samples to the whole population within the system, any obvious bias must be avoided.

Ultimately, decision-makers and researchers often have to carefully compromise between representativeness and factors such as time, budget, and practicality when designing the sampling strategy.

REFERENCE

Australian Bureau of Statistics (2024). Sample size calculator. Available at: https://www.abs.gov.au/websitedbs/D3310114.nsf/home/Sample+Size+Calculator (Accessed: 14 October 2024).

Bidlingmaier, W and Müsken, A. (2017). Analysis of Waste Composition and Characterisation of Wastelines. Orbit Science, Available at: https://www.orbit-online.net/index.php/literature/analytical-methods (Accessed: 14 October 2024).

3.3 WASTE CHARACTERISATION

Knowing the characteristics and composition of waste

BY G. BIASTOCH

Mixed solid waste from households is an inhomogeneous blend of materials and leftovers, with its composition and characteristics highly influenced by factors such as seasons, living conditions, and income levels. Understanding the composition of this waste is crucial for improving collection systems, optimising treatment facilities, and more accurately estimating waste generation.

The quality of data directly impacts the effectiveness of waste management systems. Therefore, sorting waste samples regularly by composition is essential, as well as measuring each fraction individually. Knowing the specific components of the waste, rather than just its total mass, allows for more targeted and effective interventions.

When selecting categories for the sorting process, it is important to categorise waste based on material type, recyclability, and chemical or biological composition. The World Bank, for example, differentiates waste into nine universal fractions as described by Kaza et al. (2018).:

1) food and organic,
2) glass,
3) metal,
4) paper,
5) plastic,
6) rubber/leather,
7) wood,
8) yard, garden, green waste,
and 9) other.

A somewhat more complex differentiation comes with the European list of waste according to Directive 2008/98/EC, which divides municipal wastes from household waste into three main categories: separately collected, garden and park wastes, and others. These three categories consist of 50 additional sub-categories differentiating wastes such as paper, glass, clothes, textiles, wood, and plastics as well as market waste, street cleaning waste or septic tank waste (Commission decision 2014/955/EU, 2014). A key decision is determining the sorting categories to be used consistently in the long term. Consistency in the methodology used for waste characterisation over time enhances the accuracy and relevance of the data.

Municipalities that manage the logistics of waste collection, from door-to-door pickups to transfer stations, truck transport, and the operation of treatment and disposal sites, are particularly concerned with the physical characteristics of waste. Factors such as particle size distribution, as well as the water and organic content of the waste, are crucial for proper handling and processing. These parameters are closely linked to issues such as leachate production, mosquito breeding, odour, and dust pollution.

Incoming mixed waste should generally be sorted into size fractions using sieves and manual sorting tables with the following classifications: >120 mm, >40 mm, and >10 mm. Particles or liquids smaller than 10 mm are considered residue and are categorised as dust or liquid. Solid, non-deformable items are sorted according to their longest edge, while sheets, ropes, nets, fabrics, or flat but flexible waste items are classified into the appropriate size category based on near-square compaction. The initial weighing and documentation of the sorted materials occur at this stage.

rigit objects, not deformable

Solid, non-deformable items are sorted based on their longest edge. Items are not forced or passed through the sieve lengthwise. However, parts might unintentionally fall into a lower category. In such instances, this is considered a set condition, and there is no subsequent check or reassignment to other size categories.

compressed or compressable objects, deformed

Sheets, ropes, nets, fabrics or flat but flexible waste items are categorized into the appropriate size class for nearly square compaction. Waste that is already deformed or compacted during sampling will be classified based on its compacted size, when sample was taken, not its original size.

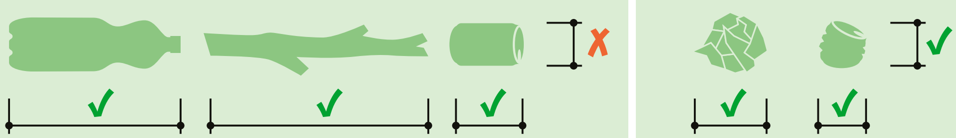

Figure 70: Example of sorting by size for non-deformable and compacted waste.

In the second step, the waste is manually sorted into predefined categories. For instance, using the World Bank categories (Kaza et al., 2018) as a framework, the waste is divided into nine categories, with an additional category for dust and liquids smaller than 10 mm. The result of a waste characterisation process is that the incoming mixed waste is sorted in each category consisting of three size fractions, as indicated in figure 70.

BY G. BIASTOCH

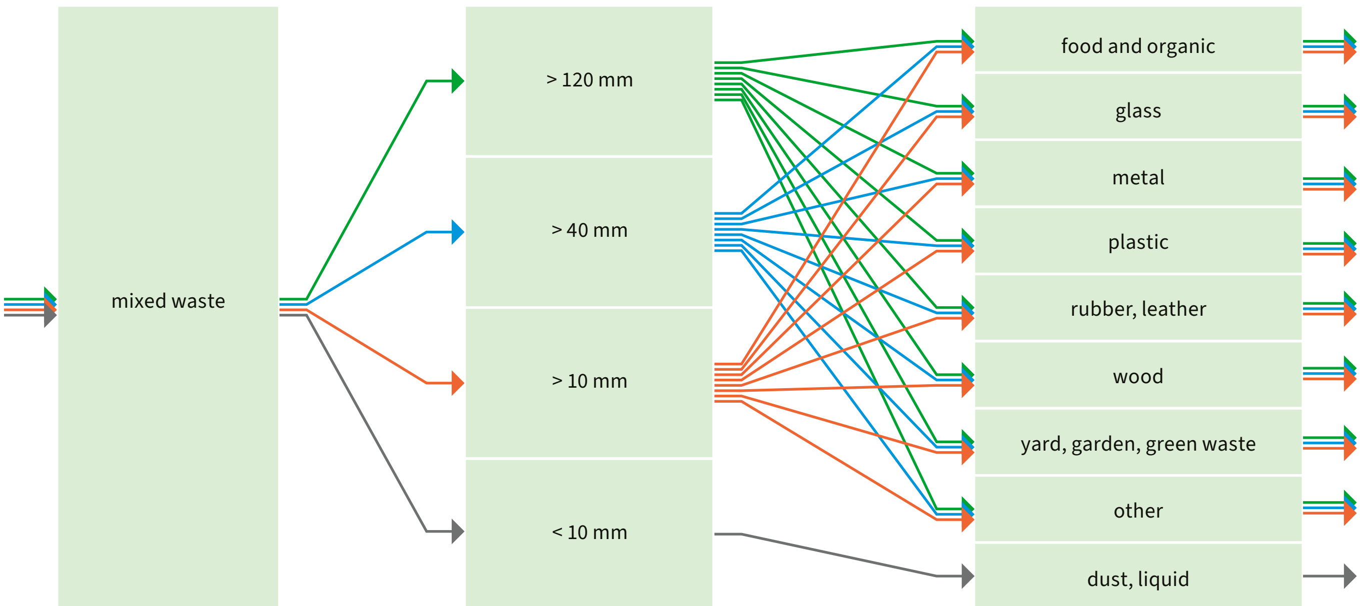

Figure 71: Waste sorting process flow from size to category.

After sorting, additional samples can be taken to determine the organic and water content, which is particularly useful for the categories food and organic as well as yard, garden, and green waste, especially when composting is considered. Moreover, recyclable and valuable materials, such as plastics, can be further sorted based on their chemical composition, depending on the specific requirements of the recycling technology.

REFERENCE

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Commission decision 2014/955/EU of 18 December 2014 amending Decision 2000/532/EC on the list of waste pursuant to Directive 2008/98/EC of the European Parliament and of the Council (2014). Official Journal of the European Union L370, pp. 44-86. 30.12.2014.

3.4 MATERIAL FLOW ANALYSIS

A simple method of measuring waste quantities

BY G. BIASTOCH

Overflowing Secondary Transfer Stations often require short-term interventions, but their apparent unpredictability may result from insufficient data. By using a structured method like material flow analysis (MFA) to predict waste quantities, these fluctuations and uncertainties can be mitigated, leading to improved service coverage and more efficient operation of treatment facilities.

MFA is an analytical method used to quantify the flows and stocks of materials or substances within a clearly defined system. This method provides a comprehensive understanding of the system's composition and helps to identify material losses. A system in this context could range from a single industry to an entire region, city, or even an entire country. In waste management, MFA is typically applied to specific areas such as transfer stations, residential blocks, or individual wards. Furthermore, a system consists of several processes, which are activities or operations that transform, transport, or store materials or flows (Brunner and Rechberger, 2016).

The method follows a structured approach by defining the following steps:

1. **Reference system (specific unit)**
   - **Material based:** Measures mass/volume flow or substance passing per unit of time (e.g., kg/d, l/d)
   - **Product or lifecycle-based:** Measures units per number of products (e.g., kWh/product, CO2/product)
2. **System boundaries**
   - **Time boundaries:** What is the study's time frame (days, weeks, years)?
   - **Spatial boundaries:** What are the physical boundaries (ward, upazila, district)?
   - **Process boundaries:** Which working steps are outside the scope of consideration?
3. **Identification of processes and flows**
   - Identify entry and exit points for materials within the system
   - List all relevant processes within the system boundaries
   - Sketch diagram of the flow of materials between different processes
4. **Measurement of processes and flows**
   - Gather existing data from records, documents, or other sources
   - Identify strategic points where material flows need to be measured
   - Design and implement a plan for data collection
5. **Interpretation of results**
   - Use mass balance equations to estimate data where direct measurement is not possible
   - Cross-check estimations with available data or literature
   - Choose a suitable way to visualise the results
   - Draw conclusions and identify losses

The first step in creating an MFA is to establish its purpose and select a specific unit for the flows. Consistency in units across the system – whether mass, energy, or volume – is essential for maintaining uniformity in measurements. A key challenge is defining the system's boundaries with a necessary and limited number of inputs and outputs. When developing the work plan, a schematic display of an MFA should adhere to ISO 5807 standards. Once the processes and flows are identified, their specific units can be measured, ideally where measurement is most feasible. The primary advantage of MFA lies in its mass balance approach, where:

BY G. BIASTOCH

Sum of all inputs into a system =
Sum of all outputs plus changes in stocks
Not all flows require direct measurement; many can be calculated using the mass balance principle: ∑in=∑out. For instance, stocks can be monitored, and current capacities and losses can be estimated within the system boundaries using this method. The long-term application of MFA, along with regular plausibility checks, helps identify measurement errors in the waste collection chain. This process enables precise quantity calculations and prevents bad investments.

When it comes to the interpretation of the MFA, it is very helpful to choose a clear form of visualisation so that single processes and notoriously important flows can be easily identified. Sankey diagrams are a visual tool to depict the flow of materials, energy, or resources, highlighting the mass of each flow with proportional arrow widths for easy interpretation. This way, hotspots and losses can be easily discovered and identified.

REFERENCE

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3.5 LIFE CYCLE ASSESSMENT

Evaluating the environmental impact of a product across its entire life cycle

BY P. LORBER

Life Cycle Assessment (LCA) is a valuable tool used in plastic waste management to evaluate the environmental impacts associated with the life cycle of plastic materials, from production to disposal. LCA provides a comprehensive analysis of the entire life cycle, including raw material extraction, manufacturing, use, and end-of-life stages, enabling a holistic understanding of the environmental impact and its implications.

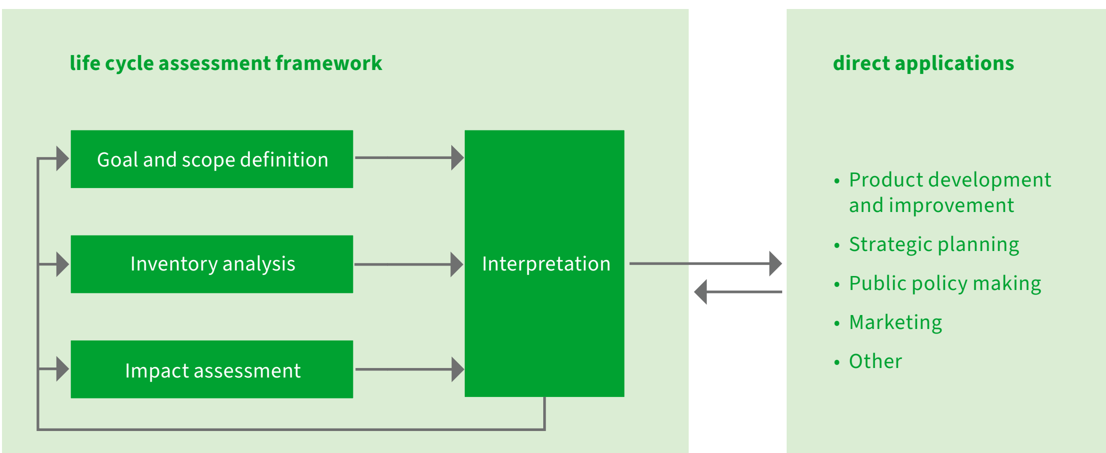
It supports decision-making, guides product and process design, and informs policy development. By applying LCA principles, stakeholders, like municipal managers and officers, can make more informed decisions, e.g., towards sustainable plastic waste management practices or a more circular and environmentally responsible economy.

Calculations are standardised according to the guideline ISO 14044:2006 outlined in the International Organization for Standardization (ISO) standards. According to the guidelines, the framework of every LCA consists of an iterative sequence of four consequential components.

Life Cycle Impact Assessment (LCIA) supports the interpretation of LCA studies by translating emissions and resource extractions into a limited number of environmental impact scores (Hauschild and Huijbregts, 2015). Methods behind the impact assessment are constantly further developed, specified and standardised. Various methods and sets of impact categories exist for different sectors and industries. Common LCIA methodologies are *IMPACT 2002+, ReCiPe 2016, ILCD 2011 or IPCC 2013 GWP.*

Climate change, ozone depletion, human toxicity and water use are typical impact categories found in most of the methodologies. LCA can be used not only for products but also for services, including public services, organisations and municipalities. The aim of the process is mostly to detect possible ecological risks and weak points and to identify potential for optimisation. Today, various software tools and databases such as *openLCA, SimaPro, GaBi, Umberto*, and ecoinvent are available to carry out LCA.

Figure 72: Components of an LCA according to ISO 14044:2006 (ISO, 2006).



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International Organization for Standardization [ISO] (2006). *ISO 14044:2006 Environmental management – Life Cycle Assessment – Requirements and guidelines, ISO.*

3.6 SOCIAL-EMPIRICAL RESEARCH METHODS

Understanding what people think and how they act

BY L. SATTLEGGER AND H. KERBER

Social-empirical research involves the systematic collection and analysis of data on human behaviours, attitudes, and interactions within society or specific social groups. This type of research aims to understand, describe, and predict social processes and outcomes based on empirical evidence.

In the context of waste management, social-empirical methods are used to understand how individuals and communities generate, handle, and perceive waste. Research can focus on households and other sources of waste, including shops, industries, and specialised institutions such as hospitals. Alternatively, it can examine the practices and attitudes of professionals, as well as both formal and informal workers involved in waste management and plastic recycling.

Social-empirical research methods include surveys, interviews, and observations and can be grouped into qualitative and quantitative methods.

Qualitative methods
Qualitative methods use open-ended approaches to collect detailed, non-numerical data, providing in-depth insights into practices, experiences and perspectives of individuals or groups. Prominent examples of qualitative methods are semi-structured interviews and focus group discussions.

Semi-structured interviews:
Semi-structured interviews are a qualitative research method that combines pre-determined questions of an interview guideline with the flexibility to explore topics in-depth based on the participant's responses. This interview format enables researchers to gather detailed and nuanced information on their research questions while also adapting to the participant's perspectives and experiences.

Focus group discussions:
Focus group discussions effectively gather insights into experiences, preferences, concerns, and intentions across different social groups. A focus group typically consists of a small, moderated, and semi-structured discussion, which generally involves between four to eight participants. Participants are selected based on shared experiences and specific socio-demographic criteria. Key questions, along with stimuli like pictures and videos, guide the discussion to shed light on a specific topic of interest.

Quantitative methods
Quantitative methods use structured tools to gather numerical data, enabling statistical analysis to identify patterns and relationships. A typical method for quantitative data gathering is a survey.

Surveys:
Surveys are quantitative research methods that use a set of structured questions to collect data from a large number of respondents. They are designed to gather specific information about behaviours, attitudes, and opinions, allowing researchers to analyse patterns and trends within a population by using statistical methods.

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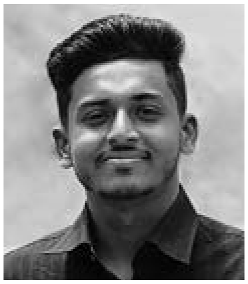
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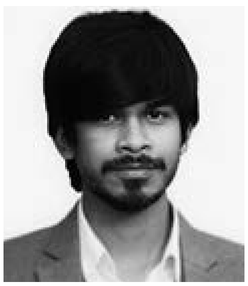
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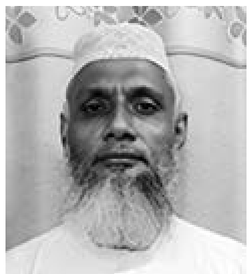
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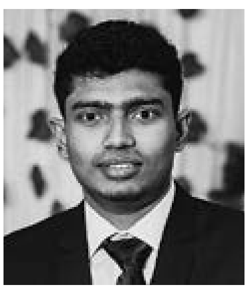
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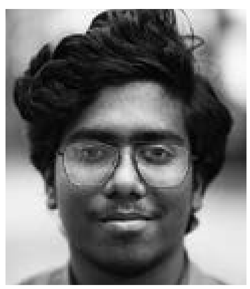
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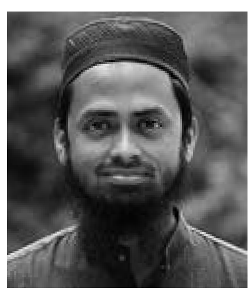
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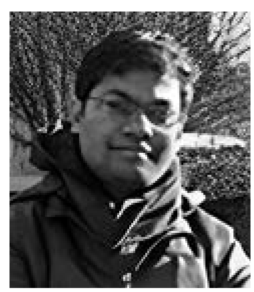
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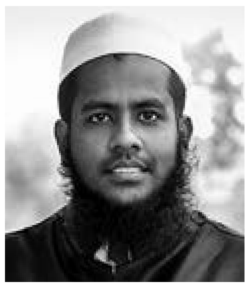

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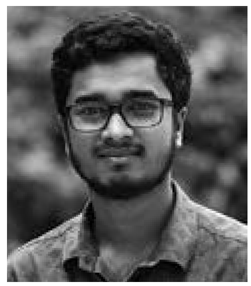

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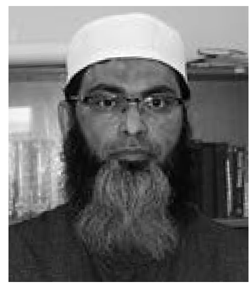

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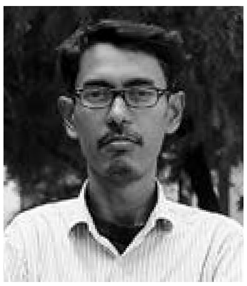
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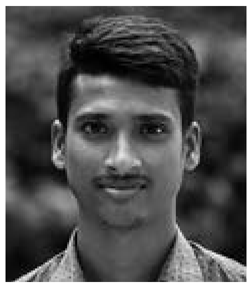
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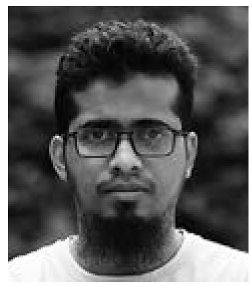
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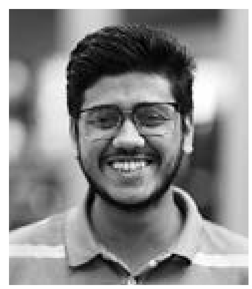
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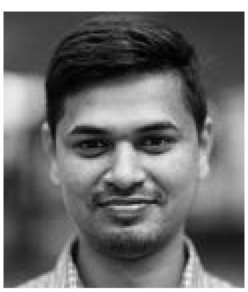
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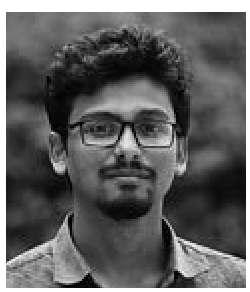
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Ananya Sarker


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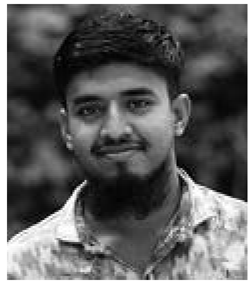
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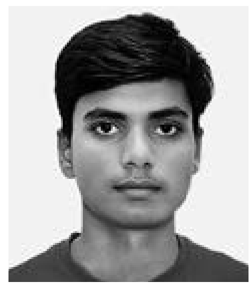
Md. Yeasin


Dr.-Ing. Martin Zimmermann


Prof. Dr. Rahman Zuthi

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Editors: Md Rafizul Islam, Abir ul Jabbar, Heide Kerber, Eckhard Kraft, Mst Farzana Rahman Zuthi

Scientific supervisors: Muhammed Alamgir, Hamidul Bari, Khondoker Mahbub Hassan, Thomas Haupt, Asiful Hoque, S M Moniruzzaman, Anne Nurunnahar, Sudip Kumar Pal

Authors: Senta Berner, Gregor Biastoch, Heide Kerber, Susanne Kühlewindt, Philipp Lorber, Jonathan Pillen, Michaela Rohrbach, Lukas Sattlegger

Contributors:
Bauhaus-Universität Weimar
Isabell Lange, Florian Wehking

Chittagong University of Engineering and Technology
Trisa Das, Niloy Das, Farjana Khan, Mehedi Hasan Masum, Md Ajijur Rahman

Institute for Social-Ecological Research
Martin Zimmermann

Khulna City Corporation
Fahima Akter, Md Abdul Aziz, Swadhin Das, Sheikh Enjamamul Haque, Md Mahmudul Hasan, Rezbina Khanom, Md Manjur Morshed, Abdullah Al Masud Pranto, S M Nahin Rahaman, Anisur Rahman, Shyamol Kumar Sarkar, Md Shimul, Md Nashid Kamal Sifat, Ankon Singh, Subrata Paul

Khulna University of Engineering and Technology
Kawsar Ahmed, Khandaker Nabil Ahmed, Tanvir Ahmed, Noor Alam, Md Tushar Ali, Md Al Amin, Ankon Baral, Md Noman Farsi, Farhana Haque, Mehedi Hasan, Md Nahid Hasan, Abdullah Al Hasan, Meherab Hossain, Md Anawar Hossain, Md Ismail Hossain, Syeda Tasnova Imam, Tariqul Islam, Md Rifat Jahan, Tasnim Tarannum Jarin, Pangkaj Kumar Mahanta, Md Tareq Mahmud, Saptarshi Mondal, Azizul Morol, Nishat Tasnim Nisha, Abdullah All Noman, Nushrat Nureen, Roksana Parvin, S M Rafew, Sharmin Rahman, Motiur Rahman, A S M Rokibuzzaman, Auntor Saha, Sourav Saha, Jobaer Ahmed Saju, Shehab Un Sakib, Abhishek Sarkar, Ananya Sarker, Sarmista Nandi Satu, Salahuddin Setu

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Contact:
Bauhaus-Universität Weimar, Faculty of Civil and Environmental Engineering, Chair of Resources Management, 99421 Weimar, E-Mail: waste@bauing.uni-weimar.de

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