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Report of current data collection tools for waste flows

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1 Introduction

Waste management is a critical enabler of any circular materials and an integral part of a safe and sustainable society. In Europe, the primary guidelines and practices for waste management comprise the EU Waste Framework Directive (EU, 2008/98/EC), which was created to further sustainable use of materials and natural resources by enhancing recycling rates and discourage or even prohibit waste disposal methods that recover little or no value from the materials – such as landfilling or incineration. To advance circular economy, efficient waste management is a must, and the associated material flows need to be thoroughly mapped and analysed to enable this efficiency. A case study by Kurdve et al. (2015) highlights the importance of mapping the waste flows and categorizing the waste fractions individually to achieve the greatest benefits.

End-of-Life plastics, textiles and waste electrical and electronic equipment (WEEE) are among the most environmentally impactful and simultaneously challenging waste categories for the waste management systems. Plastic waste includes items such as packaging and single-use products, which are long-lasting and often end up in nature (Ironside et al., 2024). In Europe single use plastics are governed by the single use plastics directive (EU 2019/904) and largely prohibited. On the other hand, while plastic packaging recycling is widely employed, at least in Europe, the rise in capacity has largely plateaued well short of the targets set by the plastic packaging waste regulation (EU 2025/40). The problems have been identified as a combination of high production costs – which is heavily influenced by the costs of waste management and logistics – and the comparably low cost of primary, fossil-based materials without regulatory incentives or restrictions favouring recyclables (Jiang & Bateer 2025). Textile waste originates from garments and other textile products, with the volume rapidly growing due to fast fashion and overproduction. Electronic waste, or e-waste or WEEE in a broader sense, includes everything from small devices like phones and computers to large household appliances, like fridges and washing machines (He et al. 2024). The common challenge spanning these waste types is heterogeneity: the products in the waste stream are made using different types of materials, often also mixed with additives and/or hazardous substances. Therefore, waste management requires tools for reliable data collection, effective sorting and smart tools to detect harmful substances.

Reliable mapping tools help visualize the movement and transformation of waste across systems enabling not only route optimization but also material flow tracking and traceability of the waste across the value chain actors (Ironside et al. 2024). Analysis tools are instead utilized to quantify, assess and interpret waste data and, in combination with models and modelling tools, simulate system behaviour, forecast outcomes, and support decision making.

This report presents an overview of prominent and emerging data collection tools used in Finland and across the European Union for this purpose. The report focuses on three key tool categories: mapping, analysis and modelling tools, highlighting how these tools are applied to the various waste streams, and especially to plastics, textiles and e-waste. The tools are utilized at various operational environments, such as research, businesses, and public services, to enhance waste management practices. The report prioritizes tools which support decision-making processes and policy development in the transition towards a fully circular economy in the Nordics (Finland and Sweden) and the Baltics (Estonia and Lativia).

This research and report have been funded through project the SustainaCycle, which will using the tools to analyse data for plastics, e-waste and textile waste. The project is co-funded by the EU and Interreg Central Baltic Programme. The project is geographically located in Finland, Estonia, Lativia and Sweden. For more information about the project, please visit the website: https://centralbaltic.eu/project/sustainacycle/

2 Overview of methods

This section focuses on describing different mapping, analysis and modelling methods. All methods are divided into subchapters.

2.1 Mapping methods

2.1.1 Waste flow mapping (WFM)

Waste Flow Mapping (WFM) is a methodology used to systematically identify, quantify, and visualise material and waste flows within a defined, limited system boundary. While WFM is frequently applied e.g. for a single manufacturing facility – particularly to analyse production inefficiencies – the conceptual basis is not limited to the production. Depending on the scope, WFM can be applied across different life-cycle stages from material sourcing, manufacturing, use, and end-of-life management (Brunner and Rechberger 2004). In the industrial context, WFM often adapts principles from Value Stream Mapping in Lean manufacturing, extended with environmental perspectives, to highlight where material losses, by-products, and wastes arise (Brunner and Rechberger 2016). Such applications of the method support pollution prevention and resource efficiency by 'visualising' the waste and linking environmental shortcomings to economic costs, such as raw material inefficiencies, or waste handling and disposal costs.

However, WFM is methodologically neutral with respect to circularity goals and strategies. The ability to incorporate concepts such as design for recyclability or post-consumer waste flows depends on the definition of the system boundaries. Regardless of the 'scale', an effective implementation requires reliable data, technical expertise, and organizational commitment across all included life-cycle stages.

There are different methods to control waste flows. A study of Kurdve et al. (2015) focused on a WFM method divided into the seven steps explained in Figure 1.

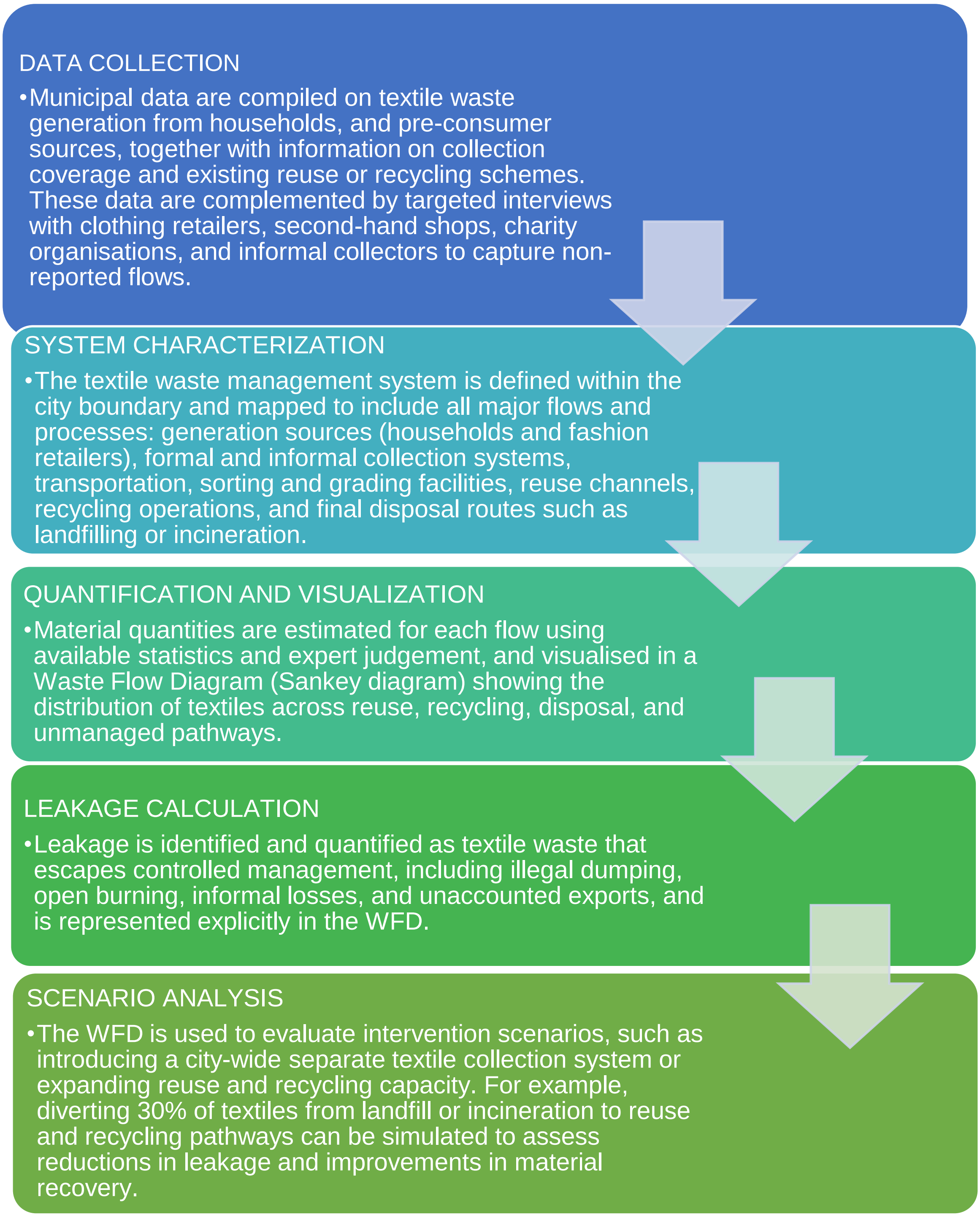
Figure 1: Seven step waste flow mapping (adapted from Kurdve et al. 2015).

2.1.2 Waste Flow Diagrams (WFD)

Waste Flow Diagrams (WFDs) are rapid assessment tools primarily developed to support city and municipal authorities in understanding and improving local waste management systems (Robinson et al. 2024). The purpose is to provide a quantitative visual snapshot of waste generation, collection, treatment, recovery and disposal within a defined urban boundary. Methodologically, WFDs are rooted in Material Flow Analysis (MFA), but are intentionally simplified for fast applicability, particularly in data-scarce and low-to-middle income contexts.

The advantage of WFDs lies in the rapid and cost-effective generation of a comprehensive system overview (Wilson et al. 2006). The WFDs visual structure makes them effective communication tools for engaging non-technical stakeholders, such as policymakers, municipal planners, and the general public. WFDs are well-suited for identifying systemic inefficiencies, value chain discontinuities or outflows, and other priority intervention points across the waste value chain (Brunner and Rechberger 2016; Wilson et al. 2012). However, as a rapid assessment method, the accuracy depends on the availability and quality of municipal data and on expert judgment to fill data gaps. WFDs often underrepresent the complexity and temporal variability of (especially informal) waste management practices. Consequently, WFD output should be interpreted as high-level estimates to support strategic planning rather than as a substitute for detailed, long-term monitoring or full MFA.

The WFD process typically follows a structured sequence of steps beginning with data collection, drawing on available municipal statistics (population, waste generation rates, collection coverage, and treatment or disposal records), complemented by stakeholder interviews with value chain actors (municipal officials, waste collectors, recycling operators) and representatives of the informal sector (Wilson et al. 2012). This is followed by the system characterisation, in which the entire urban waste value chain within the city boundaries is mapped, encompassing waste generation sources (e.g. households, commercial activities), collection systems (formal and informal), transport, sorting, recycling, composting, landfilling, and estimations of uncontrolled disposal practices such as open dumping or burning. The core output of the WFD is the ‘leakage’ calculation, i.e. estimation of material outflow from the value chain. An example of WFD process for textile waste is presented in Figure 2.



DATA COLLECTION

- Municipal data are compiled on textile waste generation from households, and pre-consumer sources, together with information on collection coverage and existing reuse or recycling schemes. These data are complemented by targeted interviews with clothing retailers, second-hand shops, charity organisations, and informal collectors to capture non-reported flows.

SYSTEM CHARACTERIZATION

- The textile waste management system is defined within the city boundary and mapped to include all major flows and processes: generation sources (households and fashion retailers), formal and informal collection systems, transportation, sorting and grading facilities, reuse channels, recycling operations, and final disposal routes such as landfilling or incineration.

QUANTIFICATION AND VISUALIZATION

- Material quantities are estimated for each flow using available statistics and expert judgement, and visualised in a Waste Flow Diagram (Sankey diagram) showing the distribution of textiles across reuse, recycling, disposal, and unmanaged pathways.

LEAKAGE CALCULATION

- Leakage is identified and quantified as textile waste that escapes controlled management, including illegal dumping, open burning, informal losses, and unaccounted exports, and is represented explicitly in the WFD.

SCENARIO ANALYSIS

- The WFD is used to evaluate intervention scenarios, such as introducing a city-wide separate textile collection system or expanding reuse and recycling capacity. For example, diverting 30% of textiles from landfill or incineration to reuse and recycling pathways can be simulated to assess reductions in leakage and improvements in material recovery.

Figure 2: Waste Flow Diagram’s logic (adapted from GIZ et al. 2020).

In the quantification and visualization phase, the collected data is processed to quantify the mass of waste moving between each stage. This can be visualized e.g. with a Sankey diagram. Sankey diagrams are a type of flow chart, where the width of the flows or arrows corresponds to the quantity they represent. These flows connect nodes, which represent different stages, categories, or entities in a system. Sankey diagrams are used to visualize where resources, like energy, materials or costs, come from and where they go, and this visualization enables stakeholders to quickly identify critical points in the system, such as significant volumes of uncollected waste. In waste management, Sankey diagrams can show how waste moves through stages, including generation, collection, treatment, and disposal. (SankeyMATIC n.d.) Figure 3 represents an example of Sankey diagram for end-of-life textile flows in Finland in 2019 (Dahlbo et al. 2021).

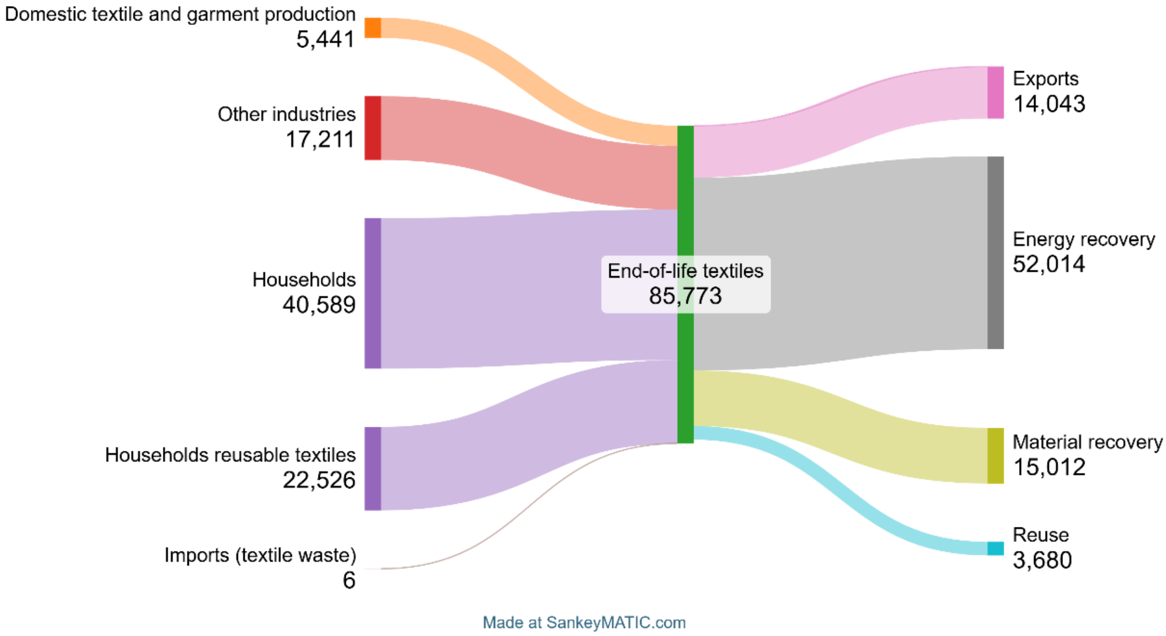


Figure 3: End-of-life textile flows in Finland (tonnes, 2019). The data used in the Sankey diagram is from Dahlbo et al. 2021.

2.1.3 Citizen Science and Community-Based Mapping

Citizen science and community-based mapping platforms have emerged as powerful tools for collecting granular, ground-level data on plastic pollution. These initiatives engage individuals and communities as active participants in the environmental monitoring to efficiently gather data from large areas during extended periods of time. Using simple web interfaces or mobile applications, citizens can report the location, type, and quantity of waste they encounter, contributing to a growing, open-access database (Lynch 2018; World Bank 2024). The crowd-sourced data provides valuable insights into local patterns, sources of waste, and can be used to raise public awareness and advocate for policy changes. Two of such platforms, OpenLitterMap (Lynch 2018; World Bank 2024), Wastebase (unwaste.io - Plastic monitoring) and the Marine Debris Tracker (www.debristracker.org), exemplify the potential of citizen science to generate high-quality, actionable data on plastic waste. For example, if a particular area shows a high concentration of plastic food wrappers, this information can be used to engage with local food vendors or to advocate for improved waste bins in that location. Through direct engagement, these tools also serve as an educational tool, raising awareness about the prevalence of plastic pollution and encouraging more responsible behaviour.

2.2 Analysis methods

2.2.1 Material Flow Analysis (MFA)

Material flow analysis (MFA) is a data intensive tool for system (e.g. city or country) specific quantitative or semi-quantitative analysis of material flows within said system and provides detailed information on critical leakage points and systemic inefficiencies with a level of detail outside the scope of more generic methods (Xavier et al. 2023). The generalized MFA procedure is demonstrated in Figure 4. The first two steps are defining the scope of the analysis and mapping the value chain. The most intensive phase in MFA is the data collection, in which data is acquired from disparate sources, such as national import/export databases, industry production figures, retail sales, municipal waste composition analyses, surveys on consumer disposal habits and operational information from collectors and recyclers. The final step is quantification and modelling, where the collected data is used to quantify the material flow between each stage.

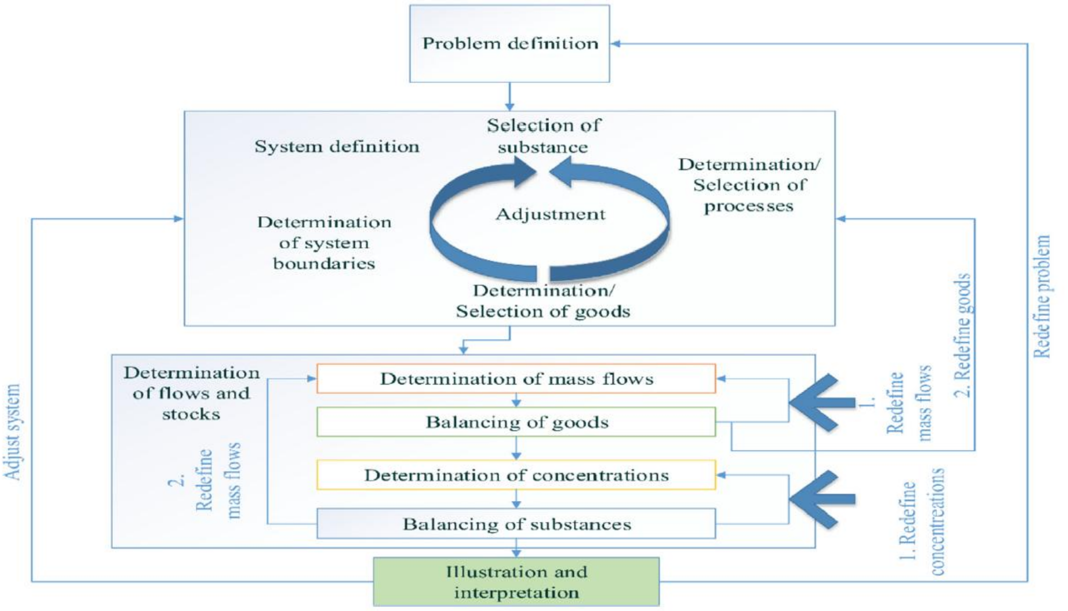


Figure 4: MFA procedure (adapted from Brunner and Rechberger 2016 according to Islam & Huda 2019).

Allesch and Brunner have investigated how MFA can be used as a decision support tool in waste management. Information about the amount of waste to be treated (inflows), handling and processing, transportation, material outflows and stored material and waste are essential for making decisions in waste management (Allesch & Brunner 2015). If MFA is used for decision making, it is important to note that it demands expertise in the field as well as time resources. The models usually require customization for each case with specific coefficients to account for variables outside the systems scope, but still relevant to the overall result (Chen et al. 2017). Overall, developing these models is extremely resource-intensive, requiring expertise and extensive data collection. The results and the model are often not transferable to another system without significant recalibration (Islam and Huda 2019).

Material flow modelling can also be done using input-output analysis (IOA) (Chen et al. 2017). According to Towa et al. (2020), IO models can be divided into different categories: the conventional input-output model with waste extension (WEIO), the waste input-output (WIO) model, the physical input-output (PIO) model and the hybrid input-output (HIO) model. The most used one is the WIO model. The specific benefit of IOA is that each ‘production activity’ is connected to the ‘final demand’ (Towa et al. 2020).

2.2.2 MFA integration with Multi-Criteria Analysis and Decision Making (MCA/MCDM)

Makarichi et al. (2018) used MFA as a support tool for MCDM in the context of solid waste management decision-making. The study proposed a four-stage decision making cycle, which includes MFA, evaluation and options analysis, MCA, and implementation and feedback. In this framework, MFA plays a critical role in evaluating the effectiveness of a waste management system and in assessing the degree of improvement that different intervention options may provide. The results of the MFA are then used as an input into the MCA, which is used to rank the different options based on a set of technical, economic, social, and environmental criteria. The integration of MFA and MCA provides a more robust and transparent framework for decision-making than either tool could provide on its own. MFA provides a quantitative and objective assessment of the material flows and environmental impacts of a system, while MCA provides a structured and transparent framework for evaluating and ranking different options based on a set of multiple criteria. The combination of these two tools allows for a more holistic and balanced assessment of the different options, and it helps to ensure that all relevant factors are considered in the decision-making process (Makarichi et al. 2018).

2.2.3 Life Cycle Assessment (LCA)

Life cycle assessment (LCA) is a method used to examine how products or services affect the environment throughout their entire lifespan. The first international standard guiding for this work was introduced in 1996, and the revised versions, ISO 14040 and ISO 14044, were published in 2006 to provide more detailed instructions for conducting assessments (SFS-EN ISO 14040 2006; SFS-EN ISO 14044 2006).

LCA has emerged as a cornerstone methodology for the environmental evaluation of municipal solid waste (MSW) management systems, providing a systematic approach to quantify the environmental impacts associated with the entire lifecycle of waste, from its generation to its final disposal (Peiris and Dayarathne 2023). The application of LCA is particularly critical in the context of textile waste, where complex supply chains and diverse material compositions make it challenging to identify the most sustainable management pathways. By analysing input and output flows, assessing a wide range of environmental impacts, and interpreting the results, LCA helps stakeholders identify potential environmental harms and informs critical economic, technical, and social decisions (Nurzhan et al. 2025). LCA helps address interconnected environmental challenges by preventing impacts from merely shifting between environmental compartments or geographic locations (Curran 2013). The software tools used to conduct these assessments can be broadly categorized into two groups: general-purpose LCA software, which offers extensive databases and flexibility for a wide range of applications, and specialized waste management LCA tools, which are specifically designed to handle the complexities of mixed and heterogeneous waste streams. The choice between these tools often depends on the specific goals of the study, the required level of detail, and the available resources.

General-Purpose LCA Tools

General-purpose LCA software tools are widely recognized for their comprehensive databases and versatile modelling capabilities, making them suitable for a broad spectrum of environmental assessments, including MSW management (Nurzhan et al. 2025). The tools are built on extensive life cycle inventory (LCI) databases, such as Ecoinvent, which contain detailed information on the environmental impacts of thousands of materials, processes, and energy systems. This allows for a high degree of granularity and accuracy in modelling the various stages of waste management, from collection and transportation to different treatment technologies like mechanical recycling, chemical recycling, incineration with energy recovery, and landfilling. The primary advantage of using general-purpose tools lies in their ability to conduct comprehensive and versatile LCAs that cover a wide range of environmental impact categories beyond those typically associated with waste management, such as global warming potential, acidification, eutrophication, and resource depletion. However, the high cost of commercial LCA software can be a significant barrier to widespread use, particularly in developing countries or in smaller organizations.

Specialized Waste Management LCA Tools

Due to specific limitations of general-purpose LCA software in the waste management context, specialized tools have been developed for the assessment of municipal solid waste management systems. These tools, including EASETECH (Lodato et al. 2021), EASEWASTE (Manfredi 2009), and WISARD (De Feo and Malvano 2009), are designed to handle the challenges of heterogeneous and mixed waste. For example, EASETECH (Lodato et al. 2021) and EASEWASTE (Manfredi 2009) model the flows of mixed substances in detail and enable the customization of technology parameters and process indicators, which is crucial for accurately representing the diverse and often site-specific conditions. The tools are particularly useful for detailed assessments of specific scenarios, as they contain data on the physical, chemical, and biological processes involved in waste management. WISARD (De Feo and Malvano 2011), in turn, offers a logical framework that encompasses the waste management lifecycle, from production and collection to treatment and disposal, and includes a database with specific information on logistics, recycling, composting, incineration, and landfilling (Nurzhan et al. 2025). However, as specialized tools the included databases are less comprehensive than those of general-purpose tools, and the focus on waste management reduces their flexibility for assessing broader environmental impacts. The choice of which LCA tool to use ultimately depends on careful balancing of the specific needs, the required level of detail, the available data, and the associated costs (Nurzhan et al. 2025).

2.3 Modelling methods

The escalating global crisis of plastic pollution, particularly within the MSW stream, has catalysed the development of a diverse suite of modelling tools for waste management. The are widely utilized for informing policy, optimizing waste management systems, and evaluating the environmental and economic trade-offs of different mitigation strategies. The current landscape of modelling tools is characterized by a spectrum of approaches, ranging from highly detailed, open-source LCA frameworks to sophisticated system dynamics models and large-scale global economic models. These tools are increasingly incorporating advanced computational techniques, including ML and AI, to enhance their predictive accuracy and decision-support capabilities. This section provides a comprehensive review of the state-of-the-art modelling tools used globally for waste analysis, with a focus on their methodologies, applications, and comparative strengths.

2.3.1 Simulation-Based Optimization (System dynamics)

Simulation-based optimization combines the strengths of simulation and optimization to solve complex decision-making problems. A simulation model can be used to represent the real-world operations of the waste collection system, including the characteristics of the vehicles, the location and capacity of the collection containers, and the generation of waste in different areas. This enables the testing and evaluation of several collection scenarios, including route plans, vehicle types, and container technologies to reduce the daily distances travelled by the collection vehicles or to highlight the advantages of sensor technology in monitoring the fill levels of collection containers to improve the efficiency of the system (López et al. 2024). Similarly, Cilleruelo Palomero et al. (2025) utilized System Dynamics modelling as an overarching view of the LCA, social LCA, circularity, criticality and plastics littering risk work end-of-life vehicle (ELV) and WEEE plastic recycling pilots.

A novel approach to modelling waste collection systems has been proposed that explicitly incorporates the behavioural dynamics of citizens, recognizing that the success of any waste management strategy depends not only on its technical and logistical efficiency but also on the active participation of the public (Zammori et al. 2025). This study resulted in a hybrid simulation platform that combines Agent-Based Modelling (ABS) with Discrete Event Simulation (DES) to capture the interdependencies between citizen behaviours, social influence, and the operational performance of the collection system. Citizens are represented as adaptive agents whose recycling behaviours evolve in response to personal experiences, surrounding attitudes, and the quality of service. The simulation allows for predicting the effectiveness of policy or infrastructure changes, financial incentives and communication campaigns, and evaluates the impact on both the system and citizen engagement. The approach provides a framework for designing effective and inclusive waste management systems and highlights the importance of the social dimensions of waste management in the design and implementation of policy changes (Zammori et al. 2025).

2.3.2 Predictive Modelling for Waste Generation

Predictive modelling is a powerful tool for modern waste management, enabling planners and policymakers to anticipate waste generation trends to design and implement appropriate infrastructure and services more proactively. Through analysis of historical waste generation data and identification of the key drivers (e.g. as population growth, economic development, consumption patterns), these predictive models provide insights into the composition and quantity of future waste streams. The use of advanced machine learning (ML) algorithms and artificial neural networks (ANNs), such as Support Vector Machines (SVM) and Long Short-Term Memory (LSTM) networks, has shown great promise in this area, offering more accurate and robust predictions than statistical methods. (Fatovatikhah et al. 2024) ML methods are designed to predict complex and non-linear relationships with suitable teaching data available and thus can be trained on large datasets to identify subtle patterns and trends that are easily overlooked with other methods. (Fatovatikhah et al. 2024; Algafri et al. 2025).

Modelling the potential for material recovery and urban mining is a key application of circular economy models to estimate the potential of valuable materials recovery from waste; particularly that of valuable materials such as gold, copper, and rare earth elements, that are prevalent in WEEE (Xavier et al. 2021). Comprehensive and qualitative assessment of the economic viability is an effective indicator also for technical maturity and a suitable economy of scale for any given circular economy approach and model-based predictions for decision making can significantly boost adoption and development of circular economy (Smith and Behdad 2025; Xavier et al. 2021).

2.3.3 Automation and Industry 4.0 in Waste Management

The integration of automation and Industry 4.0 principles into waste management is an ongoing shift from labour-intensive, manual processes to data driven, efficient, and intelligent systems (Fatimah et al. 2020). The main advantages and applications, from automated material detection and sorting systems to automated material flow management, are emerging for a post-consumer waste management and recycling. Conceptually, the methods could offer similar advantages also to pre-consumer waste, especially in terms of valuable insights into system design and optimization. The approaches combine a variety of methods from advanced robotics, material identification, AI, the Internet of Things (IoT), and data analytics to enhance the efficiency, accuracy, and traceability of waste collection, sorting, and processing. The aim is to mitigate one of the main challenges in circular waste management, the high cost and inefficiency of operator dependent sorting. (Brasch et al. 2025; Radice et al. 2025) Advanced sorting could be coupled with improved traceability tools, such as a digital product passport (DPP), which offers synergistic benefits for both tools. By automating key stages of the waste management value chain, the tools improve operational performance and generate additional data for evolving models and analysis (Fatimah et al. 2020).

3 Examples and case studies

This section reviews specific state-of-the-art tools and emerging standardized methodologies and technological solutions for waste mapping and analysis.

3.1 Specific initiatives and case studies for plastic waste

3.1.1 Recycling Infrastructure and Market Maps

Some initiatives have collected regional recycling infrastructure and waste facility data on openly accessible geographic information system (GIS) maps, such as the Recycling infrastructure and Market Opportunities Map (EPA 2025). The map includes locations of landfills, recycling facilities, composters, and specifically plastic recycling facilities, plus estimated tons of waste generated or recycled per ZIP code, broken out by material type (HDPE, PET, etc.). The Circulate Initiative has similarly collected a dashboard of data on plastic generation per capita, collection/recycling rates, waste composition, policies and key actors for 100 cities in Asia, Latin America and Africa.

3.1.2 Examples of STAN for plastic waste

For plastic waste analysis, STAN (Substance Flow Analysis) has been employed in numerous peer-reviewed studies to quantify and visualize the complex pathways of plastic materials within MSW systems. A 2025 study on sustainable plastic bag recycling in Thailand utilized STAN version 2.7.101 to analyse the flow of plastic bags across municipalities (Kittithammavong et al. 2025). STAN enabled a systematic assessment of plastic bag movement from households to landfills or recycling facilities, providing a transparent and standardized basis for comparing different waste management scenarios (Kittithammavong et al. 2025). A 2024 study in Mozambique used STAN to quantify plastic waste flows. Data for the analysis was compiled from primary and secondary sources such as interviews, national statistics, and international databases. (dos Muchangos et al. 2025) A 2021 study on the circular potential of plastic waste in Sri Lanka used STAN 2.6 to create a comprehensive plastic material flow diagram for the year 2017, revealing that out of 539,667 Mg of plastic waste generated, only 3% was recycled, while a significant portion was mismanaged (Samarasinghe et al. 2021). These examples highlight the ease of access and wide applicability of the method for varying assessments to support the development of waste management efforts.

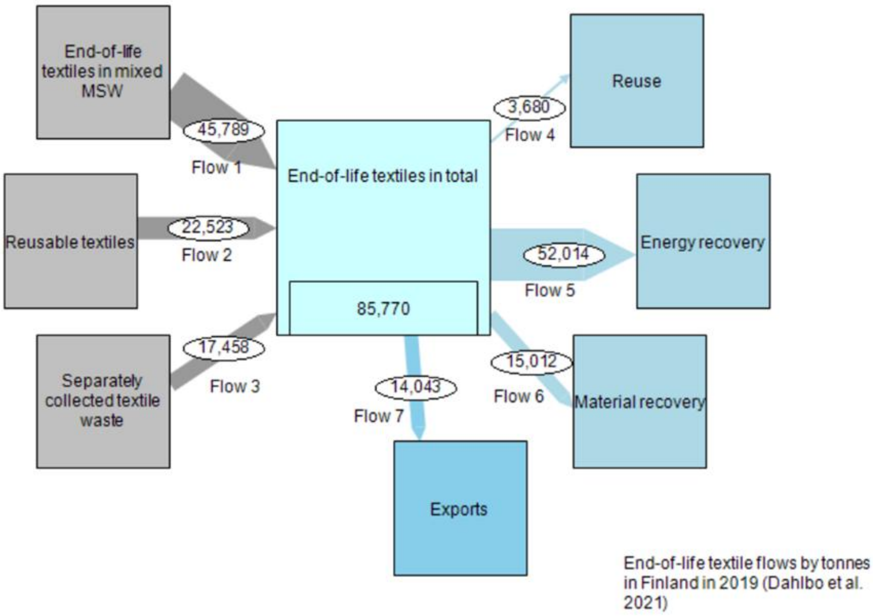
3.2 Specific initiatives and case studies for textile waste

3.2.1 Case study and example of STAN for textile waste

Costa et al. (2025) utilized the STAN software conduct a comprehensive MFA of textile waste in Portugal providing a detailed understanding of the flows and stocks of textiles within the country. STAN is an excellent tool for communicating complex system dynamics based in imperfect, real-world data to non-experts. But it is limited by its nature as a calculation and visualization tool, not a fully developed data collection or simulation engine. STAN typically models a static state for a given period and does not inherently capture the dynamic behaviours modelled by hybrid simulations (Cencic et al. 2008).

Costa et al. (2025) employed a systematic approach to map the entire textile lifecycle, from the imported raw materials to finished products and the generation of both pre-consumer and post-consumer waste followed by the subsequent management of this waste: recycling, incineration, and landfilling. The study resulted in a visual and quantitative model of the Portuguese textile system, highlighting key flows and identifying the major sources of waste. The analysis revealed significant insights into textile waste management system in Portugal, including the quantities of waste being diverted from landfill and the potential for increasing resource recovery. This provides an example of MFA as a crucial tool for informing policy and developing targeted interventions to improve the circularity.

Figure 5 is an example of STAN software based on data published by Dahlbo et al. (2021). It visualizes end-of-life textile flows in a simple way.



End-of-life textile flows by tonnes in Finland in 2019 (Dahlbo et al. 2021)

Figure 5: End-of-life textile flows modelled using STAN (data from Dahlbo et al. 2021).

3.2.2 Forecasting MSW Generation Trends

Liu et al. (2025) utilized a ML algorithm called XGBoost to develop a predictive model for MSW generation in China, with a particular focus on textile waste. The aim was to identify the key drivers of MSW generation and develop a model to predict future waste generation trends. With the inclusion of a range of socio-economic and demographic factors, such as population density, urbanization rate, urbanization index, waste composition and GDP, the results outperformed several other commonly used ML algorithms used in comparable studies (Liu et al. 2025).

3.2.3 World of Waste global textile waste mapping

The "World of Waste" is a data-driven online tool launched by Fashion for Good (2024), a Netherlands-based sustainable innovation platform. The tool represents a global effort to manage textile waste by providing a centralized and comprehensive overview of waste quantities, types, and compositions. The key partners in the development included stakeholders such as Reverse Resources, Global Fashion Agenda, Circle Economy, Accelerating Circularity, Laudes Foundation and IDH; the Sustainable Trade Initiative. The tool is designed to tackle the persistent issue of fragmented knowledge and inconsistent data that has long hindered the effective management of textile waste. The consolidated information enables informed decisions, strategic feedstock sourcing, and contribution to the development of sustainable waste management policies and regulations. The "World of Waste" primarily a centralized repository of information, including detailed information on waste attributes, data collection methodologies, and the organizations involved in the studies. "World of Waste" aims to unlock new opportunities for innovation and collaboration, driving the transition to a sustainable and circular textile industry (Fashion for Good 2024).

3.3 Specific initiatives and case studies for WEEE

3.3.1 Tracking E-waste Streams from Generation to End-of-Life

For WEEE (E-waste) the MFA often starts with for example sales data from the UN Comtrade Database, and a sales-lifespan model (Busby and Bremner 2021). The lifespan data for the different product categories is analysed based on Weibull distributions to calculate the estimated E-waste generated over the selected time period. The approach is utilized by governing bodies such as the U.S. Environmental Protection Agency (EPA) and the European Union's WEEE Directive (Busby and Bremner 2021). By tracking the identified flows, the MFA provides a detailed picture of the waste management system based on the amount of formally collected and recycled waste, the amount that is disposed in landfills or incinerators, and the stock still in use or storage in households or businesses. The critical outcome is the identification of ‘leakage points’ in the system: outflows where valuable materials are lost.

3.3.2 Multi-Criteria Decision Making for Facility Location, Police and Strategy selection

Multi-Criteria Analysis (MCA) can be used to support decision making in optimizing multiple, often conflicting, criteria such as the generation, collection, transport, storage, treatment and disposal of the solid waste (Garcia-Garcia, 2022). For example, a study by Wibowo and Deng (2015) used MCA to evaluate the suitability of different locations for an e-waste recycling facility in Indonesia, considering factors such as environmental impact, economic cost, and social acceptance. The study found that MCA was a useful tool for structuring the decision-making process and for identifying a location that was both technically and socially acceptable.

The Analytic Hierarchy Process (AHP) is the most common MCDM tool in the waste management field (Garcia-Garcia, 2022). It can be used to evaluate and compare policy and strategy options, such as different types of Extended Producer Responsibility (EPR) schemes or approaches for promoting consumer awareness. A hierarchy of more easily understood components helps make the decision-making process more transparent and systematic. (Abu-Qdais & Al-Saleh, 2024) A study by Garg (2021) used a combination of grey theory and the DEMATEL framework, a variant of AHP, to model e-waste mitigation strategies. The approach was effective in identifying key factors influencing e-waste management and developing corresponding policy interventions.

4 Challenges and Future Directions

Waste material analysis is currently defined by a tension between rapid technological advancement and critical systemic barriers, primarily regarding data standardization and global equity. The lack of consistent and reliable material data and the varying definitions for metrics like "recycling rate" or "mismanaged waste" across different nations multinational aggregate analysis very challenging. The inconsistency hampers especially the AI/ML models. As noted in a 2025 systematic review, the performance of these advanced tools is severely constrained by "noisy," incomplete, or unstandardized training datasets (Dawar et al. 2025). The problem has been recognized as evident, for example, from the EU push for fully open access data for all HORIZON funded projects. Open-access repositories and standardized protocols, such as the UNEP/IUCN guidance provide the best potential for better universal applicability.

Technological and financial barriers create a "digital divide" that prevents especially low- and middle-income countries (LMICs) from accessing the most sophisticated analysis tools. High-resolution spatial models and AI-powered sorting systems often require computational power and financial investment that are out of reach for small local municipalities. Tools like the Excel-based WFD and inexpensive UAV-based mapping for coastal regions provide practical alternatives to data-intensive models. While these tools enable regional stakeholders to break the cycle of ineffective waste management and make evidence-based decisions without requiring massive infrastructure investment, it simultaneously diversifies the metrics and data formats complicating methodology and transferability.

A systemic transformation to holistic approach requires strong Public-Private Partnerships for open access data and the scaling of citizen science platforms like OpenLitterMap and Marine Debris Tracker. By merging "crowdsourced" community data with professional monitoring, stakeholders can create a nuanced, dynamic, and resilient, data driven waste management ecosystem.

Finally, a cross-cutting challenge across mapping, analysis, and modelling tools is the limited comparability of waste flow data across the Baltic Sea region. Differences in data definitions, system boundaries, indicators, and reporting practices result in heterogeneous datasets that constrain aggregated analysis and reduce the effectiveness of advanced analytical approaches, including AI/ML-based tools. While a growing diversity of accessible and low-threshold tools enables wider participation in data collection and analysis, it also further fragments methodologies and data formats. Improving the interoperability of existing tools through shared definitions, aligned indicators, and common methodological principles therefore represents a key future direction.

5 Conclusion

In this report, different modelling, mapping and analysis tools for textile, plastic and e-waste were investigated. Case studies and examples were used to describe in concrete how different tools can be used to collect and illustrate waste flow data. User-friendly and open-access tools, such as Sankey Diagram and STAN, could easily be introduced as an optional tool to organizations' waste data collection procedures.

In SustainaCycle Project, Sankey Diagram and STAN are suitable tools for analysing and visualizing the collected data due free and open access, as well as, presenting it in an easily understandable form.

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