

Designing Circular Waste Management Strategies: The Case of Organic Waste in Amsterdam

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Urban waste management is one of the most complex and urgent challenges that the society faces. In this paper, an innovative research methodology is proposed, introducing a systemic approach to circular waste management strategy-making. Urban waste management is a complex system that needs to be tackled in a holistic, yet context-specific manner. To produce truly integrative outcomes, this paper provides insight into the system as a whole, its components and the relationships between them, using specific tools, to form the basis for a circular strategy. A toolbox is presented for transforming the current linear and fragmented waste management processes into integrative and circular strategies. The proposed integrative methodology encompassing outline, multipillar mapping, and synthesis can be applied to different locations and waste streams. The concept is subsequently demonstrated through a case study focusing on the municipality of Amsterdam (the Netherlands) and the management of organic waste streams.

Indeed, studies show that we are currently using resources equivalent to 1.5 Earths to support this economy while destroying the natural environment.^[2] Meanwhile, time is running out: the world population and the amount of waste per capita are growing, while resources are becoming scarcer and increasingly difficult to extract. In addition, our society's ability to dispose of the waste produced at such a high rate is coming to an end.^[3] The combination of these factors is affecting the Earth's ecosystems, its climate, and societies.^[4] This linear economic system must be changed.

A promising alternative is the so-called circular economy.^[5–7] In the circular approach, unlimited and renewable resources play a central role, while limited and non-renewable resources are seen as

1. Introduction


Our current linear “produce-use-waste” economic system is unsustainable. It is characterized by losses throughout the whole chain.^[1]

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supporting and are constantly reused and recycled. Materials are used rather than consumed and this is done in a cascading way, preserving their value and complexity as much as possible.^[8] Implementing a circular economy requires a shift in governance, business models, practices, and societal norms^[9,10] as well as the application of system thinking.^[11] It also needs innovative research approaches that enable the tackling of old issues from new viewpoints.^[12]

One of the most complex and urgent issues tied to the current linear system is urban waste management.^[13] The urban waste sector requires systemic changes, which in turn need a conceptual approach that spans multiple perspectives and disciplines.^[14] According to Ng et al.,^[15] undertaking a circular economy approach with systems thinking at its core, results in various economic, environmental, and social benefits in addressing waste problems.

Here we propose an innovative research methodology which, by introducing both these features in waste management strategy-making, facilitates the transition toward a circular approach. We provide a toolbox for transforming current linear and fragmented waste management processes into integrative and circular strategies. This objective is attained in three stages. We first recognize urban waste management as a complex multidimensional system and we outline its boundaries and its core components. We then map these components individually through a multipillar approach, identifying leverage points, relationships, and connection nodes within and between them. Finally, we reintegrate the results from the mapping process through the connection nodes, obtaining a systemic overview of relationships and processes, which serves as a frame for a circular strategy. To this end, we propose a set of guidelines for converting the results of the mapping process into circular

economy business models^[16] that are open and integrative. The subject matter is extremely broad, and one must set boundaries to avoid dispersive and inconclusive results. Thus, we focus in each case on one waste stream and within a specific city of interest. While these boundaries are artificial, created for the purpose of the research and not the system itself,^{[17][18]} the methodology is adaptable to any waste stream and city.

1.1. System Thinking, Systemic Design, and Holistic Diagnosis

Systems thinking is a holistic analysis approach aimed at describing and understanding the intricate network of relations between a components and their patterns of behavior.^[18–20] Many scholars attribute its origin to Bogdanov's Tektology theory^[21] and Von Bertalanffy's^[22] attempt of unifying sciences through the "General System Theory" (GST).^[18,23,24] Since then, such systemic approaches were further developed and refined, gaining attention in several fields. The holism theory, crucial to system thinking,^[24] introduced the notion that the whole is more than the sum of its single parts.^[18,25–27] According to this theory, complex systems present properties that arise from the interrelation between the system's components and with the environment.^[26]

Systemic design is an approach integrating principles and tools of systems thinking and design thinking. It can provide solutions to complex issues in economic, environmental, and social contexts.^[25,28] Systems thinking enable a broader view of the system's interrelations and its embedding context. Design thinking allows for "zooming in," identifying and visualizing systems' leverage points that can be targeted with tangible and effective solutions.^[25,28] According to Ryan,^[28] such an approach encourages innovative solutions to complex problems such as waste management.^[25]

Holistic diagnosis (HD) is a tool of systemic design. It comprises the mapping of the current situation and the quality and quantity of its processes.^[25] HD is used in the first stage of system design as a method of problem definition, before stepping over to the stage of solutions design.^[25,29] According to Battistoni et al.,^[25] this approach has two phases, referring to two different levels of diagnosis. The first phase entails an analysis of the material flows, while the second examines the social and cultural context.^[25]

These three approaches have inspired us in developing the methodology proposed below.

1.2. The Limitations of Current Waste Management Practices

Waste has, typically, a negative connotation. It is usually irrelevant to production processes and only worth its proper management when the exerted (external) pressures exceed the convenience of its disposal.^[18,23] Most waste management approaches are reductionist, treating waste streams, waste sources, and management processes in a fragmented way.^[18,23] This, besides reducing the effectiveness of the whole system, drives the focus on single technologies supported by linear policies that provide for compartmentalized and temporary solutions, often turning themselves into future problems.^[18,23,30–32] Such an approach is unsuitable for handling complexity.^[18,23]

In the last decades, several developed countries have started implementing an integrative waste management. In theory, this holistic approach should connect all the stakeholders, increasing the system's resilience and adaptation.^[18] In practice, however, this theory is rarely applied. Often, the "integrated waste management" ends up simply incorporating the waste hierarchy and involving stakeholders mildly but without proper integration.^[18] According to Wilson,^[33] waste management systems, also in high-income countries, are still far from integrated.^[18] The major limitation of current waste management systems was identified by many as a lack of "systems thinking."^[18,23,31,34]

1.3. Research Objective, Target, and Application

Our objective is to propose an innovative methodology which integrates concepts of system thinking and systemic design to facilitate and support the production of circular waste management strategies. Such methodology is open and flexible, allowing for dynamic development and adaptation to changing contexts. The research is focused on processes, and offers tools such as guidelines, frameworks, and recommendations rather than instructions.

The proposed methodology is targeted to local authorities, policymakers, and stakeholders willing to jointly undergo the transition toward circular waste management. Such a cooperation between all the actors in the waste management sector is crucial for a successful implementation. In addition, the frameworks and guidelines developed here can be useful to other researchers aiming at integrating system thinking and design into their approaches.

The application of the methodology is illustrated with a case study of organic waste management in Amsterdam. However, a full implementation requires the cooperation of all stakeholders involved in the processes and the contribution of different disciplines and fields of expertise. Therefore, we report here only the implementation of the part of the methodology that are within our interdisciplinary competences. An illustrative implementation of the remaining part of the methodology is included in the Supporting Information.

2. Methodology

Our methodology draws upon system thinking, systemic design, and holistic diagnosis approaches, integrating the principles of the circular economy and sustainable waste management. For this, we derive inspiration and insights from two main frameworks.

Systems Thinking Approach to Resource Recovery (STARR): Developed by Ng et al.,^[15] the STARR framework is a systemic approach to resource recovery from waste. It is based on the principles of circular economy,^[8] industrial ecology,^[35] and design for sustainability.^[36] STARR proposes a three-stage analysis:

1. Multilevel system analysis through MFA at the different levels (national, community, organizational, domestic)
2. Scenario creation and comparison
3. Sustainability assessment, evaluating the benefits and impacts of the system designed in the environmental and social dimensions.

Systemic Design for the Circular Economy: This approach, developed by a research group at the Department of Architecture and Design in Politecnico di Torino in collaboration with the ZERI Foundation, promotes a paradigm shift towards the blue economy and the circular economy.^[25] It comprises four steps:

1. HD analysis and visualization of the current scenario, considering material flows and the surrounding context;
2. Using the HD results to identify leverage points, opportunities and challenges in the system.
3. Design of the new system
4. Preliminary assessment of the benefits produced by the new system at environmental, social and economic level.

Waste management is an extremely complex issue, which must be considered in all its activities.^[15,18,23] Thus, in our methodology, we consider all the key and support activities of waste management, from collection to processing. There is no one-size-fits-all solution. Instead, the suitability of a waste management strategy depends on aspects that are specific to its context.^[23,25,37] Sustainable waste management strategies require a comprehensive and interdisciplinary analysis approach providing tools and methods from different domains.^[38–40] To enable an analysis that is both systemic and yet specific we propose an integrative approach, with three main stages: outline, multipillar mapping, and synthesis. The flows and processes of this methodology are visualized through a gigamap that shows all the processes and the relationships between them (see **Figure 1**).

2.1. Outline

The first stage of this methodology consists of outlining boundaries and core components of the system of interest, urban waste management. Outlining a system boundary that best fits the purpose of the research at hand requires mental flexibility and context specificity. We have chosen to set the system's boundaries around one waste stream (to retain its maximum value, each waste stream demands a specific management) and one city (a scale that pertains to homogeneous governance and management). To facilitate this, we recognize our system as the intersection between two larger systems, "waste management (for that specific waste stream)" and the "urban ecosystem" (**Figure 1**). Every system is composed of smaller-scale elements, which we call "components," that in turn are themselves systems composed of smaller units.^[18] Therefore, outlining system boundaries and components reduces the complexity but does not impact the systemic approach. The overall "waste management" supersystem is very complex and presents a myriad of components.^[23] However, for the purpose of this research, it is viewed as the set of practices for the management of the waste stream of interest. To simplify this even more and transform it in a useful component we can extract from it the best practices for our waste stream of interest. Similarly, the "urban ecosystem" presents an intricate structure. According to Pickett et al.,^[41] the urban ecosystem presents four main components: physical complex, built complex, biotic complex, and social complex. Building on this concept but adapting it to the purpose of this methodology, we can reformulate three main

components of this supersystem. These are territory, urban community, and governance (**Figure 2**). Now, by placing in relation the components of one system to the domain of the other system we can extract the components of the intersection "Urban Waste Management System." These are best fitting practices (best waste management practices fitting in the urban environment), relative governance (governance processes relative to waste management), specific territory (urban territorial characteristics relevant to the waste system), and community response (urban community perception of the waste management system).

2.2. Multipillar Mapping

The mapping stage is the core of our methodology and is based on a multipillar approach. In this stage, the components are tackled individually, reducing further the scale of complexity but retaining a systemic approach. Each component is processed with specific tools and with the aim of mapping leverage points, challenges, and opportunities that can work as connection points (nodes) between them for their successive reintegration. **Table 1** shows the mapping pillars, the specific tools and the connecting nodes that the process aims to uncover. The multipillar mapping presents elements of stage 1 of the STARR framework.^[15] It also unifies stage 1 and 2 of the systemic design for the circular economy framework, namely HD and identification of leverage points. The results of the mapping process are visualized through different tools, to simplify the interpretation of complex systems.^[25] This creates a common ground of information, accessible to actors with different backgrounds (common in interdisciplinary research teams).

2.2.1. Current Situation

This pillar maps the system component of relative governance, including all the processes of interaction between and within the different actors involved in the organization/regulation/control of waste management in the city. To map this component, we use a pragmatic bottom-up approach. The specific tool used for this pillar is the material flow analysis (MFA) backed by desk and field research. It allows for mapping the flows of the waste stream of interest through the city, identifying inputs, stocks, and outputs.^[15,25,40] Inputs are represented by the different sources of the waste (e.g., households, commercial activities, or industries). Stocks are represented by all the facilities in which the waste stream is collected, stored, and/or treated (e.g., incineration plants, landfills, and recycling facilities). Finally, outputs are materials or emissions resulting from the processing and transformation of the waste stream in the stocks. The MFA is then visualized using a Sankey diagram, giving a clear and systemic vision of the waste stream's current situation. The Sankey diagram highlights and easily visualizes the biggest waste flows in the city and whether they are treated adequately and sustainably. It also identifies potential losses and inefficiencies in the system. Indeed, the MFA is an effective tool for identifying the limitations and bottlenecks in the current system,^[23] and helps us find the leverage points.^[17] These are current practices, which

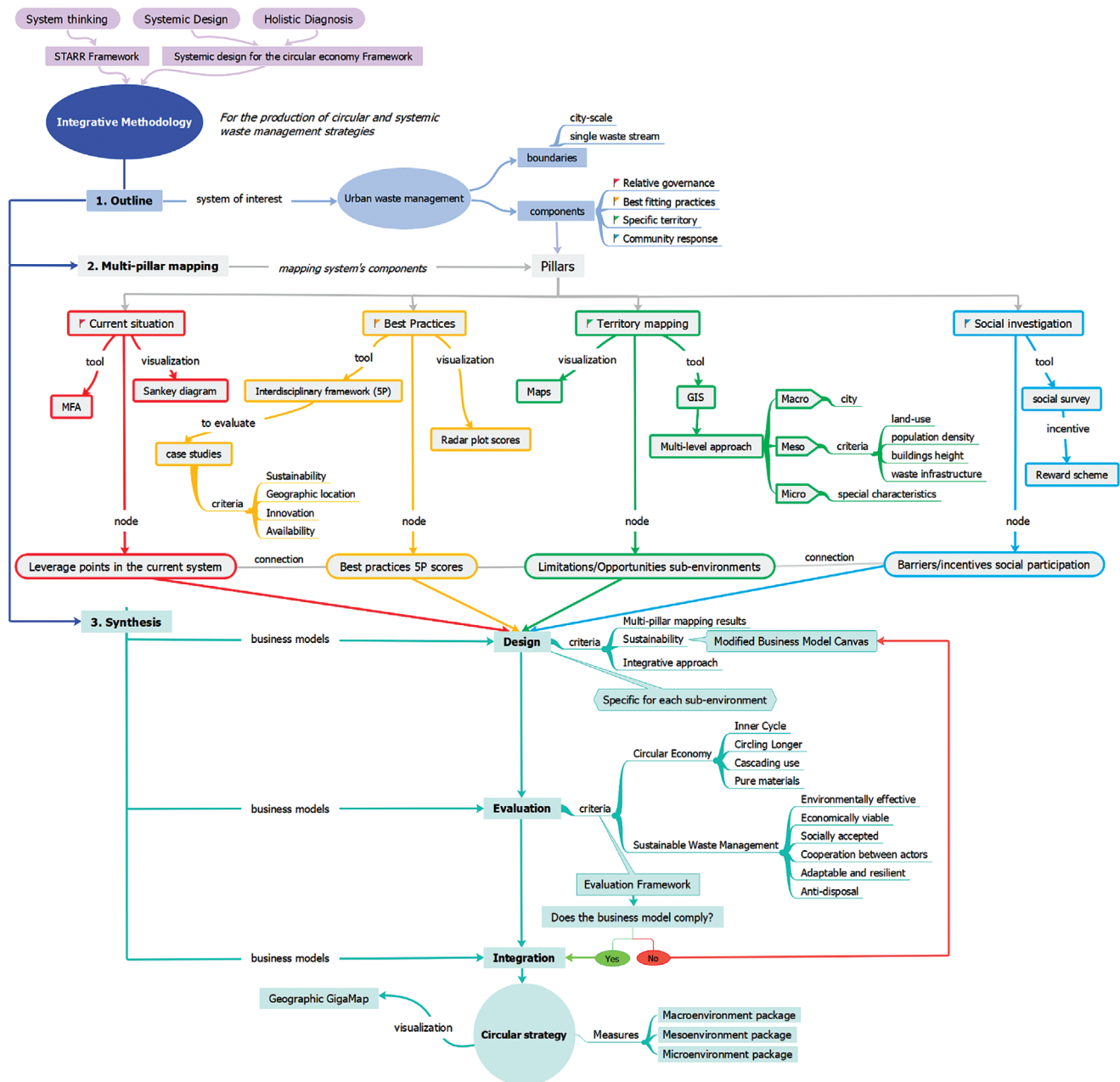


Figure 1. Gigamap visualizing the major workflows, processes, and relationships of our proposed integrative methodology. The color of the boxes indicates their belonging to a particular stage, the color, and the direction of the arrows shows the relationships between elements, and the color of the contours in the multipillar mapping indicates which system component is tackling the specific workflow.

make the system unsustainable and that, if changed, can produce a large impact.^[17] Such points represent the connection node of this mapping pillar since they give information about problems and weaknesses of the current system, and offer an integration opportunity with other analysis pillars.

2.2.2. Best Practices

This pillar covers the system component “best practices” and entails the mapping of the most sustainable and efficient

practices for the management of the waste stream that are already available and around the world. This is done following an integrated approach, which considers all activities of waste management. According to Khan and Samadder,^[42] the main activities of solid waste management are generation of waste, on-site handling, collection, transportation, recycling, and disposal. Within this methodology, we reinterpret these activities disregarding the first (since it is not directly involved in waste management practices although influenced by educative and incentives schemes), and the last, because ideally in a circular economy all waste is diverted from disposal. We then add



Figure 2. Origin and composition of the system of interest: urban waste management.

some support activities, by identifying five waste management activities: collection, monitoring, incentivizing participation, transportation, and processing (including recycling and on-site handling). The practices that we want to include in our strategy are surely sustainable, when possible innovative, but also ready for implementation and adaptable to the target context. Therefore, the best practices for each of these activities are selected following four main criteria: sustainability, geographic location, innovation, and availability. Sustainability means that the practice does not harm the environment and/or society, practices that create environmental and/or social value are preferred. Geographic location indicates that practices implemented in similar environments are more likely to succeed in the city of interest. Innovation means that, all other parameters being comparable, innovative solutions are preferable to traditional ones, because they introduce new methods and features and exploit the latest technological developments. Finally, availability means that the practices chosen need to be already available for and exportable to the city of interest. To this aim, the practices are exposed and analyzed through practical case studies.

All practices identified according to the abovementioned criteria are then evaluated through an interdisciplinary perspectives framework (Table 2). This approach considers five different perspectives (5 P: environmental, economic, logistic, social, and legislative), and allows for a thorough and systemic assessment of each practice's impacts and outcomes. This is an important process that avoids misleading evaluations based on a single viewpoint. The five perspectives were selected following Wilson et al.,^[43] who identified the main factors influencing the municipal solid waste decision-making process. For each perspective, the pros and cons of the practice under investigation are appraised. Each high-impact pro or con counts as +2 or -2, respectively. Similarly, each low-impact pro or con counts as +1 or -1. This gives an overall numerical score for each of the five perspectives. The scores are

then visualized in a radar plot, summarizing the advantages and disadvantages of each practice, which represent the connecting node to the other pillars. Scores can have positive or negative values, reflecting the practice's impact within a particular perspective. They can also have a neutral value (zero) when their positive and negative impacts cancel each other out.

2.2.3. Territorial Mapping






This third pillar maps the system component "specific territory" and studies the region of interest using a multilevel approach inspired by the first stage of the STARR framework.^[15] Here, we identify three levels of complexity, cascading from the most to the least complex: macro-, meso-, and microenvironments. The macroenvironment encompasses the city itself, while the meso and microenvironments are subsections of the macrolevel, corresponding to specific characteristics that are relevant for a waste management strategy. The tool used in this pillar is the geographic information system (GIS), fed with data possibly coming from municipal databases or other official databases. GIS allows us to map the territory of interest according to the characteristics of its environments. This enables the identification of challenges and opportunities at each level, which will constitute the connecting node with the other system's components. The results are visualized under the form of GIS maps.

Macroenvironment: The macroenvironment is the total area of the city of interest. The boundaries of the city correspond to the boundaries of the system under investigation. Every city is influenced by the higher-level context in which it is embedded, such as national regulations, international laws, and agreements. While we acknowledge these external influences, we use the city scale as the highest scale of the territorial mapping, as this is the area of intervention.

Table 1. Multipillar mapping.

Pillar	Multipillar mapping			
	Current situation	Best practices	Territorial analysis	Social analysis
System component	Relative governance	Best fitting practices	Specific territory	Community response
Specific mapping tools	- MFA	- Case studies - Interdisciplinary framework	- Multilevel approach - GIS	- Questionnaire - Reward scheme
Connection nodes	Leverage points	Interdisciplinary framework score	Subenvironments	Social incentives and barriers

Table 2. Interdisciplinary perspective framework. Icons used with permission.^[44]

S P	Perspective description
	Environmental perspective Evaluation of the practice's impact on the environment (CO ₂ emission, pollution, nutrient recycling)
	Economic perspective Evaluation of the economic feasibility of the practice (investment, maintenance costs, valuable output)
	Logistic perspective Analysis of the logistic implication of the practice (transportation, storage, area required)
	Social perspective Analysis of the potential impact of the practice on the society (acceptance, refusal, participation)
	Legislative perspective Evaluation of the implementation feasibility of the practice according to current legislation

Mesoenvironments: The mesoenvironments are identified by investigating and comparing specific features of the macroenvironment, namely population density, land use, building heights, and waste infrastructure. These features were selected because they are relevant to any waste management strategy. Population density is strictly related to the quantity of residential waste.^[45] Land use indicates the type of waste produced in the different areas. Building height is a relevant spatial characteristic since taller residential buildings produce a larger amount of waste per area unit. Finally, mapping the existing waste infrastructure is particularly important for purposes of conversion and adaptation to the current system when possible. According to these characteristics, we subdivide the macroenvironment in different functional mesoenvironments. Each mesoenvironment is then individually mapped, identifying the major opportunities and limitations connected to that specific area. With this information, it is possible to couple each mesoenvironment to a specific waste management approach.

Microenvironments: These are specific activities within the mesoenvironments that deserve special attention. These activities present particular challenges or opportunities, which cannot be properly represented at the mesoscale. The specificity of these areas can be related to the quantity or quality of the waste stream and/or the social or economic potential of some activities.

2.2.4. Social Investigation

We consider source-separation a prerequisite to any sustainable waste management strategy. The last pillar thus covers the system component “community response” and maps the social engagement toward the waste stream of interest. Social acceptance is a key factor in the success of any waste management strategy.^[18,30,46] The repetition social investigation relies on data about the major barrier and incentives perceived by city-level actors with regard to waste separation. To collect the data, we set up a survey that covers three main points:

respondent's interest and opinion about the waste stream of interest (is it valuable, is it important?); respondent's engagement with waste separation in general; factors perceived as barriers or incentives for the separation of that waste stream. The survey also includes demographic questions, to gain insights into the respondents' sample composition. To be significant, this sample must be both large and diverse. Considering an acceptable error of 5%, a distribution of 50%, and a confidence level of 95%, we suggest minimum sample of 385 respondents (to be then adjusted according to the population of the city of interest). In addition, the sample should be diverse to realistically represent the city, therefore respondents should be distributed throughout the territory, be of various age ranges and living in different housing solutions. For this purpose, both digital and non-digital promotional strategies should be used, and a rewarding mechanism could be adopted, to foster a wider participation, also among actors who are not familiar with the waste management issue.

2.3. Synthesis

This last stage involves the actual strategy-making through the synthesis of the results obtained in the multipillars mapping. Here, the connection nodes between system components that have been uncovered are used as interlocking points to reintegrate them together. This is done in three steps: circular business model design, evaluation, and integration. The synthesis stage presents elements inspired by the phases 3 and 4 of the systemic design for circular economy framework,^[25] design and preliminary assessment of the new system and by the stage 3 of the STARR framework,^[15] sustainability assessment. We indeed provide in this stage tools, guidelines, and recommendation for the design of a strategy for the transition to a new system and its evaluation according to the principles that we want to see integrated in it.

2.3.1. Circular Business Models Design

The first step is the design of innovative “circular business models,”^[16] which will be the building block for the strategy. Such circular business models (CBM) are “open,” inclusive and integrative.^[47] We propose using a specific business model for each subenvironment identified in the mapping process, connecting the nodes uncovered from the other mapping' pillars to that specific territory. The business models are designed following these criteria.

Integrated Approach: Each business model encompasses the whole system of activities^[48] performed by the entire network of actors involved in waste management. These include key activities (i.e., waste collection, transportation, and processing), supporting activities (i.e., incentivizing methods and monitoring), and related activities, which allow to close the loop and make the business model as circular as possible.

Sustainability: The business models create not only economic value but also environmental and social value.

Multipillar Mapping Results: The business models address the leverage points uncovered in the current situation, include a

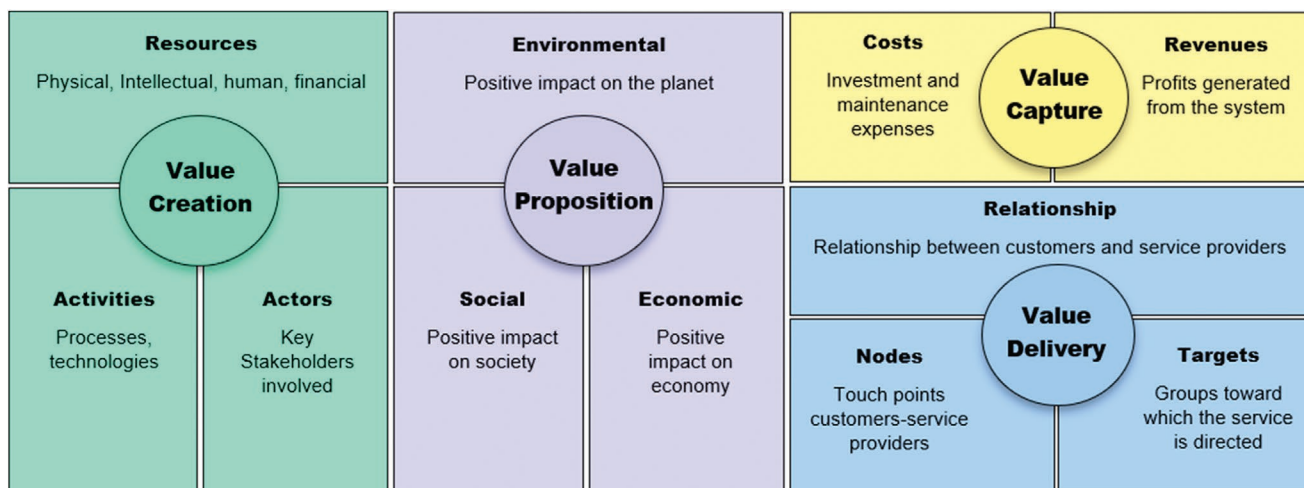


Figure 3. Sustainable business model canvas proposed as a template for the production of business models resulting from the multi-pillar approach methodology adapted from ref. [49] and developed from ref. [50].

combination of the best practices identified, take into account the territorial characteristic mapped for each subenvironment and the result of the social investigation.

Building on Bocken et al.'s,^[49] which in turn reinterpreted Osterwalder and Pigneur,^[50] we propose the following modified business model canvas shown in **Figure 3** as a guiding and visualizing tool for these models. This business model canvas includes four main elements, i.e., value proposition, value creation, value delivery, and value capture, each one comprising a set of components. The value proposition consists of the products and services offered “and the value embedded in them.”^[51] Within the value proposition, we replace Bocken et al.'s,^[49] “profit” component, which indicates a more narrow view of value in terms of “financial return,” with “economic,” to reflect a systemic perspective and embrace the entire positive impact created by the business model in the economy. The value creation includes the whole infrastructure of resources, activities, and relationships that the focal actors have to provide and manage to create value for the customers,^[51] the society, the environment, and the economy. While Osterwalder and Pigneur,^[50] in their business model canvas, conceptualize the relationship with other actors for value creation as “partnerships,” we prefer to adopt Bocken et al.'s,^[49] “key stakeholders” construct, to capture the multiple types of actors, relationships, and influences, which are crucial for the circular business model to create value. However, differently from Bocken et al.,^[49] and stemming from Zott and Amit's^[48] conceptualization of business model as “activity system,” we added the label “actors,” to convey more effectively the active role played by those external parties in the business model. The value delivery describes the targeted customer segments and how the relationships with them “are structured and managed.”^[52] While Bocken et al.,^[49] include the “channel” component in the value delivery, we conceptualize this component as “nodes,” as we consider this construct to be more representative of the multiple types of points of contact that may be established with customers to deliver value. Finally, the value capture element represents the financial model, i.e., the costs and investments

needed and “how to earn revenues (i.e., capture value) from the provision of good, services or information to users and customers.”^[53]

2.3.2. Evaluation

In the second step of the synthesis stage, we assess the benefits of the new system at the environmental, economic, and social level.^[15,25] In addition, we evaluate the fitness of the business models proposed in an integrative and circular strategy, whose production is the objective of such methodology. This is done using an evaluation framework (**Table 3**). This allows us to assess whether the focal waste stream is managed according to the key circularity elements identified by the Ellen MacArthur Foundation.^[8] It also evaluates the overall sustainability of the business models according to the integrative and sustainable waste management (SWM) concept adapted from Morrissey and Browne^[46] and Seadon.^[23] If the business models proposed comply with the evaluation framework, you can proceed to the next step of the synthesis. Otherwise, you must return to the design step and adjust them.










2.3.3. Integration

Once the business models have been evaluated to satisfaction, we can integrate them for the different subenvironments into a city-wide strategy for the whole city. To do so, we recommend using three packages of measures, one for each territorial level identified in the mapping stage.

Macroenvironment package: set of measures to implement at the city level, setting the conditions and the context for a successful implementation of the business models proposed for the different sub-environments.

Mesoenvironment package: set of business models defining measures proposed for each of the mesoenvironments identified in the mapping process and tailored to their particular characteristics.

Table 3. Evaluation framework proposed for the assessment of the business models produced through the methodology proposed above, built upon concepts presented by the Ellen MacArthur Foundation;^[8] Morrissey & Browne^[46] and Seadon.^[23] Icons reproduced with permission.^[44]

Key elements	Description	Presence in the BM			
		Y	N	Comments	
Circular economy approach					
	Inner cycle	The waste stream always enters the smaller and more local cycle so that the most value is retained.			In which way these elements are present in the BM or why are they missing.
	Circling longer	The waste stream is retained in the cycle as long as possible and recycled as much as possible.			
	Cascading use	The reuse of the waste stream is diversified across the chain according to its value.			
	Pure materials	Contact of the waste stream with toxic and contaminants substances is avoided as much as possible.			
Sustainable waste management					
	Environmental effectiveness	The BM does not harm the environment and possibly it is beneficial to it.			In which way these characteristics are present in the BM or why are they missing.
	Economic viability	The BM does not require extreme expenses which might not be possible to sustain.			
	Social acceptance	The practices proposed in the BM are acceptable by society.			
	Actors cooperation	The different actors involved in the various BM activities collaborate in an integrated approach.			
	Adaptability	The BM is adaptable and resilient to changes.			
	Antidisposal	The BM diverts waste from disposal.			

Microenvironment package: set of business models defining measures proposed for each of the microenvironments identified in the mapping process and tailored to their particular characteristics.

We also recommend the visualization of the strategy through a “geographic gigamap,” showing the flows of the waste stream of interest within and through the different levels according to the business models.

3. Results

Case Study: Organic Waste in Amsterdam: Amsterdam is the capital of the Netherlands, a city spread over nearly 220 km² and home to more than 800 000 people.^[54] The city council is highly committed to sustainability and aims to be a pioneer in circularity. Indeed, it set some ambitious targets in its sustainability agenda, such as separating 65% of waste by 2020 and becoming completely circular in 2050.^[55] However, at the moment it is still far from these goals. The recycling rate is under 30% and many waste flows in the city are linear and unsustainable.^[56] This is especially true for organic waste, which currently is not separated, but just incinerated with residual waste. Through this process, all nutrients and precious organic waste’s components are lost and exit the biological cycle. Moreover, biowaste

typically has a high water content, so burning it is energetically ineffective. Organic waste represents over 35% of the municipal waste in the city,^[56] and its proper management would enable the recovery of a substantial fraction of waste. In addition, proper organic waste treatment would allow for the production of renewable energy and the creation of valuable materials^[57] out of a waste stream that is currently used at its lowest value. The large room for improvement offered by organic waste management in Amsterdam makes it particularly interesting. Proper management of this waste stream can play a fundamental role in improving the overall circularity of the city.^[58] However, the introduction of another separately managed waste stream raises various issues and calls for a significant change in the current waste management system. In this case study, we develop only the second stage of the methodology, as the first stage is the same for any waste management strategy and the third stage, the actual strategy-making process, is beyond the scope of this paper. Indeed, as specified in the introduction, our aim is to provide a set of tools and recommendations to guide local authorities, researchers, and policy-makers in developing circular waste management strategies. A full implementation of the methodology requires far more resources (our interpretation and realization of the synthesis stage for the case study is available in the Supporting Information).

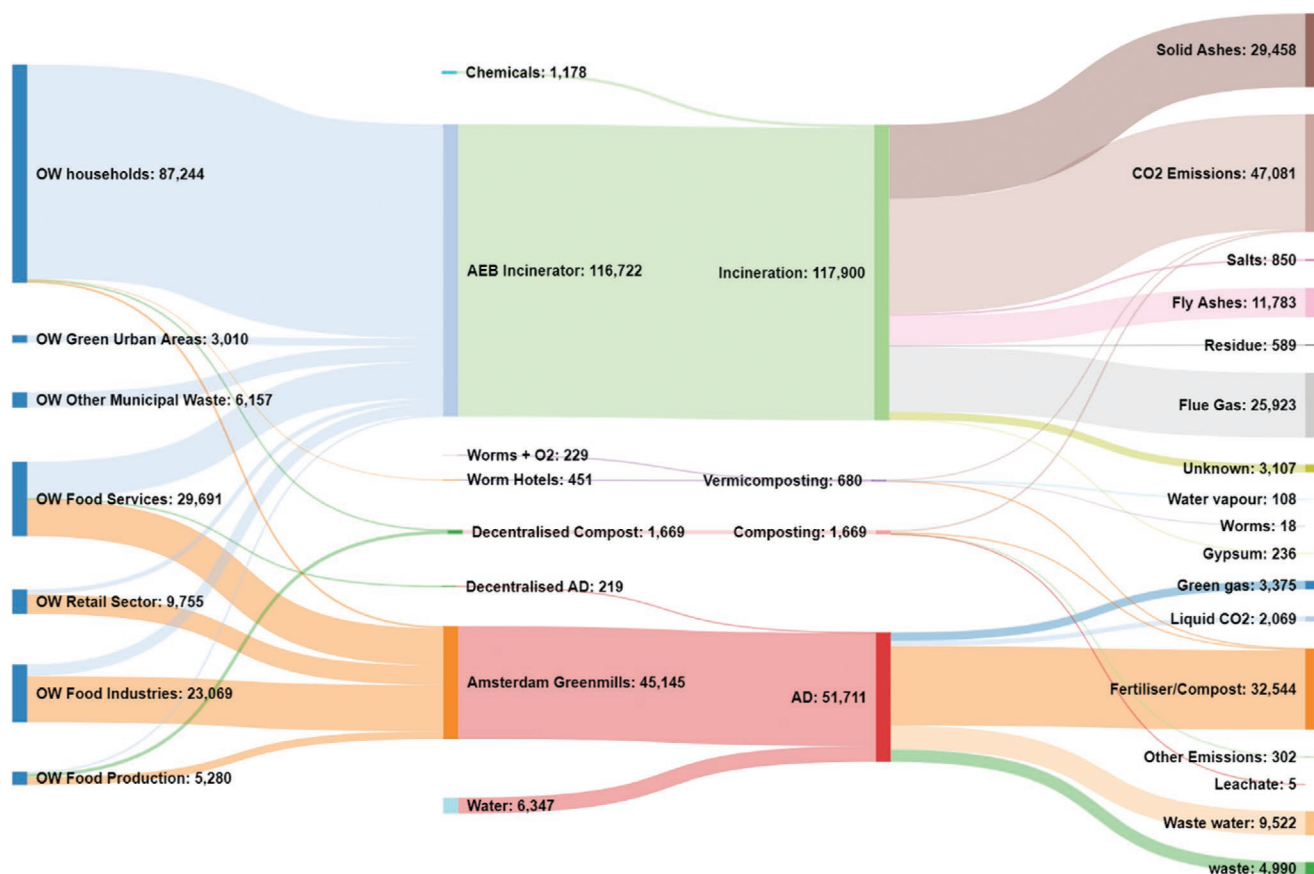


Figure 4. Material flow analysis (MFA) for organic waste in Amsterdam visualized through a Sankey diagram. All flows are in t/year.

3.1. Multipillar Mapping

3.1.1. Current Situation

The data for the material flow analysis (MFA, **Figure 4**) were collected through a combined top-down and bottom-up approach mixing desk research, field studies, and interviews. Unfortunately, obtaining data on waste production and management is difficult, particularly when it concerns commercial or industrial activities (a limit encountered also by Battistoni et al.,^[25]). Commercial and industrial waste is managed by various private companies, and the data are fragmented and discontinuous. Moreover, all the parties involved, from the waste producers to waste collectors and processors are reluctant to share data, as this may not be in their commercial interest. The MFA in **Figure 4** summarises the flows of organic waste in the city (t/year), their sources, how they are treated and what these treatments produce in the process.

Our analysis shows that households are the largest source of organic waste in the city and incineration is the most used treatment for this waste stream. The system is very centralized, decentralization is still an immature concept. Only a small share of the organic waste produced in the city is recycled to produce fertilizer. The biggest outcomes of the process are emissions (of CO₂ and flue gases) and ashes (solid and fly), all produced by the incineration process and all to be considered waste products. All the data collected and used in this analysis

with the relative sources and references, as well as a more detailed interpretation of the analysis, are available in the Supporting Information. Based on the MFA and on information gathered for its production, we can identify five leverage points in the current management of organic waste in Amsterdam.

Mixed Collection with Residual Waste: The majority of the organic waste produced in the city, especially from households, is not separately collected and ends up in residual waste. This contaminates organic waste and makes it unrecoverable. Indeed, the diagram shows that practically all household organic waste goes to the incineration plant which is the typical destination of mixed waste.

Incineration: By observing the MFA, it is clear that most of the organic waste produced in the city is incinerated. This is not a suitable treatment for this kind of waste since, although energy and heat are produced, it does not allow for the recycling of nutrients and other organic waste components. Therefore, this treatment hampers the closure of the biological cycle in the city and it is not compatible with a circular strategy. Moreover, we see that incineration requires the addition of chemicals in the process and produces emissions, flue gasses, and ashes, which must be disposed of afterwards. Finally, organic waste is a typically “wet” waste, and therefore far from ideal as incineration feed.

Fragmentation Management System: The data collected for the MFA showed that organic waste collection and processing is scattered among many different actors (public and private)

and different sources (commercial, domestic, industrial) also in areas where it would be much more efficient to have a joint collection. Moreover, there is a significant fragmentation and logistics inefficiency among the different collectors. Amsterdam's urban texture is very dense and interlinked, but this is not reflected at all in the waste management approach.

Lack of Transparency: This was deduced from the extreme difficulty encountered during the data collection for the production of this MFA. Most waste management companies deny access to information, with many claiming to be unaware of the precise quantity, composition, or provenience of the waste that they produce, collect or treat. The same attitude and ambiguity are also often found among commercial and industrial waste producers.

Lack of Informative and Educative Campaigns: There is a lack of clear information regarding waste separation in general in the city. During the interviews carried on for the production of the MFA we found that most residents are confused about the waste stream destination of several goods and about the location of the dedicated bring-points for recyclables.

3.1.2. Best Practices

The data for the mapping of this component were collected through a literature review, web research, and interviews aimed at understanding, which are the most sustainable and successful practices for organic waste management worldwide. Best practices were selected based on the criteria explained above, covering all phases of waste management. **Table 4** shows

Table 4. Best practices in organic waste management selected for the case study.

Activity	Practice	Case study
Collection	Door-to-door	Milan
	Smart bring-points	Ecobin
	Smart return logistic	Woolworths' Foodbank, Coles Myer
Transportation	Electric boat	Mokum Mariteam
	Electric vehicles	Groen Collect
	Green gas vehicles	Meerlanden
Incentivizing tools	Education and information	Milan, Västerås, London
	Different taxation	Västerås
	Reward scheme	WASTED
Monitoring	Coded bags or containers	Milan, Australia
	Fining system for offenders	Milan, Västerås,
	Centralized AD	Meerlanden
	Decentralized AD	The waste transformers
Processing treatments	Decentralized composting	Ecocreation
	Vermicomposting	Worm Hotels in Amsterdam
	Household-scale solutions	Compostgilde
	Pyrolysis	Bioforcetech
	Biobased Industry	Protix, Eggbrane, PeelPioneer, ChainCraft, Renewi

the practices resulting from the mapping process as potential solutions to organic waste management in Amsterdam. We then evaluated and graded these practices following the interdisciplinary framework. The resulting scores are shown in the radar plots in **Figure 5** (see the Supporting Information for the detailed tables with the pros and cons for each practice). These plots provide an immediate and comprehensive overview on the strengths and weaknesses of each practice evaluated according to the different perspectives. Table 4 shows the list of best practices selected for the Amsterdam case study.

3.1.3. Territorial Mapping

We mapped the territory of Amsterdam with respect to four features: population density, building heights, land use, and waste infrastructure (detailed maps are included in the Supporting Information). This was done using the Geographic Information System (GIS) software package and data retrieved from the Amsterdam municipal database. Stemming from these four characteristics, the city was divided into five mesoenvironments (**Figure 6**). The macroenvironment was first divided in its three main functional zones according to land use: industrial, agricultural, and residential. Then, as the residential part is the most extended and diverse area, it was further divided into two subenvironments based on population density and building heights. This resulted in a residential area with a high population density and a residential area with a medium to low population density. A threshold of 6000 inhabitants per km² was set to distinguish the two areas. This value is appropriate, considering that the population density in Amsterdam's neighborhoods can be as high as 32 000 inhabitants per km². Within the residential area with a high population density another subenvironment was identified, due to its very different waste infrastructure distribution: the city center (*het centrum*). Subsequently, each subenvironment was analyzed according to the abovementioned characteristics, identifying its opportunities and limitations. All the maps produced in the analysis of the subenvironments are available in the Supporting Information.

Industrial Area: The industrial area corresponds to the city district of Westpoort, located in the north-western part of Amsterdam. Since the population in this area is close to zero, we can predict that organic waste here is produced mainly by the food production and processing industries. The main opportunities identified for this mesoenvironments are a well-developed road network, port and naval accessibility, high-quality industrial preconsumer waste potential feedstock for high-value processing and upcycling, the concentration of many industries in one site, space available for new waste infrastructures, polluted soil to remediate as the potential destination of organic waste recycling products, and waste processing plants already in place with the potential of being adapted. The main limitations connected to this area are the lack of a resident community to carry on the transition toward a sustainable waste management, the presence of Europe's largest waste-to-energy plant^[59] which currently burns most of the organic waste in the city,^[60] and a lack of waste collection infrastructure.

Agricultural Area: This mesoenvironment is located at the northern part of the east side of the city, as part of the Noord

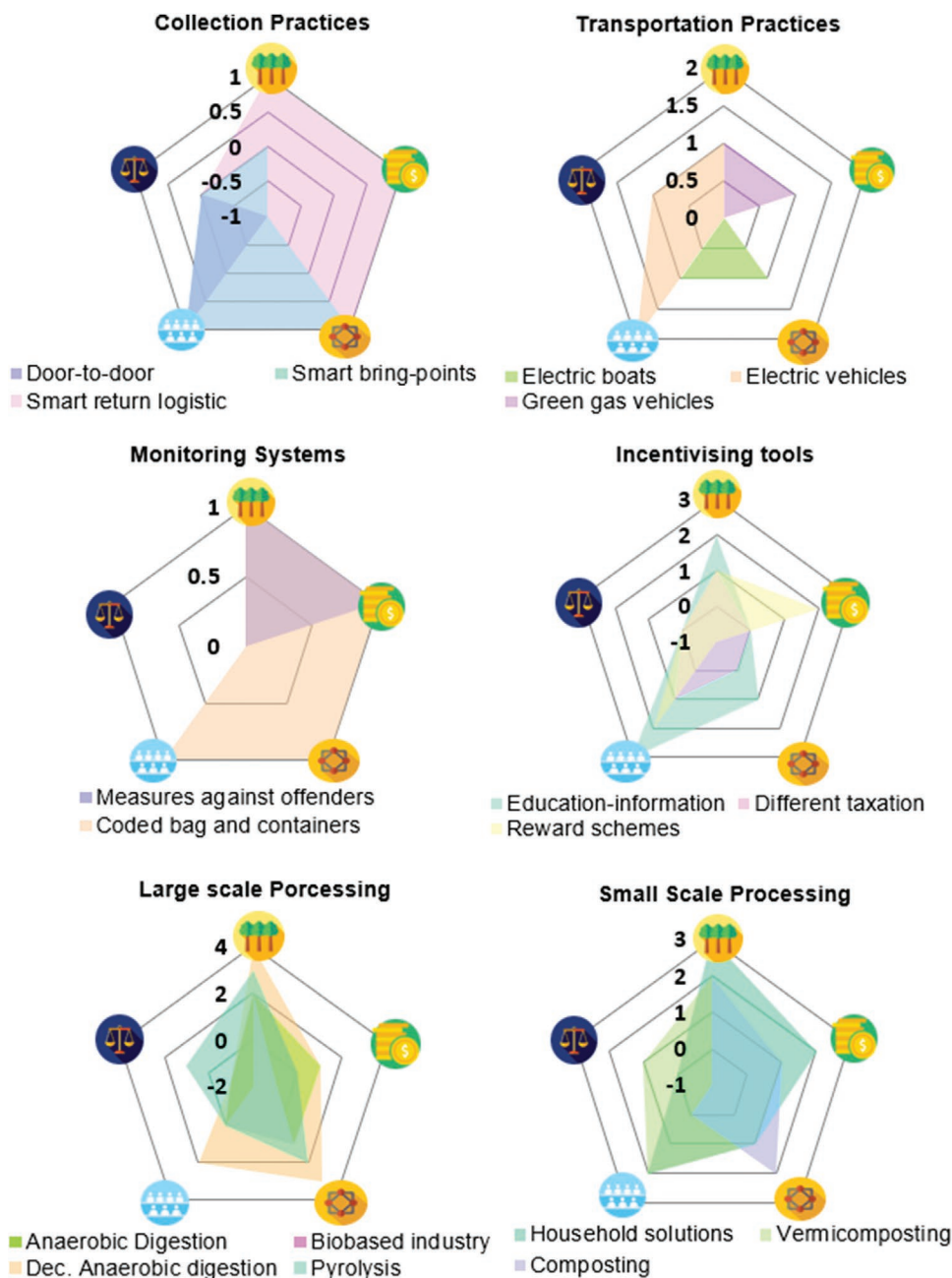


Figure 5. Radar plots for the different practices wherein each of the five axes shows the score of one perspective. Icons retrieved from FlatIcons.com.^[44]

district. As the analysis of this area showed that most of the land is dedicated to agriculture or cattle breeding, we can conclude that most of the organic waste in the area is produced by farmers. This is most likely composed of agricultural residues, animal waste and by-products of meat and cheese production. The main opportunities identified for this mesoenvironment are a large source of preconsumer organic waste, potential naval accessibility, most important destination for organic waste recycling products (compost, organic fertilizer), space available for new waste infrastructure, and the few houses in the area have almost all large outdoor space suitable for decentralized solutions. The main limitations connected to this area are an

underdeveloped road network; potential resistance of farmers in using organic waste recycling products, lack of waste collection infrastructure, a large quantity of manure to be managed, and dispersion of the sources of waste throughout the area.

Residential Areas with Medium to Low Population Density: The urban texture of this area is typical of suburbs. Infrastructure is well developed, and the population is either concentrated in high-rise buildings or dispersed; industries and commercial activities are frequent and in large size; and there are green areas and not-yet developed urban spaces. From analyzing this mesozone, we can assume that the organic waste produced here is a mix of household, industrial, and business waste

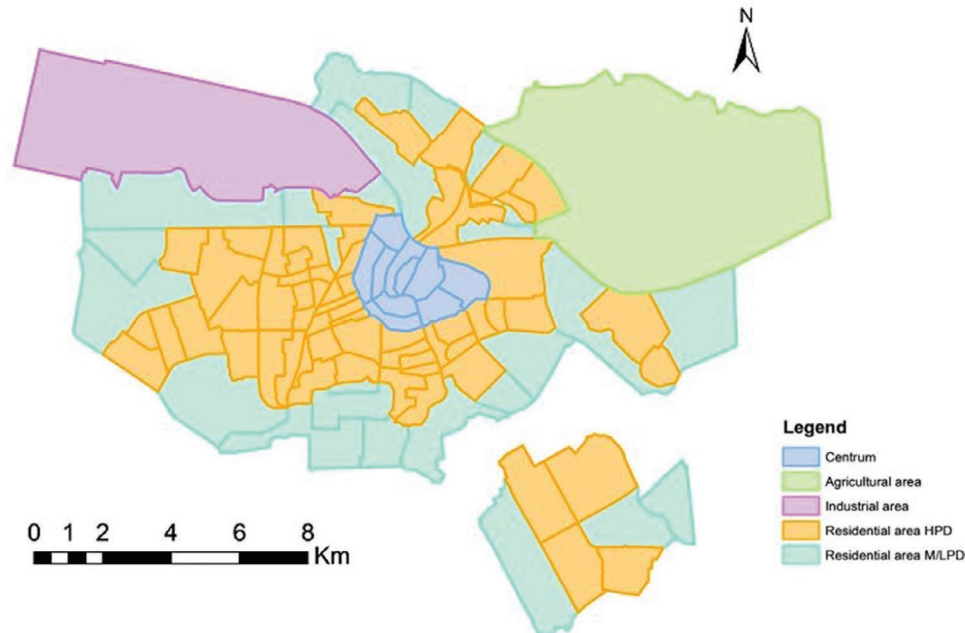


Figure 6. The five mesoenvironments in Amsterdam (detailed maps of population density, building heights, land use and waste infrastructure are included in the Supporting Information).

plus green areas residues. The major opportunities identified in this area are well-developed main-road networks and waste collection infrastructures, many green areas, or urban farming locations as potential destinations of organic waste recycling products, modern buildings with large indoor and outdoor space, almost no tourists (besides business-related ones), and mainly long-term residents. The main limitations in this area are mixed land use and functionality texture, high-rise buildings clusters, weak sense of community in both high-rise buildings^[61] and single houses since fewer social relations are likely in such housing forms, lack of waste infrastructure for businesses and offices, likelihood that secondary roads are less developed and accessible, and dispersed houses which increase travelling distance for waste collection.

Residential Areas with High Population Density: Most of this area is residential, with many small commercial activities, business and industrial areas are very limited, and there are green areas. Our analysis shows that most of the organic waste in this mesozone is produced by households and to a lesser extent by food services, retailers, and office buildings. The main opportunities of this mesoenvironment are well-developed road networks and waste collection infrastructures, residential neighborhoods with a well-developed sense of community, some green areas as a destination of organic waste recycling products, some outdoor space, and mainly low-medium-rise buildings. The main limitations found in this case are extremely high population density, limited underground space for new bring-points and excavation works which create strong inconveniences, pests (e.g., rats), repetition, can be erased a large hospitality sector and many food retailers.

The City Center (het centrum): The Amsterdam city center present peculiar characteristics, it is a residential area but it is

also the center of tourism and shopping. There is a high concentration of retailers and hospitality sector services, many businesses, and offices but a lack of green spaces. The analysis of this mesozone suggests that organic waste is produced mainly by food services, the hospitality sector, and households. The major opportunities identified in this area are a well-developed canal network potentially connected to the industrial and agricultural areas, a high concentration of food services and retailers, mostly low-rise buildings, and there is a door-to-door waste collection scheme already in place. The main limitations are reduced road surface, connections, and accessibility, large numbers of tourists, small indoor and outdoor spaces, limited waste infrastructures in place and limited underground space for new bring-points, high population density, pests, and very limited green areas.

The smallest scale of the territorial mapping consists of the microenvironments: specific activities that deserve special attention. The microenvironments identified for the city of Amsterdam are:

- Supermarkets, because of their extremely high concentration in the city, their large production of preconsumer organic waste and their great potential in reverse-logistics and food rescue schemes. ^[9,62]
- Street markets, because of their high concentration in the city and their production of a large quantity of organic waste daily on one site.
- University campuses, because they are small “villages” hosting daily thousands of students and employees and producing large quantities of organic waste in one site. They also offer the potential of getting to a share of the population (the students) usually hard to reach as far as organic waste is concerned.

- Schools, because they have a high potential in the education process and in the amplification of the impact. Indeed, kids are likely to bring home the lessons they learn at school and trigger their parents to change their behavior toward organic waste.
- Festivals, because they are a kind of closed systems and therefore can be used as a testing ground for implementing circular strategies at a small scale.^[63] In addition, they can have a positive influence and inspire visitors in changing behaviors.

Therefore, the mapping process allows us to identify a total of 11 subenvironments in the city of Amsterdam, each requiring a different and targeted approach.

3.1.4. Social Investigation

The social investigation encompassed a survey based on a questionnaire translated both in Dutch and in English. The survey has been open to respondents from July 30th to November 6th 2018. We promoted the questionnaire digitally through a dedicated website, a Facebook page and by sharing it in several digital platforms. As regards the non-digital promotion, 2500 flyers were printed (on recycled paper with eco-ink which makes their further recycling easier) and distributed around the city in different locations. Moreover, to incentivize respondents, we added the possibility of winning some prizes. We collected 660 valid responses, which are considered significant according to our calculation of minimum sample population (385 respondents). The results are summarized in **Table 5**. Overall, the majority of respondents recognize organic waste as a valuable waste stream and state that they would start separating it if given the opportunity (94% and 76%, respectively). However, the questionnaire revealed some bias, since 75% declared that they are already separating waste and 15% said that they separate organic waste even in the absence of centralized services and infrastructure. These figures do not reflect the behavior of the entire population of Amsterdam, thus indicating that the sample is more environmentally conscious than the total population. The survey also shed light on the biggest perceived barriers to organic waste separation, which were the lack of indoor space and of transparency in waste management. Similarly, according to the respondents, the main factors incentivizing waste separation are a convenient and efficient collection infrastructure and the availability of clear information.

4. Discussion

In an ideal circular economy, waste should gradually disappear.^[64] Obviously, waste management alone is insufficient, if other measures are not taken at the top of the event chain (e.g., changing product design practices).^[8] Moreover, this methodology alone does not guarantee a circular strategy. To start with, waste management cannot be circular if the economic system in which is embedded is linear. However, between the current average waste management and a completely circular management there is still much room for improvement.

Our methodology has the objective of facilitating the integration of concepts as circular economy and system thinking into waste management practices. This can help in shifting mind-sets toward approaches that will become prerequisites for the actual transition to happen. In a linear approach to waste management, the system itself and its components are not recognized.^[23] Waste management strategies are driven by cost minimization,^[65] standardized and nonspecific for the city they serve. They are based on moving waste streams outside cities and disposing of them. Conversely, our methodology treats waste management as a system and its components are outlined, mapped and all included in the picture (**Figure 7**). The results of the multipillar mapping set the basis for a circular waste management strategy. Each mapping pillar already encompasses valuable data when considered independently, but it is their integration and combination that enables us to capture the complexity of the issue at stake and thus produce the maximum value. Complex problems often require complex solutions. Our methodology has several points where the scale of complexity is reduced to allow the focus on specific elements, yet the systemic approach is always retained. The complexity is restored by reintegrating the elements together and is enriched by the process, due to the appearance of “emerging characteristics” resulting from the interaction between the system’s components and the environments. The multipillar mapping highlights specific opportunities and limitations inherent to each pillar and uncovering the connecting nodes between them. These nodes then are used to identify the best pattern of integration between the pillars, i.e., the combination of pillars which enables the optimization of the strengths and the minimization of the weaknesses of the system.

In our case study of organic waste in Amsterdam, the results of the first two methodology stages set the basis for transforming the current linear waste management system into an integrative and circular one. These results must be strengthened, refined, and integrated, yet they already uncover the major nodes of connection and highlight the major point of interventions. An interpretation of the synthesis stage for the case study is included in the Supporting Information.

Beside the illustration of our methodology, the case study of organic waste in Amsterdam produced valuable data and results. For instance, through the multipillar mapping we highlighted some serious issues in the current linear organic waste management: Currently, the different system’s components are neither outlined nor interconnected and therefore their function and value are lost. The current management disregards the territorial and social characteristics of the city as well as the flow of its organic waste streams and the potential for their recovery.

5. Limitations of the Present Study

In our view, the main limitation of this methodology is the complexity of the issue that it wants to tackle which forces the setting of boundaries and may lead to oversimplification. We outlined the system boundaries for our methodology around one city and one waste stream. A truly circular and integrative waste management would consider all waste streams within a

Table 5. Summary of the survey questions and results.

General and demographic questions						
Question	Answer	% of respondents				Comments
What is your postcode?	Open	100				Respondents span 72 different postcodes. The sample is considered representative of the whole city.
	<20	1.67				
	20–30	35.30				
	30–40	23.94				
What is your age?	40–50	16.67				The sample is representative of the city population above 20 years old which was the main target
	>50	21.81				
	Not specified	0.61				
	1	26.67				
How many people live in your household?	2	40				The sample is representative of the different housing solutions considering that one-person and two-person apartments are common in Amsterdam.
	3	16.06				
	4	12.42				
	5 or more	4.84				
What is your email? (in order to be eligible for the prizes)	open	84.4				Most people gave their email addresses, showing that prizes were a motivation in completing the questionnaire.
Targeted questions						
Do you think that organic waste is a valuable waste stream?	Yes	93.48				The sample shows a clear engagement towards organic waste which is probably not representative of the entire population.
	Not really	1.97				
	I don't know	4.39				
	Not at all	0.15				
Do you currently separate other waste in your household (plastic, glass, textile, paper)?	Yes, all of them	75.45				The sample shows a clear engagement towards waste separation which is surely not representative of the entire population.
	Only some	21.67				
	No	2.88				
	I already do that	14.54				
Would you like to start separating organic waste?	Yes	76.06				The sample shows a clear engagement towards organic waste separation which is probably not representative of the entire population.
	I don't know	6.36				
	No	3.03				
Some circumstances could create difficulties/ barriers in separating organic waste. Rate the following statements based on your household and opinion.						
I have no space for a separate organic waste bin	38.94	17.88	15	14.54	13.64	The only circumstance that creates a barrier among the proposed ones is the lack of space for another bin.
I have no time to separate organic waste	77.58	16.21	3.94	1.82	0.45	
The separation of organic waste is useless	83.03	9.55	4.39	1.36	1.67	
I do not care about organic waste separation	90.76	4.85	1.67	1.97	0.76	
To what extent would the following propositions motivate you to separate organic waste? 1 = very little, 5 = very much (%)						
A financial reward	17.27	9.55	21.82	19.09	32.27	The most efficient motivating factors are the vicinity of organic waste bins to households and their efficient management. The least effective factor is receiving information about the value of organic waste. Receiving clear information about how to separate organic waste is more motivating.
Receiving information on the value of organic waste	11.6	8.18	23.03	29.85	27.88	
Receiving clear instruction on how you should separate organic waste	5.91	3.64	15	29.09	46.36	
Having organic waste container close to my house	0.91	0.30	3.94	11.67	83.18	
An efficient organic waste collection system (e.g., high frequency collection)	1.67	1.67	6.67	18.94	71.06	
Transparency of the company involved in the management of organic waste	3.79	6.36	18.18	25.45	46.21	

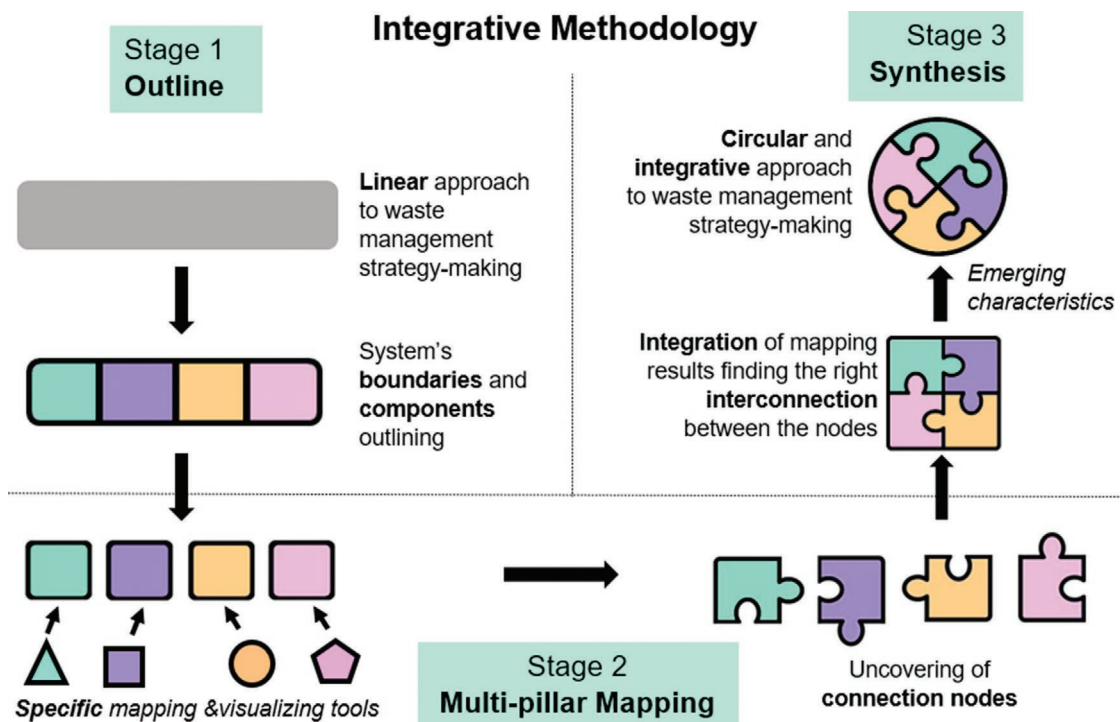


Figure 7. Schematic of the proposed integrative methodology operation.

much larger context than a city and would connect all the processes of the “production chain” instead of focusing on its end. However, we are still far from this ideal and we believe that without scaling down complexity these issues become almost impossible to handle.

In addition, some technical issues can be improved: The score matrix for evaluating best practices considers now only low impact versus high impact, and the perception of impact is subjective. Similarly, the evaluation framework in the integration phase does not give information on how to perform the measurements. While some of the points to be evaluated are easily observable, others, such as the environmental or economic benefit produced by the business models, should be calculated.

In the case study, the main limitation is the partial demonstration of the methodology. Even though the implementation of the synthesis stage of the methodology is available in the Supporting Information, we lack the expertise to consider it as a full demonstration. For the part implemented in the paper, the case study presents two limitations. The first is the lack of data accessibility for the MFA that forced us to make many assumptions (this reflects the murkiness of current waste management, which makes it even more difficult to change). The second pertains to the sample population of respondents to the social survey. Although the sample is significantly large and diverse, the survey exposed some bias given the already high engagement of respondents with recycling in general, which make them more prone to be willing to start separating also organic waste. Nevertheless, the survey provides valuable data on measures perceived as barriers or incentives for separate waste collection.

6. Conclusions and Outlook

We present here a toolbox for circular and integrative waste management strategy-making which is adaptable to every city and waste stream. However, as already said, employing circular practices in the current system is not enough—the entire model needs to be reconfigured. The methodology presented here represents a first step in facilitating this transition toward a new, circular model in the field of waste management. The Amsterdam case study shows how implementing this integrative approach helps to keep a systemic view of the waste management issue throughout the process without overlooking specific results. Examining the issue from different perspectives and through multiple tools allow for developing a thorough mapping process that provides a solid foundation for the design of innovative business models. Such business models, being the outcome of the integration and interconnection between the mapping pillars, are especially designed to incorporate circular activities and a network of multiple actors involved in waste management.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

Conflict of Interest

The authors declare no conflict of interest.

Keywords

circular business model, circular economy, holistic diagnosis, integrative strategy, multipillar mapping, sustainable waste management

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- [60] In July 2019, AEB was forced to halve its incineration operations due to safety reasons. As a result the company (100% owned by the municipality) has incurred in serious financial problems as well

as the waste management in the city. Indeed, local and imported wastes are quickly accumulating. At the time of the writing, the municipality is still looking for a financial and logistical solution to overcome this situation.

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