



**LAND MANAGEMENT, ENVIRONMENT & SOLID-WASTE:  
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**MICRO-CREDENTIAL**

**CIRCULAR ECONOMY  
FOR LAND AND WASTE MANAGEMENT**

## **4.- Solid Waste Streams and Material Flows**

***Foundations of Circular Economy for Land and Waste  
Management  
PDF W04***



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## 1. SUMMARY OF KEY IDEAS

The transition from a linear to a circular economy requires a profound understanding of how materials flow through our socio-economic systems and how they eventually become waste. In the linear "take-make-dispose" model, waste is viewed as a final, negative externality. Conversely, a circular economy views waste as a "contaminated resource" or a secondary raw material. This core lesson explores the diverse streams of solid waste — municipal, agricultural, and industrial — and examines how these streams can be tracked and managed. By employing Material Flow Analysis (MFA), environmental planners can quantitatively map resource flows, identify material leakage, and design targeted interventions. Furthermore, this lesson critically evaluates the Waste Management Hierarchy within the circular economy framework, expanding the traditional "3Rs" to the more comprehensive "10Rs", thereby prioritising the preservation of embedded energy and labour in products. Finally, the lesson highlights the socio-economic dimension of waste management, specifically the critical role of informal waste systems in developing and transition economies, and how these systems must be integrated into modern circular frameworks to ensure equitable and sustainable development.

## 2. LEARNING OBJECTIVES

Upon successful completion of this core lesson, learners will be able to:

- Analyze the composition, scale, and drivers of municipal, agricultural, and industrial waste streams on a global and regional level.
- Explain the principles and methodological steps of Material Flow Analysis (MFA) and apply them to track resource efficiency.
- Evaluate the Waste Management Hierarchy and the expanded "10Rs" framework in the context of biological and technical cycles.
- Assess the socio-economic contributions and vulnerabilities of informal waste sectors in developing nations and propose inclusive integration strategies.

## 3. INTRODUCTION

Modern industrial societies are characterized by a highly accelerated "socio-economic metabolism". In this metabolism, natural resources are extracted, processed, consumed, and discarded at rates that vastly exceed the Earth's regenerative carrying capacity. According to recent global assessments, humanity generates roughly 20 gigatonnes of processing and end-of-life waste annually, equating to approximately 7.5 kilograms of waste per person every single day. This massive accumulation of solid waste is the ultimate symptom of the linear economic model — a system that inherently leads to the irreversible transformation of valuable natural capital into useless, often hazardous, environmental burdens.

The circular economy provides a systemic alternative. It aims to deliver a "new-modern society" where economic growth is decoupled from resource depletion and environmental degradation. To achieve this, we must first understand the anatomy of our waste. Waste is not a monolithic entity; it is highly heterogeneous, comprising everything from biodegradable food scraps and durable plastics to toxic industrial by-products. Managing these diverse materials requires sophisticated tools like Material Flow Analysis (MFA) to map where resources enter the economy and where they leak out. It also requires strict adherence to a prioritized hierarchy of interventions — from waste prevention and eco-design down to recycling and, as a last resort, disposal.

As we will see in this lesson, transforming waste management into resource management is not merely a technological challenge; it involves complex governance, economic restructuring, and the integration of informal labor markets that currently form the backbone of recycling in many developing regions.

#### 4. MUNICIPAL, AGRICULTURAL, AND INDUSTRIAL WASTE

To implement circular strategies effectively, environmental managers must first categorize and understand the specific properties, origins, and volumes of different waste streams. Waste is generally classified by its sector of origin, its material composition, and its potential for recovery.

*Municipal Solid Waste (MSW)* primarily consists of everyday items discarded by households, as well as similar commercial, institutional, and industrial wastes. In 2016, the world generated approximately 2.01 billion tonnes of MSW, a figure that is projected to grow significantly, especially in rapidly urbanizing regions like Asia.

The composition of MSW is highly dependent on the geographic and economic context of the generators. Global averages indicate that organic waste (food and green waste) constitutes the largest fraction at 44%, followed by paper and cardboard (17%), plastics (12%), glass (5%), and metals (4%). However, there is a stark contrast between income levels. High-income countries generate significantly more waste per capita (1.6 to 1.9 kg/capita/day) compared to low-income countries (0.40 to 0.56 kg/capita/day). Furthermore, in developing and low-income nations, the organic fraction of MSW is substantially higher because a larger proportion of household income is spent on basic food ingredients rather than heavily packaged processed goods. In Central Asian cities like Almaty, MSW management remains a critical challenge, with the vast majority of waste currently directed to official and unauthorized landfills rather than material recovery facilities.

*Agricultural and agro-processing wastes* represent a massive, yet often underutilized, material stream. These wastes include crop residues (such as rice husk, corn cobs, cane bagasse, and palm oil empty fruit bunches), animal manure, and post-harvest losses.

In a linear system, these residues are frequently burned in open fields — causing severe air pollution (PM<sub>2.5</sub>) and greenhouse gas emissions — or left to rot, creating methane. However, in a circular economy, agricultural waste is viewed as a high-value "biological nutrient". Through processes like anaerobic digestion and composting, these organic streams can be transformed into biogas (renewable energy) and nutrient-rich bio-fertilizers (digestate). For example, returning separated household and agricultural food waste to the soil can drastically reduce a nation's dependency on synthetic mineral fertilizers, thereby restoring soil organic matter and mitigating land degradation. In regions like Uzbekistan, developing circular agri-food value chains is recognized as a major opportunity for both economic growth and environmental sustainability.

*Industrial waste* encompasses residues from manufacturing, chemical processing, mining, and utilities. By sheer volume, industrial and construction/demolition waste (CDW) dwarfs municipal waste. In the European Union, for instance, mining and quarrying account for approximately 29.2% of total waste, construction for 32.6%, and manufacturing for 10.7%.

These streams range from highly toxic materials — such as heavy metals from metal-finishing industries and Air Pollution Control Residues (APCR) from incinerators — to inert materials like concrete, brick, and excavated soil. The circular economy approach to industrial waste relies heavily on "Industrial Symbiosis," where co-located industries exchange by-products, water, and energy, ensuring that one facility's waste becomes another's feedstock. In the construction sector, circularity involves "urban mining"—recovering steel, timber, and aggregates from demolished buildings to substitute virgin material extraction, a critical step for fast-growing cities in transition economies.



Did you know that globally only about 8–10% of materials are cycled back into the economy, while the rest become waste or emissions?

This means that despite growing recycling efforts, most material flows remain linear.

In many developing regions, up to 50% of recyclable waste is recovered by the informal sector, often without formal recognition or support. These actors play a hidden but crucial role in circular systems.

## 5. MATERIAL FLOW ANALYSIS (MFA)

To manage the complex streams of municipal, agricultural, and industrial waste, policy-makers and engineers utilize a specialized assessment method known as Material Flow Analysis (MFA). This approach is particularly relevant within the circular economy framework, where understanding the movement and transformation of materials is essential for minimizing waste and maintaining resource value.

MFA is a systematic assessment of the flows and stocks of materials within a system defined in space and time. It enables the construction of a quantitative model of material cycles, capturing how resources

enter, circulate within, and exit economic systems such as cities, regions, or entire countries. In doing so, MFA aligns with circular economy principles that emphasize the need to keep materials in use for as long as possible and reduce leakages into the environment.

The primary purpose of MFA is to represent complex socio-economic systems in terms of material inputs, transformations, accumulations, and outputs. This includes tracking raw material extraction, production processes, consumption patterns, and waste generation. By quantifying these flows, MFA provides a structured basis for evaluating resource efficiency and identifying inefficiencies within the system. Such analysis is particularly important in regions where data gaps and fragmented waste management systems limit effective decision-making, as highlighted in studies on circular economy development in Central Asia. MFA allows decision-makers to address critical questions, such as: How much plastic, biomass, or construction material enters a regional economy? What proportion is reused, recycled, or disposed of? Where do significant losses occur? By answering these questions, MFA reveals material leakages and accumulation points, which are often associated with environmental pressures such as landfill overuse, pollution, and inefficient resource utilization.

Importantly, MFA supports a transition from traditional waste management approaches toward integrated resource management systems. Instead of focusing solely on end-of-pipe solutions (e.g., disposal or treatment), MFA highlights upstream opportunities for intervention, including waste prevention, eco-design, and improved collection systems. This systemic perspective is essential for achieving circular economy objectives, particularly in rapidly developing regions where waste streams are increasing and infrastructure remains underdeveloped.

Furthermore, MFA provides a foundation for evidence-based policy and planning, enabling governments and stakeholders to prioritize investments in recycling infrastructure, organic waste treatment, and industrial symbiosis initiatives. By visualizing material flows across sectors, MFA also facilitates cross-sectoral collaboration, which is a key requirement for implementing circular economy strategies at scale.

*The mass balance principle* constitutes the theoretical foundation of Material Flow Analysis (MFA) and is derived from the law of conservation of mass. According to this law, matter cannot be created or destroyed within a defined system; it can only be transformed or transferred. Consequently, MFA operates on a strict accounting identity expressed as:

$$\text{Inputs} = \text{Outputs} + \text{Addition to Stocks}$$

This equation ensures that all material flows within a system are consistently quantified and reconciled. In practical terms, it provides a robust analytical framework for tracking materials across production, consumption, and waste management stages. Within circular economy research, this principle is essential for understanding how materials circulate and where inefficiencies or losses occur in the system.

The application of the mass balance principle allows analysts to infer unknown flows based on known data. For instance, if the quantity of materials entering a Material Recovery Facility (MRF) and the volume of sorted recyclables leaving it are known, the residual fraction — comprising unrecovered waste or

process losses — can be calculated. Similarly, the principle enables the estimation of stock accumulation, such as materials embedded in infrastructure, buildings, or long-life products. This is particularly important in circular economy analysis, where stocks represent both a temporary storage of resources and a future source of secondary raw materials.

In dynamic MFA, the focus extends beyond static snapshots to the temporal evolution of flows and stocks. By analysing changes over multiple years, researchers can assess trends in material accumulation and anticipate future waste generation. For example, the accumulation of construction materials in urban environments today directly influences future demolition waste streams. Such long-term perspectives are critical for planning circular strategies, including recycling capacity, material recovery systems, and infrastructure development.

Conducting an MFA requires the definition of several key analytical parameters:

1. **System Boundary.** The system boundary defines the spatial and functional scope of the analysis. It may refer to a city, a national economy, or a specific sector (e.g., construction or agriculture). Clearly defining boundaries ensures consistency and comparability of results.
2. **Time Frame.** MFA can be conducted for a single year (static MFA) or over multiple years (dynamic MFA). Dynamic assessments are particularly relevant for circular economy applications, as they capture long-term trends in resource use and waste generation.
3. **Flows and Stocks.** Flows represent the movement of materials (e.g., biomass, metals, fossil fuels), while stocks refer to materials accumulated within the system (e.g., buildings, products in use, landfills). Distinguishing between flows and stocks is essential for understanding both current resource use and future waste potential.
4. **Processes.** Processes describe the stages through which materials pass, including extraction, manufacturing, consumption, and waste treatment. Mapping these processes enables the identification of transformation points and potential inefficiencies.



**Reflect** Take a moment to reflect on your local context:

- which waste stream (e.g., organic, plastic, construction, agricultural) is most visible in your region?
- where do you think the biggest losses of material value occur — during collection, processing, or disposal?
- do informal waste systems exist in your area, and how do they contribute to recycling or reuse?

Within the circular economy framework, MFA serves as a core measurement tool for evaluating resource efficiency and circularity performance. It underpins key indicators such as Domestic Material Consumption (DMC) and supports the assessment of how effectively materials are retained within the economy. By quantifying the proportion of materials that are reused, recycled, or lost, MFA provides an empirical basis for tracking progress toward circularity goals.

Moreover, MFA is instrumental in evaluating policy interventions and management strategies. For example, when applied to separate waste collection systems, MFA enables municipalities to quantify recycling rates, identify contamination in waste streams, and assess the effectiveness of collection and sorting infrastructure. Such evidence-based insights are particularly important in regions undergoing transition toward circular economy models, where improving data availability and system efficiency remains a key challenge .

In addition, MFA contributes to broader sustainability planning by linking material use to environmental impacts. As emphasized in regional circular economy analyses, improving material flow monitoring can support more efficient resource management, reduce environmental pressures, and guide investments in waste infrastructure and circular solutions .



Identify 3 main waste streams (e.g., organic waste, plastics, construction waste).

Indicate where these materials:

- are generated,
- are collected,
- are treated (recycled, composted, landfilled, etc.).

## 6. THE WASTE HIERARCHY AND CIRCULAR ECONOMY

While Material Flow Analysis provides the quantitative foundation for understanding how materials move through economic systems, effective decision-making in waste and resource management requires a complementary conceptual framework. This role is fulfilled by the waste management hierarchy and the broader principles of the circular economy, which together guide the prioritization of actions aimed at minimizing environmental impacts and maximizing resource efficiency.

To maximize resource efficiency, the circular economy promotes a more granular approach, often described as the "10 Rs":

- **Refuse:** Prevent raw material use entirely (e.g., eliminating single-use plastics).

- **Rethink:** Make product use more intensive (e.g., sharing platforms, product-as-a-service).
- **Reduce:** Increase efficiency in product manufacture or use.
- **Reuse:** Use a discarded product again in its original function.
- **Repair:** Maintain and repair defective products to extend their life.
- **Refurbish:** Restore an old product and bring it up to date.
- **Remanufacture:** Use parts of discarded products in a new product with the same function.
- **Repurpose:** Use discarded products or its parts in a new product with a different function.
- **Recycle:** Process materials to obtain the same (high grade) or lower (low grade) quality.
- **Recover:** Incineration of materials with energy recovery.

The 10 Rs emphasize "slowing" resource loops (extending product lifespans through repair and reuse) before attempting to "close" loops (recycling).

### 6.3. Biological vs. Technical Nutrients

A critical addition of circular economy theory—popularized by the Cradle-to-Cradle concept and the Ellen MacArthur Foundation's "Butterfly Diagram"—is the strict bifurcation of waste streams into biological and technical cycles.

- **Biological Cycles:** Consist of renewable, biodegradable materials (e.g., food waste, cotton, timber). These materials should be cascaded through various uses and ultimately safely returned to the biosphere via composting or anaerobic digestion to regenerate natural capital (soil health).
- **Technical Cycles:** Consist of finite, abiotic materials (e.g., metals, synthetic polymers). These materials cannot safely decompose in nature and must be kept in closed industrial loops through the inner Rs (reuse, repair, remanufacture) and eventually recycled.

For several decades, environmental policy has been structured around the waste hierarchy, a normative framework that ranks waste management options according to their environmental desirability. Traditionally summarized through the "3 Rs"—Reduce, Reuse, Recycle—this hierarchy reflects a progression from the most preferred strategies, which prevent waste generation, to the least preferred, which involve final disposal. At its highest level, prevention focuses on avoiding waste before it is created, through measures such as eco-design, material efficiency, and reduced consumption. This aligns closely with circular economy thinking, which emphasizes upstream interventions rather than downstream treatment.

Following prevention, preparation for reuse involves extending the life of products through cleaning, repair, and refurbishment, allowing them to be used again without significant reprocessing. Recycling, while widely implemented, represents a lower level in the hierarchy, as it requires additional energy and

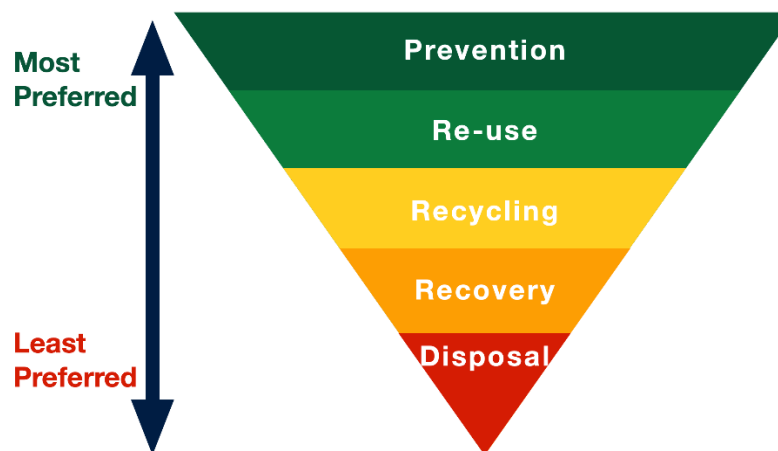
often results in partial loss of material quality. Below recycling, energy recovery converts waste into usable energy through processes such as incineration or anaerobic digestion. Although this reduces waste volume and recovers some value, it does not preserve materials in their original form. At the lowest level, disposal, typically through landfilling or uncontrolled incineration, represents the final loss of material value and is associated with significant environmental risks, including land occupation, emissions, and potential soil and groundwater contamination. This hierarchical structure remains a central reference point in both European and global waste policy frameworks .

Building upon this foundation, the circular economy introduces a more comprehensive and systemic approach to resource management. While the traditional hierarchy emphasizes prioritization, circular economy frameworks expand the range of strategies available for maintaining material value. In particular, the concept of the “10 Rs” provides a more granular classification of circular interventions, reflecting different stages and intensities of resource retention.

At the highest level of circularity, strategies such as refuse and rethink aim to eliminate or fundamentally transform material use. Refusing unnecessary products or materials—such as single-use plastics—directly reduces resource extraction and waste generation. Rethinking product use, for example through sharing platforms or product-as-a-service models, increases the utilization rate of existing goods and reduces overall demand. Reduce focuses on improving efficiency in production and consumption, minimizing material input per unit of service.

Subsequent strategies, including reuse, repair, and refurbish, aim to extend product lifespans and slow down material flows. These approaches preserve the highest possible value of products by maintaining their original function. Remanufacturing and repurposing further extend material utility by incorporating components into new products, either with the same or a different function. Only at later stages do strategies such as recycling and recovery come into play. Recycling reprocesses materials into new raw inputs, although often with some degree of quality degradation, while recovery extracts energy from waste streams. As highlighted in circular economy literature, these latter strategies represent “outer loops,” which are less efficient in retaining value compared to inner-loop strategies such as reuse and repair .

To better understand how different waste management strategies are prioritized, the waste hierarchy provides a structured framework that ranks options according to their environmental impact (Figure 1).



As illustrated in Figure 1, strategies at the top of the hierarchy—such as prevention and reuse—retain the highest material value and should be prioritized over lower-level options such as recycling, recovery, and disposal.

A key insight of this expanded framework is the distinction between slowing and closing resource loops. Slowing loops refers to extending the duration of product use through maintenance, repair, and reuse, thereby reducing the frequency of resource input. Closing loops refers to returning materials back into production cycles through recycling. Circular economy strategies prioritize slowing loops wherever possible, as this preserves more of the embedded energy, labor, and material value.

An additional conceptual advancement within circular economy theory is the differentiation between biological and technical material cycles, which has been widely disseminated through models such as the “butterfly diagram.” This distinction recognizes that not all materials can or should be managed in the same way.

Biological cycles consist of renewable and biodegradable materials, such as food waste, natural fibers, and biomass. These materials can be safely returned to the biosphere through processes such as composting or anaerobic digestion, thereby contributing to the regeneration of natural systems, including soil fertility and ecosystem health. In circular systems, biological materials are ideally cascaded through multiple uses before being returned to the environment, maximizing their value at each stage.

In contrast, technical cycles involve finite, non-biodegradable materials such as metals, plastics, and synthetic compounds. These materials cannot be safely reintegrated into natural systems and must therefore be managed within closed industrial loops. Circular strategies for technical materials prioritize reuse, repair, remanufacturing, and, ultimately, recycling. Maintaining these materials within controlled cycles is essential to prevent environmental contamination and reduce reliance on virgin resource extraction.

Together, the waste hierarchy and circular economy frameworks provide a comprehensive basis for decision-making in waste and resource management. While the hierarchy establishes a clear order of preferred actions, circular economy principles expand the scope of intervention, emphasizing system redesign, value retention, and the regeneration of natural systems. By integrating these approaches with analytical tools such as Material Flow Analysis, decision-makers are better equipped to develop effective, evidence-based strategies for transitioning from linear waste management systems to circular material economies.

#### *Informal waste systems in developing regions.*

Theoretical frameworks like the Waste Hierarchy and MFA often assume the existence of highly formalized, state-regulated waste management infrastructures. However, in many developing countries and transition economies, the reality of solid waste streams is deeply intertwined with the informal sector.

**The Role of the Informal Sector.** In low- and middle-income countries, municipal waste collection is often incomplete, and formal recycling infrastructure is scarce. Instead, a vast network of informal waste workers—often referred to as waste-pickers or scavengers—perform the critical task of resource recovery. These individuals manually sort through mixed municipal waste at collection points, street bins, and open dump sites, recovering recyclable materials such as PET plastics, aluminum cans, glass, and cardboard.

For example, in Tepito (Mexico City) or the historically significant Jardim Gramacho landfill in Brazil, the informal economy has been the primary engine for urban recycling. Waste-pickers segregate materials and sell them to intermediary aggregators, feeding secondary raw materials back into the global industrial supply chain. In doing so, they provide a massive, subsidized environmental service: diverting millions of tonnes of waste from landfills, extending the life of disposal sites, and reducing greenhouse gas emissions.

**Social Impacts and Vulnerabilities.** While the informal sector contributes significantly to circularity, it poses severe social and health challenges. Informal workers operate in hazardous conditions, exposed to toxic substances, medical waste, and pathogens without adequate protective equipment. Their work is highly stigmatized, and they frequently suffer from social marginalization and extreme poverty.

The social impacts of waste management are profound. When municipalities modernize their systems—for instance, by closing open dumps to build sanitary landfills or waste-to-energy incinerators—they often displace thousands of informal workers, destroying their livelihoods overnight. Therefore, a "just transition" to a formal circular economy must address these social impacts.

#### **Integration Strategies.**

For regions developing new Circular Economy Action Plans (CEAPs), such as countries in Central Asia, recognizing and integrating the informal sector is a prerequisite for success. Effective integration strategies include:

1. Formalization and Cooperatives: Organizing waste-pickers into legal cooperatives or micro-enterprises. This allows them to bid for municipal collection contracts, providing them with legal recognition, stable incomes, and social protections.
2. Capacity Building: Providing training and equipment to informal workers so they can operate safely and efficiently at decentralized Material Recovery Facilities (MRFs).
3. Extended Producer Responsibility (EPR): Designing EPR schemes—where producers pay for the end-of-life management of their packaging—in a way that financially compensates informal workers for the collection of low-value, high-volume plastics.

By bridging the gap between informal resource recovery and formal industrial recycling, transition economies can leapfrog traditional linear waste models and build socially inclusive circular systems.

## 7. CONCLUSIONS

Solid waste streams are complex, dynamic reflections of human economic activity. The linear economy has historically treated these streams as unavoidable nuisances, resulting in the massive depletion of natural capital and severe environmental pollution. However, through the lens of the circular economy, waste is recognized as a mismanaged resource.

By applying rigorous assessment tools like Material Flow Analysis (MFA), we can visualize the exact scale and trajectory of municipal, agricultural, and industrial materials. This visibility is the first step toward intervention. Guided by the expanded Waste Management Hierarchy (the 10 Rs) and the distinct management of biological and technical nutrients, societies can begin to close the loop on material flows.

Crucially, this transition cannot be purely technological. As evidenced by the informal waste systems prevalent in transition and developing economies, resource recovery is deeply tied to human livelihoods and social structures. An effective, modern circular economy must be socially inclusive, recognizing the value of informal labor while upgrading infrastructure. For regions like Central Asia, mastering the management of these solid waste streams is not merely an environmental obligation; it is an unprecedented opportunity for economic resilience, job creation, and sustainable land management.

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