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RESEARCH ARTICLE OPEN ACCESS

SOLID WASTE GENERATION IN SANTA CLARA, CIRCULAR ECONOMY CHALLENGES AND OPPORTUNITIES.

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ABSTRACT

The municipality of Santa Clara generate high volumes of waste with critical environmental impacts, requiring urgent strategies for reuse and recycling to achieve sustainability. The aim of this work is to implement circular economy indicators that optimize waste management and generate socio-economic benefits. The study characterized the current management system, identifying three major deficiencies: inadequate infrastructure, lack of an appropriate regulatory framework, and insufficient knowledge of circular economy concepts. Therefore, the circular economy indicators we proposed to improve efficiency in the system, reduce final disposal in landfills by 48%, and generate positive environmental and socio-economic impacts.

However, obstacles such as limited funding and low public awareness exist. To overcome these challenges, it we recommended to strengthen collaboration among the government, businesses, universities, and the community; implement educational campaigns; improve infrastructure; promote source separation; and adopt technologies for waste treatment, such as recycling and composting. With these strategies, Santa Clara will be able to transition towards a circular model, maximizing resource use and minimizing its environmental footprint.

I. INTRODUCTION

Inadequate management of municipal solid waste (MSW) poses a serious environmental, social, and economic challenge, affecting public health and the ecosystem. The proliferation of open-air landfills and the lack of sustainable strategies contribute to the contamination of soil, water, and air, generating risks for the population. The implementation of circular economy models and comprehensive management are essential to reduce, reuse, and recycle waste, promoting sustainable development. However, social, institutional, and technological obstacles hinder the transition toward more responsible and inclusive systems, requiring a multidisciplinary and participatory approach.

II. THEORETICAL REFERENCE

The inadequate management of municipal solid waste (MSW) is a significant environmental challenge. Household appliances, plastic containers, glass, cleaning products, and clothing, at the end of their useful life, often end up in landfills, causing soil, air, and water pollution, with adverse effects on public health [1]. Open landfill remains common due to their simplicity and low cost, but they pose a significant risk to environmental safety due to the presence of potentially toxic compounds in MSW [2]. Environmental pollution accelerates ecosystem degradation and affects health, as fine particles can cause respiratory and cardiovascular diseases and physical

damage [3-4-5]. To achieve effective and orderly waste management, it is important to know its type and composition in order to identify it and understand it clearly [6-7]. The design of models, guidelines, and procedures for waste management in Cuba, such as those developed by [8-9], are validated tools that support waste management at the local level. However, at the municipal level, local authorities are responsible for collecting, transporting, and properly disposing of waste generated in households, public and private facilities, as well as waste from construction, demolition, and service activities. Waste generators, for their part, are required to properly transport and dispose of waste generated in households, public and private facilities, as well as waste from construction, demolition, and service activities.

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Thus, in recent years, the focus has been on improving MSW recovery and recycling systems for use as raw materials in different processes, thus contributing to the development of the circular economy and the fulfillment of the Sustainable Development Goals (SDGs), which include among their targets “reducing waste generation through prevention, reduction, recycling, and reuse.” However, the waste hierarchy should be understood as a crosscutting strategy to address several SDGs and promote more sustainable development. Therefore, both formal and informal education are essential for transforming civic culture, promoting the identification of economic opportunities in reuse and recycling, and encouraging the reduction of resource consumption [16-17-18-19]. Qualitative research allows for a deep understanding of the processes and actors involved in solid waste management, as well as the dynamics that influence the implementation of a circular economy model [20].

Finally, the circular economy represents a model of sustainable production and consumption, whose main objective is to minimize the use of raw materials, make the most of existing resources, and recycle or transform waste to give it a new life. This approach seeks to extend the useful life of products, promoting a balance between sustainability and modernization of consumption, understanding that everything has value and can be reused [21]. From the above statements by various authors, it is clear that analyzing the factors that can cause variations in the generation of municipal solid waste (MSW) in a population is essential for implementing efficient management. Without a clear interpretation of the generation data, it is impossible to establish effective policies and strategies for its proper management, which can lead to a greater environmental, social, and economic impact. In addition, the analysis and dissemination of information on generation and collection help to raise awareness among the population about the importance of adopting more sustainable habits, promoting their active participation.

The study analyzes the management of urban solid waste (USW) and proposes the implementation of circular economy indicators as a strategy to transform these wastes into useful resources. It promotes practices such as the use of organic waste for composting and the reuse of materials in production processes. The multidisciplinary approach addresses environmental, sanitary, technical, social, and political aspects. However, it presents significant limitations. It does not sufficiently consider socioeconomic and cultural inequalities that influence waste generation, segregation, and community participation, especially in vulnerable communities. Additionally, institutional and political obstacles such as resistance to change, corruption, and resource scarcity that hinder the implementation of sustainable policies are omitted.

The technological dimension is also limited, without exploring recent innovations that could optimize processes. Economically, there is no in-depth analysis of financial challenges, investments, and necessary incentives. The study prioritizes immediate solutions rather than structural and social changes that ensure sustainability. Finally, it does not adequately address the role of the informal economy and unregulated actors, whose inclusion is key for an inclusive and efficient management. In summary, moving toward sustainable waste management systems requires integrating social inequalities, institutional barriers, technological innovations, economic challenges, and social participation to achieve a more equitable and resilient management. The objective of the study is to implement circular economy indicators as an integral strategy to transform USW into useful resources. The enumerations of citations in the body of the article must be sequenced in the order in which they appear, according to the example shown below.

III. MATERIALS AND METHODS

III.1. CURRENT CONTEXT OF THE MSW MANAGEMENT SYSTEM IN SANTA CLARA

The municipal solid waste (MSW) management system in Santa Clara follows a linear model based on generation, collection and final disposal in an open dump. According to municipal data (2023), the composition of MSW is distributed in:

- Household sector (82.3%)
- Industrial sector (16.6%)
- Hospital sector (1.1%)─

Collection covers only 72.51% of the waste generated, with a coverage of 92.8% in urban areas, but without segregation at source. Final disposal is carried out without leachate treatment or valorization processes.

III.1.2 Calculate the percentage reduction of waste for disposal in the landfill.

Total Reduction

$$TR = \sum(Recycling \ + composting \ + reuse \quad (1)$$

$$\% \, Reduction$$

$$\%Red = \frac{Total\ Reduccion}{Base} \ x\ 100 \quad (2)$$

III.2 PROBLEMS.

Lack of segregation at source; waste is mixed at all stages of the collection system (storage, transport and disposal). Deficiencies in collection and transportation due to the lack of adequate vehicles and the absence of sorting and recycling plants. The municipal landfill lacks a leachate treatment system.

III.3. STUDY DESIGN

III.3.1. METHODOLOGICAL APPROACH

- Diagnose the current MSW system through documentary analysis and surveys.
- Evaluate the perception of key actors (citizens, companies, government).
- Propose a circular economy model based on practices adapted to the local context.

III.4. Constraints.

III.4.1 Lack of Awareness and Sensitization.

- The population and companies are unaware of the benefits of the circular economy.
- Resistance to change in consumption habits and waste separation.

III.4.2. Insufficient Legal Framework.

- Absence of specific regulations for the treatment and recovery of materials.
- There are no sanctions for violators who do not comply with proper disposal.

III.4.3. Inadequate Infrastructure

- There are no recycling plants in the territory.
- The current landfill operates without technical control.

III.4.4. Limited Financing

- The transition requires investment in technology, training and equipment.
- Difficulty in accessing public or private funds.

In order to effectively address the solid waste problem in Santa Clara, it is essential to develop the key steps presented in the attached figure. These steps will allow structuring, implementing and consolidating a Solid Waste Management System based on the Circular Economy, guaranteeing its sustainability and efficiency.
To ensure an effective transition to a sustainable solid waste management system in Santa Clara, it is essential to implement the eight key steps described in Figure 1:

- Structure a model aligned with circular economy principles.
- Implement technical and operational solutions adapted to the local context.
- Consolidate the system ensuring its efficiency and long-term sustainability.

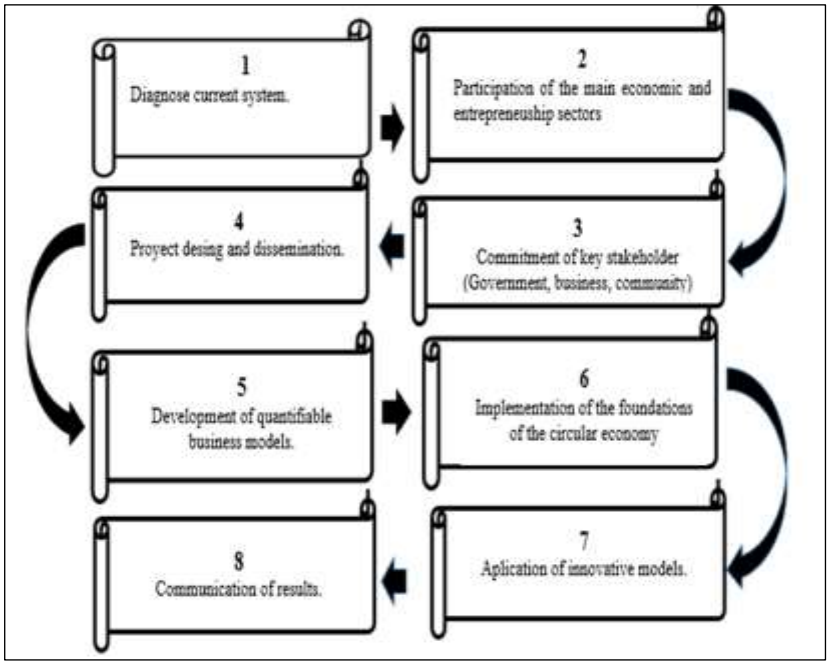

Figure 1: Steps to achieve the development of the Circular Economy in the Waste Management System.
Source: Authors, (2025).

IV. RESULTS AND DISCUSSIONS

The transition to a circular economy (CE) represents a key challenge for sustainable development, especially in communities like Santa Clara, where waste management and resource efficiency require significant improvements. A strategic framework for implementing a CE system is proposed, addressing organizational, participatory, regulatory and technological aspects and highlighting the actions needed to strengthen municipal solid waste (MSW) management, promote multi-sectoral collaboration and design circular business models.

IV.1 CHARACTERIZATION OF THE CURRENT SYSTEM AND COMPOSITION OF GENERATED WASTE.

The Santa Clara Community Services Company collects an average daily amount of 253.69 metric tons (t/d) of municipal solid waste (MSW). For waste characterization, the quartering method established in the Mexican standard NMX-AA-015-1985 [22], was applied, using a 50 kg sample. Table 1 details the percentage composition of the components identified in the study.

Table 1: Daily generation of urban solid waste in Santa Clara.

Type waste	Solid Waste generated (t/day)	Waste generated daily (%)	Valuation potential
Organic waste (food waste, garden pruning)	167.37	65.95	Composting / Biodigester
Plastics, glass and metals (potentially recyclable)	45.26	17.86	Recycling
Paper and cardboard	12.10	7.77	Recycling / Reuse
Waste (textiles, leather)	13.14	5.18	Recycling
Ash and others	15.82	4.24	Landfill
Total	253.69	100	

Source: Authors, (2025).

The municipal solid waste (MSW) management system in Santa Clara follows a linear model with simple stages. According to estimates, the generated waste will be treated as follows: 80% of paper and cardboard, 60% of plastic, glass, and aluminum, 50% of organic waste, and 15% of textiles and leather. As a result, a total daily waste reduction of 122.45 tons is projected, representing a 48% decrease compared to the initial levels deposited in the landfill.

IV.2 MAIN PROBLEMS DETECTED

a) Waste generated is mixed during the storage, transportation and final disposal stages.
b) Deficiencies in the collection and transportation services due to the lack of adequate vehicles and logistical resources.
c) Inadequate final disposal in landfills without leachate treatment, whose pollutant loads affect the water table and adjacent surface waters.

Currently, most of the waste in Santa Clara is deposited in the municipal landfill without prior classification, which generates problems such as:

- Soil and groundwater contamination.
- Methane emissions (a potent greenhouse gas derived from the decomposition of organic waste).
- Santa Clara's waste stream contains recoverable materials that could boost local economies if recycled.

IV.3 IMPLEMENTATION OF INDICATORS FOR THE CIRCULAR ECONOMY

To promote the circular economy in Santa Clara, it is essential to establish indicators that allow:
• Measure progress and evaluate the impact of implemented actions.
• Identify areas for improvement and facilitate decision-making.
• Promote transparency and accountability.
Examples of key indicators:
• Recycling and waste recovery rate obtain the percentage of waste recycled or reused.
• Amount of materials recycled per inhabitant or economic sector.
The circular economy is a key strategy for reducing environmental impact and promoting sustainable development. Its success depends on the rigorous monitoring of indicators that guide public policies in municipalities such as Santa Clara.

IV.4 METHODOLOGY AND EXPECTED RESULTS

Ten indicators categorized into key dimensions are proposed:
1. Reduction of waste sent to final disposal.
• Indicator: Volume of waste sent to landfill (inter-annual comparison).
• Objective: Promote reduction, reuse and recycling.
Products designed for durability and reuse.
• Indicator: Number of products manufactured under circular economy criteria.
3. Materials reuse rate
• Indicator: Percentage of materials reused versus new materials.
4. Business participation in circular economy
• Indicator: Number of companies with circular practices.
5. Investment in circular infrastructure
• Indicator: Resources allocated to recycling plants, composting and repair centers.
6. Consumption of natural resources
• Indicator: Reduction in the use of water, energy and non-renewable raw materials.
7. Circular employment generation
• Indicator: Jobs created in reuse, recycling and sustainable design.
8. Circular product innovation
• Indicator: New products or services with a circular approach developed locally.
9. Citizen participation
• Indicator: Level of awareness of sustainable management programs.
These indicators will make it possible to evaluate progress towards a circular economy, identify gaps and optimize public policies.

IV.5 CHALLENGES AND SOLUTIONS FOR THE TRANSITION

The implementation of the circular economy faces barriers that require comprehensive solutions:
1. Lack of awareness.
• Problem: Lack of awareness of the benefits of the circular economy.
• Solution: Educational campaigns and partnerships with academic institutions.
2. Insufficient legal framework
• Problem: Lack of regulations for waste recovery.
• Solution: Public policies with incentives and oversight mechanisms.
3. Lack of infrastructure
• Problem: Lack of sorting and recycling plants.
• Solution: Investment in sorting technologies and reverse logistics.
4. Financial constraints
• Problem: High modernization costs.
• Solution: Public-private funds and green business models.
5. Technical gaps
• Problem: Lack of training in circular methodologies.
• Solution: Specialized workshops and technology transfer.
Overcoming these challenges requires a multi-sectoral approach that combines regulation, innovation and community participation.

IV.6 EXPECTED BENEFITS

Economic
• Generation of green jobs in sectors such as recycling, repair, composting, sustainable design.
• Cost savings for businesses and municipality by reducing dependence on virgin raw materials and optimizing resource use.
• Attraction of investments in clean technologies and circular business models.
• Waste valorization, transforming waste into economically useful resources (compost, recycled materials).

Environmental.

- Reduction of soil and groundwater contamination by reducing the amount of waste to be disposed of in landfills by 48%.
- The reduction of gas and particle emissions from landfills and incineration processes will reduce atmospheric pollution, benefiting the health of the population and the environment.
- The promotion of recycling and reuse will reduce the extraction of non-renewable raw materials.
- The implementation of circular practices will reduce the amount of waste that ends up in landfills and in the natural environment, protecting biodiversity and local ecosystems.
- The incorporation of sorting and recycling technologies will promote more efficient and environmentally responsible management of municipal solid waste.

Social

- Increased environmental awareness among the population, promoting responsible consumption habits and citizen participation.
- Improved quality of life by reducing pollution and health risks associated with uncontrolled landfills.
- Social inclusion by creating jobs in emerging sectors, especially for vulnerable communities.
- Strengthening of the local economy by promoting enterprises based on reuse and recycling.

The transition to a circular economy in Santa Clara will solve problems in the waste management system and lay the foundation for a sustainable future. With the implementation of environmental education, public policies and adequate infrastructure, the municipality can become a regional and national model demonstrating that a balance between economic and environmental progress is possible.

This approach is not only theoretical, but an urgent necessity for a cleaner city. By promoting reuse, recycling and waste reduction, resources are conserved, pollution is reduced and responsible economic development is promoted. These practices improve quality of life, strengthen the local economy and protect the environment for future generations.

V. CONCLUSIONS

1. The waste management system in Santa Clara operates under a linear model, characterized by generation, collection and disposal in landfills without prior segregation, which generates pollution, loss of valuable materials and harmful emissions. Limited infrastructure, lack of public awareness and an insufficient legal framework hinder the transition to more sustainable practices.

2. The implementation of circular economy principles in Santa Clara's waste management system - including source segregation, material recycling, product reuse, and durable design - could reduce landfill disposal volumes by 48%, while simultaneously decreasing environmental pollution and recovering value from materials currently lost in the linear system.

3. There are significant obstacles that hinder the sector's progress, including the lack of adequate infrastructure, limitations in public awareness and participation, deficiencies in legislation and regulation, and the need to strengthen technical and management capacities.

4. Santa Clara has a high potential to implement innovative solutions, such as waste treatment technologies, collaborative economy and sustainable business models, which can contribute to reduce waste generation and promote resource recovery.

5. Is necessary strengthen cooperation between public and private actors, promote environmental education, develop technical capacities and establish regulatory frameworks that encourage the transition to the circular economy in waste treatment.

6. The transition to the circular economy in waste treatment in Santa Clara constitutes a fundamental opportunity to reduce environmental impacts and promote more sustainable management, thus minimizing inadequate disposal in the landfill.

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