

Smart Management Of Household Waste Using Artificial Intelligence In Urban Areas: A Promising Sector In The Circular Economy – The Case Of Oran

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Abstract :

Cities are a key component in achieving the 2030 Sustainable Development Goals, as they inhabit more than 55% of the world's population and contribute over 70% of global carbon emissions. In this context, the need to integrate sustainable urban planning and waste management is essential as a pivotal strategy for achieving the Sustainable Development Goals, particularly Goal 11 (Sustainable Cities and Communities), Goal 12 (Responsible Consumption and Production)¹, and Goal 13 (Climate Action).

Waste management is a cornerstone in the transition from the traditional linear economy to the circular economy, which is defined as “a regenerative industrial economic system that aims to preserve the value of products and materials for as long as possible by giving them a second life.”² Oran is the second capital of Algeria and a major economic and commercial hub, placing it at the forefront of national economic activity. Oran is experiencing profound demographic and economic transformations. Its population has exceeded 1.5 million, and its urban expansion has accelerated, supported by various development projects. This has been accompanied by significant environmental challenges that threaten the achievement of sustainable development goals.

It is a model of accelerated urban transformation in the Mediterranean region and, like other cities on both shores, it faces increasing climate risks. Studies indicate that unregulated urban expansion in Oran has consumed more than 35% of the agricultural land surrounding the city over the past decade³. Furthermore, the percentage of green spaces does not exceed 2.5 square meters per capita, far below the World Health Organization's standards (12 square meters per capita)⁴, which impacts the deterioration of infrastructure, ecosystems, and the quality of urban life.

Oran produces more than 0.8 kg of household waste per person per day, at an annual rate of nearly half a million tons. Despite ongoing efforts, the recycling rate does not exceed 5% of the total waste produced, with approximately 2% to 5% of plastic, 0.2% of metals, and 0.5% of cardboard and paper.

Oran represents a case study of the complexities of household waste management in major Algerian cities. The city suffers from a deteriorating urban landscape due to rapid urban growth, a weak infrastructure for sorting at the source, and a near-total reliance on technical landfills, which in turn face saturation issues and the risk of environmental contamination. Collection and transportation operations also pose another obstacle due to a shortage and deterioration of vehicles, the insufficient quantity and quality of containers, and their poor distribution, leading to waste accumulation, especially in densely populated and unorganized neighborhoods. The human factor also plays a major role in complicating the process (through the lack of sorting at the source at the household level). Oran also lacks organic composting units, with the exception of two: one at the wholesale fruit and vegetable market in El Kerma and the other at the technical landfill center in Hassi Bounif. There are also no centers or units for producing bioenergy or exploiting waste and lost biogas from technical landfill centers. This reflects Algeria's lagging behind in waste management and renewable energy exploitation, despite Algeria's attempts to encourage investment in renewable energy through the new Investment Law 22-18 on investment in Algeria. In light of these challenges, Oran can adopt an integrated planning approach aimed at improving waste collection (quantitatively and qualitatively) into separate functional recycling companies and cooperatives or local communities. This allows them to operate under sanitary conditions and receive legal protection, thereby integrating them into the circular economy, improving their social status, and ensuring their health and safety.

Oran also has the opportunity to benefit from the experiences of other Mediterranean cities, such as Marseille (France) and Barcelona (Spain), as they are very similar in geographical, urban, and economic characteristics. This allows for the adoption of innovative waste management technologies and the building of effective partnerships with the private sector, research institutions, and local authorities, thus promoting sustainable urban governance and environmental resilience.

Keywords: Metropolis, household waste, bioenergy, artificial intelligence, smart city.

¹ Ghisellini, P., et al, 2016, A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11-32

² MacArthur, Ellen, 2019, *The virtuous circle*. Luxembourg: European Investment Bank and Ellen MacArthur Foundation

³ Belaroussi, M., & Guerfi, M, 2022, Urban Sprawl and Agricultural Land Loss in Oran. *Journal of Urban Planning*, 45(3), 234-245

⁴ World Health Organization, 2021, *Global Database on Green Urban Areas*

Introduction:

The management and disposal of household waste is one of the major environmental, social, and economic challenges facing cities around the world, both in developed and emerging countries. This is due to continued population growth, urban expansion, the expansion of cities, the increase in production, and excessive consumption resulting from changing consumer habits and consumer culture, on the one hand, and a lack of environmental awareness and the practice of sorting and recycling, on the other. This has increased the production of tons of waste daily.

In contrast, reports issued by UN bodies and the scientific outcomes of international conferences concerned with environmental issues and climate change indicate that the planet faces unprecedented challenges and increasing pressures that diminish its ability and the effectiveness of the natural system to achieve sustainability. This is due to accelerated demographic growth, urban expansion, and the problematic nature of waste management. This is in light of the challenge of urbanization and the transformation of space and cities into commodities, according to the analysis of the French philosopher and sociologist Henri Lefebvre. Urbanization of the planet is characterized by the spread of urban logic in every corner of the planet and its transformation into a space for both production and consumption⁵ (commodification of urban space). This has increased the complexity of urban and environmental systems, their sustainability, and the erosion of the principles of spatial justice.

In 2015, the world produced approximately 2 billion tons of waste⁶, with expectations that this number will exceed 3.4 billion tons by 2050 if current trends continue. This staggering amount of waste expresses and warns of the alarming environmental situation if it is not addressed seriously, imposing economic and environmental burdens. A heavy burden rests on its shoulders. Data reveals the enormous costs associated with managing this waste. In 2021⁷, €19.6 billion was spent on waste management in France, equivalent to €60.1 billion or 0.8% of GDP. The cost rises to \$361 billion annually in the United States.⁸

In Algeria, official data confirm the magnitude of the challenge. Statistics for 2018 indicated that the amount of household and similar waste reached approximately 13 million tons annually, with a daily per capita rate of 0.8 kilograms. Studies predict that this amount will reach 20 million tons by 2035 due to population growth and the pace of urbanization. These figures place waste management at the forefront of environmental and economic challenges that require sustainable and effective policies.

Recognizing the seriousness of these data, Algeria has made efforts on the environmental policy front by ratifying the Paris Climate Agreement on October 13, 2016, in a move aimed at fulfilling international commitments to reduce greenhouse gas emissions. This process was reinforced by participating in the United Nations Environment Programme (UNEP) during 2019, seeking to maximize international cooperation and the exchange of expertise.

At the local level, Oran faces escalating problems resulting from the production and accumulation of household and similar waste. Oran is a model for Algerian cities experiencing significant demographic growth and urban expansion, along with the implementation of housing projects of various types, and consequently, the production of a huge amount of household and similar waste. An estimated 1,300 to 1,600 tons of total waste are produced daily, according to public institutions for the management of technical landfill centers in the province of Oran, with its three centers (Hassi Bounif, Arzew, and El-Ançor). This number does not reflect the actual amount of waste, which peaks during summer seasons, Ramadan, and Eid al-Adha.

There is also the presence of uncontrolled random dumps (black spots) linked to informal neighborhoods whose waste does not reach the formal disposal system, placing significant operational and financial burdens on the city. The burden of waste management remains on the shoulders of municipalities and relevant environmental institutions. It represents the main problem surrounding the current situation of household waste management in Oran, identifying the performance gap between the current reality of waste management and the desired achievement through the application of environmental governance and smart management models.

This will help achieve efforts aimed at finding sustainable solutions that respond to Goals 11 and 12, highlighting the extent of the need for effective waste management.

In other words, the extent of the need for smart waste management in Oran – especially since this system does not exist in Oran or any other city in Algeria – requires in-depth examination. Therefore, we pose the following sub-questions:

What is the current state of household and similar waste management in Oran?

⁵ Ibid p 32

⁶ Practices for Solid Waste Management, 2020, : A Guide for Decision-Makers in Developing Countries, United States Environmental Protection Agency Office of Resource Conservation and Recovery , October 2020

⁷ ministères territoires ecologie logement, Données et études statistiques ,Pour le changement climatique, l'énergie, l'environnement, le logement, et les transports, la dépense de gestion des déchets en 2021, publié le 12-08-2021

⁸ United Nations Environment Programme Report ,February , 2024

What are the key challenges and risks in its management?

What is the expected role of environmental governance and the adoption of smart management systems in addressing the problems of the waste sector?

How can successful regional Mediterranean models and experiences, such as those of Barcelona (Spain) and Marseille (France), be leveraged to formulate contextual solutions compatible with the Algerian environment?

To answer these questions, we developed three hypotheses:

Research Hypotheses:

Based on the research problem, the following three hypotheses were proposed:

1. First Hypothesis: There is a lack of efficiency and capacity in managing household and similar waste in Oran due to shortcomings in technical systems, administrative processes, and enforcement of legal regulations. This is evident in the current waste situation in the metropolitan area of Oran.
2. Second Hypothesis: Efficient and effective waste management can be achieved if there is genuine political and institutional will. This requires digitizing the sector, integrating technology and artificial intelligence, providing adequate resources, encouraging start-ups and investors, training stakeholders, fostering environmental awareness, engaging actors from various sectors, and enforcing environmental legislation.
3. Third Hypothesis: Despite Algeria's legal and institutional framework and the allocation of material and human resources, the country still lacks investment in human development. True advancement depends on educating and shaping citizens—especially children, as future generations. Building environmental awareness and civic responsibility in individuals will help achieve goals and reduce long-term costs.

Significance of the Study:

The study derives its importance from its focus on the following aspects:

1. Connection to Sustainable Development:

Effective household waste management represents a fundamental pillar for achieving sustainable economic growth. It constitutes a potential source of raw materials and renewable energy through treatment and recycling processes, thereby contributing to the conservation of natural resources and the achievement of environmental balance.

2. Community and Urban Gains:

Waste management is a pivotal issue in the field of urban geography, representing a crucial measure of the efficiency of spatial organization and the quality of urban planning. From a geographical perspective, this management is not limited to the technical aspect alone but extends to include the spatial analysis of waste production patterns, distribution, transportation networks, and treatment sites – striving to achieve functional integration and environmental balance within the urban fabric.

Waste management is a geographical process par excellence, requiring an integrated approach that combines spatial vision with environmental and economic strategies. The path to achieving a “sustainable city” inevitably requires adopting smart geographical waste management practices, utilizing Geographic Information Systems (GIS) and network analysis to significantly improve effectiveness. This approach is based on scientific planning supported by modern technologies and informed community participation.

Achieving the principle of “environmental justice” within cities requires ensuring a fair distribution of waste management facilities across different neighborhoods and social classes, and reducing the concentration of facilities with negative environmental impact in specific areas. Cities that adopt integrated urban policies that take this dimension into account succeed in shaping a healthier and more sustainable urban environment, which positively impacts the quality of life of residents.

3. Economic and Investment Value:

The waste sector is a promising market characterized by steady growth, driven by the proliferation of collection and treatment centers and the integration of specialized companies and start-ups. Recycling creates jobs and generates significant financial returns. Global estimates show that recycling 108,000 tons of waste annually could generate billions of dollars in profit.

4. Untapped Economic Potential: The system for managing household and similar waste represents a missed opportunity for economic growth. It can serve as an alternative to natural resource depletion and as a source of raw materials. Recycling helps reduce the loss of materials such as plastic, paper, glass, metal, and wood.

5. Job Creation and a Growing Sector: The waste sector has the potential to provide significant employment opportunities. These jobs include in collection, landfilling, technical incineration, and start-ups specializing in programming and artificial intelligence. In countries such as Germany (with over 108,000 recycling companies), Spain, Singapore, and the United Arab Emirates, the financial returns from waste management exceed half a trillion dollars globally.

6. Energy Production: Biowaste contributes to the generation of bioenergy through the production of methane and carbon dioxide gases. These are used to produce electricity.
7. Digital Transformation and Predictive Efficiency: There is a pressing need to integrate new digital technologies in waste management. Artificial intelligence systems enable predictive analysis based on databases, allowing for improved efficiency, sustainability, and support for the circular economy.
8. Urgent Need for Innovation in E-Waste Management: There must be innovation in the handling of different types of waste—especially electronic waste (e-scrap or e-waste). Lithium batteries, in particular, pose a major risk as they are highly flammable and responsible for many fires. They represent a serious and collective global challenge

Research Methodology:

The study adopted a research methodology that combines theoretical and practical aspects, as follows:

First - Theoretical Aspect

This aspect involved the following procedures:

Analysis of relevant Algerian legislative and regulatory texts, most notably:

Law No. 01-19 of December 12, 2001, relating to waste management, monitoring, and disposal.

Law No. 03-10 of July 19, 2003, on environmental protection within the framework of sustainable development.

Law No. 04-20 of December 25, 2004, on major hazard prevention and disaster management within the framework of sustainable development.

Review of national and local planning documents, such as the National Waste Management Plan (2008).

Examination of the Master Plan for the Province of Oran and the Regional Waste Management Plan for the period 2020–2030.

Review and analysis of a set of previous studies and academic research to establish a solid theoretical framework for the study.

Second - The Practical Aspect

This aspect was implemented through field interviews with a sample of key stakeholders in the waste management sector in the Province of Oran, including:

Officials of the technical and field services of the Environment Directorate of the Province of Oran.

Those responsible for managing technical landfill centers (sanitary landfills) in Hassi Bounif, El-Ançor and El Arzew

Representatives of the municipalities affiliated with the Greater Oran Group and officials of the Public Establishment for the Management of Technical Landfill Centers (EPIC CET) in Oran.

1- The Conceptual and Legislative Framework for Household and Similar Waste:

According to Algerian Law No. 01-19 of December 12, 2001, relating to waste management, control, and disposal, household and similar waste is defined as:

“Waste resulting from citizens’ domestic activities, as well as waste similar in composition and nature, resulting from commercial, craft, industrial, or agricultural activities.”

Robert Gillet, a United Nations expert, defined it in his book “A Study of Algerian Waste” as:

“The collection of heterogeneous, diverse remains produced within homes, such as food scraps, newspapers, and anything that can be placed in special containers, whether individual or collective, for the purpose of being removed by municipal services.”

In addition to household waste, similar waste may also come from administrations, markets, merchants, craftsmen, and abandoned items.

On the international level, the United Nations Environment Programme (UNEP) (2015) provides a broader definition, describing it as:

“The set of materials and solid waste disposed of as a result of daily activities in homes, as well as in commercial establishments and offices, consisting of a complex mix of organic and inorganic materials.”

From these definitions, it can be concluded that household waste is an inevitable product of daily human activities. It includes food scraps, paper, plastics, metals, and waste generated by small businesses, making it a heterogeneous mixture that requires specialized treatment.

2- Scientific Classification of Household Waste:

Household waste is classified according to several criteria, most notably its ability to be biodegraded, which directly affects the methodology for its management and treatment.

A. Biodegradable Waste

This category constitutes the largest share of household waste in Algeria. It consists of materials that can be biodegraded by microorganisms, including food scraps, fruit and vegetable peels, and garden waste.

The Food and Agriculture Organization (FAO) indicates that managing this waste through composting or anaerobic digestion not only reduces pressure on landfills but also produces organic fertilizer that improves soil fertility and enhances food security.

B. Non-Biodegradable Waste

This category includes materials that are resistant to natural decomposition or require very long periods of time to break down, making them a major source of long-term environmental pollution. These include:

Recyclable materials: such as paper and cardboard, glass, metals (such as aluminum and iron), and plastics. According to a World Bank report, promoting the separation and recycling of these materials at the source is a fundamental pillar of the circular economy.

Household hazardous waste: such as batteries, fluorescent lamps, paints, and old electronic products (e-waste), which contain toxic elements that require special treatment to prevent their release into the environment.

Other waste: such as textiles and rubber.

3- The Current Status of Household Waste Generation in Algeria: A Quantitative Analysis:

The latest reports issued by the Ministry of Environment and Renewable Energy indicate that the annual quantity of household waste ranges between 9 and 13 million tons, with an estimated per capita generation rate of 0.8 to 1.0 kg per day. These figures have doubled over the past two decades, placing an increasing burden on the existing collection, transportation, and treatment infrastructure. Although local studies indicate that the percentage of recyclable materials (organic, plastic, paper, and metals) may exceed 60% of the total waste in the future, actual recycling rates remain modest, not exceeding 7% at the national level.

Table 1: Evolution of Algeria's Population and Waste Generation (2011–2018)

years	2011	2014	2016	2018
Population min	36.3	39.1	39.6	43.22
Quantity of waste m. tons	3.9	11	11.6	13

Source: Bouadam, Roukia (2022). Algeria and Its Waste: Management Tools, Challenges, and Future Prospects. University of Constantine 3, Algeria, p. 72.

According to the table, the population produces approximately 13 million tons of waste annually. This volume results in an estimated cost ranging between 58 and 94 billion Algerian dinars, drawn from the public treasure. Data from the National Waste Agency show that 54% of this waste is organic matter. From every 3 tons of such waste, it is possible to produce 1.5 tons of high-quality compost. Moreover, about 17% of plastic waste is recoverable, especially PET-type plastic. This type alone could create up to 7,600 direct jobs across the waste management chain, including sorting, transportation, and processing. It can also generate additional indirect employment.

4. Study Area Overview:

Oran Metropolis is one of the most important cities on the southern shore of the Mediterranean. It forms a key part of Algeria's national urban network. Located on the western coast for Algeria, Oran covers an area of 2,114 km² and has a coastline stretching 140 km. It is bordered to the north by the Mediterranean Sea, to the west by Aïn Témouchent Province, to the east by Mostaganem, to the southeast by Mascara, and to the southwest by Sidi Bel Abbès. According to the most recent statistics from 2024, the population of Oran is estimated at 1,584,607. The province consists of 26 municipalities and 9 administrative districts. Today, it is considered the country's second capital and the leading center of the western region due to its influence and functional roles. It is a hub for industry, education, culture, and tourism, and lies at the intersection of major land, sea, and air transport routes

Map 1: Administrative Division of Oran



Table 2: Population Growth in Oran and the Quantity of Household and Similar Waste (DMA)

years	1987	1998	2008	2022
Population	430022	589697	721356	1213839
Amount of waste tons	/	/	/	402,560,584

Source: National Office of Statistics + Epic CET Oran

5- The Relationship Between Urban Pole and Waste Generation in Oran:

Oran is the most important urban hub in western Algeria and the country's second-largest city, with a population of 1,584,607 according to the latest national census (2022). It is a dynamic center combining administrative, industrial, commercial, and tourist functions, making it a magnet for residents and various activities. This dense urban concentration makes it one of the areas that generates the most waste of all kinds, due to the complex interaction between rapid population growth and the expansion of economic activities. This results in what is known as compound environmental pressure.

According to the table, Oran experienced sharp population growth between 1987 and 2022, exceeding the national average. This reflects its economic attractiveness. However, there are no official statistics on the amount of household waste produced before 2012.

Before the beginning of the third millennium, household waste production in Oran was not as severe. Waste was dumped haphazardly in unregulated landfills (estimated at 17 in Oran, considered black spots) that were not subject to monitoring, sorting, treatment, or even classification. The only method of treatment was burning. Some individuals would search through the landfills, recover materials, and sell them as scrap metal – a low-paying job given the availability of jobs in other sectors at the time.

With the increasing quantities of household waste and the negative impacts of these unregulated landfills on public health, the environment, and the surrounding areas, coupled with global challenges and the emergence of sustainable development and its goals, a policy that takes environmental considerations into account has been adopted by establishing technical landfill centers.

Starting in 2001, Algerian waste policy changed, adopting a stricter approach. This led to the development of the National Program for Special Waste Management (PNAGDEM), the creation of the National Waste Agency (AND) by Executive Decree 02-175 of May 20, 2002 (which outlines the agency's establishment, organization, and operation), the Municipal Plan for Household and Similar Waste Management (SDGDMA) based on Law 01-19, reinforced by Executive Decree 07-205 of June 30, 2007 (which specifies the procedures for the implementation, publication, and review of the municipal plan for household and similar waste management), the Wilaya Program for Special Waste Management and Removal (PWAGDES), and the acquisition of equipment for waste management.

As shown in the table above, the amount of waste has quadrupled since 2008. A rough estimate shows that the waste quantity in 2008 was 131,647 tons, increasing to 402,560,584 tons in 2022 – a fourfold increase – due to the following. This shift was driven by several factors:

1. **Population Growth and Urban Expansion:** Oran's population grew rapidly, accompanied by an increase in waste volumes. New urban zones have emerged, especially in the suburbs, with the development of housing projects such as AADL, LSP, and LPP.
2. **Decline in the Traditional Role of Mothers:** Previously, mothers played a central role in managing the household and, often unintentionally, applied the “4R” principles of waste management (**Reduce, Reuse, Recycle, Recover**).
3. **Changes in Lifestyle and Daily Habits:** Consumer habits evolved. Eating out became more common. Visits to bakeries, restaurants, and cafes increased. As a result, more food and bread went to waste.
4. **Open Markets and the Spread of Plastic Packaging :** Economic liberalization and the rise of imported goods encouraged mass consumption. Traditional shopping practices, which involved using reusable baskets (qaffa made from palm or halfa), were replaced by single-use plastic bags.
5. **Women Entering the Workforce:** Women's roles shifted, with more of them joining the labor force. They spent less time at home and delegated many domestic responsibilities. Cost-efficiency became a key factor in decision-making.
6. **Modern Marketing and Online Shopping:** Digital platforms and social media influencers accelerated consumer trends. Promotions like Black Friday and Super Promo encouraged people to buy unnecessary items, many of which eventually ended up in landfills. Trends, brand loyalty, and impulsive purchases led to more waste and a growing disconnect between needs and wants.
7. **Digital Fast Fashion:** some companies have mastered the art of using these platforms to market thousands of new designs weekly at low prices, encouraging a "wear-once" culture and the quick disposal of clothes, which is the second largest polluter in the world.
8. **Delivery Accessibility:** Removing Friction and Promoting a Culture of Instant Consumption: Express delivery services complete this equation by removing the last obstacle to impulsive consumption through 24-hour delivery (next-

day delivery). This reduces the "effort cost" associated with going to the store. With same-day or even minutes-delivery services (as with food and grocery delivery), purchasing transforms from a planned process into a reaction to an immediate need

6. Reality of Household and Similar Waste Management in Oran (DMA)

To understand how household and similar waste (DMA) is managed in Oran, we must assess the infrastructure's capacity, the management mechanisms, and treatment methods.

a- Waste Management Mechanisms in Oran

A primary goal in managing household solid waste is to specify the type and size of containers and place them optimally for efficient collection. Knowing the volume and chemical or microbiological makeup of waste is essential for proper sorting and processing.

Oran is divided into 26 municipalities, each responsible for managing its waste. Municipalities oversee collection, transport, and treatment and must develop local waste management plans following sustainable development principles. Among all, only Oran municipality implemented a guiding plan for 2010–2020. Other municipalities, due to limited budgets and the high cost of environmental planning, prioritized investments in equipment rather than developing formal management strategies. All household and similar waste eventually winds up at technical landfill centers.

Regarding hazardous waste, Oran lacks a national-level facility for its processing due to its high cost and complex handling. However, some compliant facilities exist:

- Private company Hamane Ibrahim facility Handles hazardous waste under technical and sanitary norms.
- company Eco-West Treats hazardous waste after sterilization.
- For inert waste, there are two centers: one at Berria, operational since 2020, receiving around 950,394 tons per year and nearing capacity; and a second opened in the Ahmed Zabana urban hub on February 5, 2025, receiving an average of 3,168.38 tons of inert waste daily. There are also two urban selective sorting centers for household and similar recyclable waste (plastic, cardboard, paper):

- The first is located in an unused municipal depot in Hay El Madina Jadida (New Town), covering 4,625 m². It handles 2–3 tons daily from shops and approximately 650 kg from households. It's ideally placed near the neighborhood's commercial hub (CBD), making it economically and strategically significant. The center covers an area of 1008 m² and receives between 2 to 3 tons of waste daily. Due to the commercial significance and function of the neighborhood, trucks make 2 to 3 patrols per day.

The second Selective Urban Sorting Center in Colonel Lotfi Neighborhood, Oran The center covers an area of 1008 m² and receives between 2 to 3 tons of waste daily. Due to the commercial significance and function of the neighborhood, trucks make 2 to 3 patrols per day..

b. Structure and Capacity of the Waste Management Infrastructure

1. Collection and Transport Capabilities

Each day, approximately 355 trucks operate at the Technical Landfill Center in Hassi Bounif, 53 trucks at the El-Ançor center, and 54 trucks at the Arzew center. The region of Oran is equipped with around 20,000 containers of varying sizes and types, unevenly distributed across the territory.

Municipalities are responsible for managing waste, starting from collection and transport to final disposal at treatment centers. This is in accordance with Article 88 of Law 11-10 relating to the municipality. The mayor, under the supervision of the wali (governor), oversees the administrative authority in the field of environmental protection.

In Oran, there is a partnership between the municipality and the private sector regarding the distribution of containers, as well as the collection and transportation of waste. Notable private institutions involved in this process include:

- **EPIC Property Oran** (Oran Cleanliness Corporation)
- **EPIC CET Oran** (Provincial Public Institution for the Management of Technical Landfill Centers)
- **Private investors managing waste from university residences**

Table 3: Distribution of Municipalities Among Technical Landfill Centers

Hassi Bounif CET	El-Ançor CET	Arzew CET	Sidi Al-Shahmi	Overloaded
Oran	Ain Al-Karma	Qadeel	The landfill center for inert waste receives 26 municipalities and private individuals.	He entered service and is responsible for all tasks after the closure of the
Sanya	Ain al-Turk	Arzew		
sidi Shahmi	element	Bethioua		
Bir El Djir	Bootliles	Ain El Bia		
Ben Freha	Marsa Al-Kabir	Ben Yebka		
Boufatis	Bosphorus	Marsa Al-hajaj		
Hassi Bounif	Properties	Properties		

Wadi Tlelat				Wilderness Center.
Tafrawi				
Ibn Uqba				
The wilderness				
Vine				
Assi ameur				
Properties				

Source: Provincial Public Institution for the Management of Technical Landfill Centers of Oran

Table 4: Waste Quantities by Population in the Western Oran Coastal Cluster - 2019

Waste quantity 2019 tons	Population 2019 people	Area km ²	Municipalities
5243	17957	10.98	Marsa Al-Kabir
10420	35687	39.98	Ain al-Turk
5361	18361	46.20	Bosphorus
3348	11469	66.44	El-Ançor
2193	7513	107.92	Ain Al-Karma
6984	23920	135.97	Bootliles
33549	114907	407.49	the total

Source: National Office of Statistics (ONS) + Technical Services of the Municipalities

Household and similar waste from the western coastal region of Oran, estimated at 33,549 tons, is processed at the technical landfill center in the municipality of El-Ançor. The volume of waste increases significantly during the summer months due to the influx of tourists from both within Algeria and abroad.

Table 5: Waste Quantities by Population for the Eastern Municipalities of Oran - 2019

Municipalities	Area km ²	Population 2019 people	Waste quantity 2019 tons
Arzew	64	91400	26688
Qadeel	93.82	39129	11425
Marsa Al-hajaj	52.29	13153	3840
Bethioua	108.57	18215	5318
Assi ameur	25.67	12836	3748
Ain El Bia	51.69	7825	2284
the total	396.04	182558	53306

Source: National Office of Statistics (ONS) + Technical Services of the Municipalities

The waste generated by the eastern cluster of Oran, estimated at 53,306 tons, is processed at the Arzew Municipal Technical Landfill Center, which receives household waste from six municipalities.

c. Composition of Waste by Type

Understanding the composition of waste by type is essential for taking the right measures to manage it in a sustainable and efficient way. This supports public health and maximizes the benefits of recycling. It also helps in choosing the appropriate size and type of containers, and ensures their effective distribution across neighborhoods.

Table 6: Average Composition of Household Waste in the Province of Oran - 2023

Waste components	Weight tons	%
organic matter	81.77	54.9
wood	2.27	1.5
paper and cardboard	16.12	10.8
plastic	15.92	10.7

minerals	2.72	1.8
diapers	9.02	6.1
glass	2.98	2
fabric	1.83	1.2
leather and rubber	3.18	2.1
sand and dust residue	13.26	8.9
the total	149.07	100%

Source: Provincial Public Institution for the Management of Technical Landfill Centers

In Oran, organic waste accounts for the largest proportion, at 54.9%. This is a positive indicator because organic waste—such as food scraps and green residues—can be converted into organic fertilizers to improve agricultural productivity. It also offers an opportunity for producing biogas as a renewable energy source, a practice not yet developed in Algeria. As for other materials, including plastics, cardboard, paper, and metals, these are recycled and sold to private operators. The Hassi Bounif Technical Landfill Center (CET HB) has a four-year contract with a private Covers and mattresses company, which receives plastic waste. Additionally, CET HB cooperates with the Tosyali Iron Company in Oran.

Table 7: Quantity of Recovered Materials at CET HB (Hassi Bounif Center) from 2021 to 2023

years	2021	2022	2023
Materials			
amount of plastic tons	1448,680	2427.240	2342,646
Quantity of mineral materials tones	34,020	209,520	165,680
Quantity of cardboard and paper recovered tons	304,340	138,420	306,780

Source: Provincial Public Institution for the Management of Technical Landfill Centers, Oran

The table shows a 3.5% decrease in the quantity of plastic materials. This decline is linked to the activities of individuals operating outside the municipal sector, within the informal sector known locally as “Sharamtiya.” The term Sharamtiya is commonly used in Oran to describe the first people who arrive at waste containers. They tear open garbage bags to sort out their contents. These individuals and groups are usually the first to reach containers, where they search through and rip bags to collect plastics, metals, and cardboard. They use carts and trucks and work with private entities such as recycling companies and scrap dealers inside and outside Oran.

7. Opportunities and Challenges Related to Waste Management in Oran:

a- Potential Opportunities for Effective Waste Management and Circular Economy Activation in Oran

The term "circular economy" first emerged in 1989 with the publication of a book titled *Natural Resource and Environmental Economics*. The authors, David Pearce and Kerry Turner, discuss the relationship between the economy, natural resources, and the environment. (Ghallab, December 2022, p. 446).

The circular economy, by contrast, is defined as an industrial system that produces no waste and causes no pollution. It seeks to shift manufacturing processes from reliance on fossil fuels to the use of renewable energy. The goal is to address the increasing demand for energy and resource consumption. Additionally, it fosters a culture of coexistence with ecosystems and promotes respect for the environment.

• Table 8: Waste Quantities at Technical Landfill Centers (2021-2024)

Technical Landfill Center	2021	2022	2023	2024
Hassi Bounif	440,535,790	402,560,584	444,197.64	475,310,280
El-Ançor	51,976,220	53,327,566	48,225.33	47,006,950
Arzew	43,623,460	42,604.93	4061141	45,808,610

Source: The Public Provincial Institution for the Management of Technical Landfill Centers of Oran
 The annual waste generated across the three centers in Oran for the year 2024 is estimated at 568,125.84 tons. Of this amount, 55% could be converted into organic fertilizer, while 10% of plastic and 10% of paper and cardboard could be recycled. These represent lost opportunities to recover raw materials that are readily available.

If societal and economic views of waste shifted from seeing it as pollution and a cost burden to regarding it as a free resource, significant benefits would follow. For example, 300 to 1000 kg of waste can yield a barrel of biofuel. Additionally, one kilogram of cow dung produces approximately 50 liters of biogas, and one kilogram of chicken waste produces approximately 70 liters.

A positive outlook on the increasing amounts of waste, combined with the experiences of emerging countries, the integration of artificial intelligence, and the encouragement of innovative mechanisms, reflecting material and energy gains—provided these are sustainably and innovatively valued. Moreover, such developments can generate direct and indirect employment opportunities for marginalized groups by integrating them into the formal sector (notably referring to the informal waste collectors known locally as “sharamtiya”). Waste volume also serves as an indirect indicator of quality of life.

In Algeria generally, and Oran in particular, there remain untapped golden opportunities to benefit from and valorize waste. The Hassi Benif Technical Landfill Center has attracted European and Russian interests in biogas production and electricity generation. It is estimated that between 1.2 and 2.5 kg of waste can produce about 1 kilowatt-hour of electricity. This suggests the potential to provide renewable public lighting energy for every municipality.

During the Mediterranean Games hosted by Oran in 2022, a prototype of smart waste containers was presented at the Mediterranean Sports Village. However, this initiative was limited to that event and location and was not extended or implemented in other neighborhoods to facilitate recycling processes and improve the city's urban environment.

In 2024, Oran gained an opportunity with the first pilot project to establish an “Intercommunal” institution responsible for waste management. The ARDAL project operates through international cooperation involving the Ministry of Interior and Local Authorities, the French Union, and the Italian Ministry of Environment. The project aims to foster international cooperation to strengthen local development in municipalities and support decentralization, especially in waste management, drawing on the expertise of other Mediterranean cities.

Furthermore, Oran benefits from multiple twinning agreements with foreign cities under Executive Decree 17-329. This decision authorizes national local authorities to establish international twinning partnerships in fields such as urban development and planning, transportation, environmental protection, renewable energy, water resources and irrigation, public facilities and modernization of regional administration, education, hygiene and social protection, culture, youth and sports, economic and social development, agriculture, forestry and fisheries, tourism and traditional crafts, and training for local officials (Derrar, 2018, p. 82).

From the Mediterranean shore, notable twinning agreements include Oran with Valencia and Alicante in Spain, supported by the European Center for Small and Medium Enterprises. Additionally, there is a partnership with Bordeaux, France, which facilitates guidance and support for project holders. Oran is also twinned with Sousse in Tunisia and the city of Java in Indonesia. Such twinning collaborations significantly assist Oran in promoting local development and encouraging startups in waste management from technical, scientific, and financial perspectives.

a-a Valorization of Organic Waste

Optimal utilization of organic waste—including food scraps, green waste, livestock manure, and slaughterhouse residues—greatly contributes to the production of organic agricultural fertilizers. Composting results from the natural decomposition of organic materials containing carbon and nitrogen. This method offers a sustainable approach to managing organic waste. It reduces waste volume, extends the lifespan of technical landfill trenches, improves soil productivity, and lowers the financial burden of purchasing chemical fertilizers. Moreover, it helps protect consumer health by ensuring the vitality and safety of food.

According to the National Waste Agency, only about 1% of organic waste in Algeria is currently exploited for composting. Examples include the Blida project, which is a collaboration between the Ministry of Environment and the Belgian Cooperative Directorate, as well as composting units in Mascara, Mostaganem, and Sidi Bel Abbès.

In Oran, the NGO AR20MED leads an ecological project to convert organic waste into agricultural organic fertilizers. This involves processing vegetable and fruit waste from the wholesale fruit and vegetable market in the El Karma municipality, one of the most important regional markets in Algeria, managed by the Public Institution for the Management of Wholesale Fruit and Vegetable Markets. The NGO, based in Oran, focuses on environmental issues in the Mediterranean region and has an ecological cooperation agreement with the Belgian Cooperation Directorate. It also runs a project for sorting household waste and similar materials across 1,200 homes in the Bir El Djir municipality.

The treatment of household organic waste in Oran presents a significant opportunity to support environmental entrepreneurship and to establish startups producing eco-friendly organic fertilizers, provided the waste is first sorted at its source (homes, restaurants, hotels, etc.).

Oran has great potential for organic waste production due to the daily output from homes (food scraps, vegetables, fruits), the presence of over 150 hotels and more than 1,000 restaurants, university service areas, educational institution cafeterias, 122 local markets, 109 covered markets, 67 weekly markets, and 285 slaughterhouses (Regional Directorate of Commerce, Oran report). These residues can be effectively exploited and transformed into sustainable organic fertilizers.

a-b Recycling and Reuse

Recycling and reuse contribute significantly to activating the circular economy and advancing the green economy by protecting the environment and biodiversity. These processes help reduce raw material consumption and extend product life through reuse. For example, recycling one ton of paper saves 17 trees, conserves 7,000 gallons of water, and reduces air pollution by 90%. It also prevents biodiversity loss by protecting thousands of trees from being cut down and preserving marine and terrestrial ecosystems that serve as habitats for thousands of animal and plant species. Furthermore, recycling reduces soil erosion, groundwater pollution, and the depletion of non-renewable energy resources, thereby preserving them for future generations. Recycling also encourages the development of manufacturing industries.

A 2012 economic study from the Arab League University reported that Arab countries lose about 5 billion dollars annually due to neglecting waste recycling. These countries generate approximately 6.89 million tons of waste annually. This amount could allow the remanufacture of around 3.14 million tons of paper valued at \$2.145 billion, 8.1 million tons of iron valued at \$135 billion, and roughly 75,000 tons of plastic worth \$4.1 billion (Hebri, 2019, p. 10).

Algeria alone loses approximately 300 million euros annually because of inadequate recycling, reflecting a delay in waste recycling efforts. This situation is being addressed by encouraging investors to enter this sector through the 2014 finance law, which introduced significant tax exemptions.

At the end of 2021, the National Waste Agency (AND) and the National Youth Employment Support Agency launched a project to establish 5,000 very small enterprises. This project aims to implement a support program for the environmental entrepreneurship sector, funded by the European Union with 34 million euros. It targets two main objectives: socio-ecological transformation and ecological transition by supporting the circular economy and encouraging the green economy.

a-c Energy Valorization

Biomass utilization is considered one of the key components of the so-called circular economy and the bio-economy. It plays a crucial role in using organic waste residues, which strongly contributes to achieving sustainable development goals. This is particularly relevant to Sustainable Development Goal 7, which focuses on providing clean energy sources for sustainable development in agriculture and industry, at affordable costs, especially in developing or less-developed countries.

Biodegradation is the process of converting organic matter into bioenergy, either in the form of biogas (a gaseous fuel) or biofuels such as ethanol and biodiesel (liquid fuels). Biogas mainly consists of methane (CH₄) and carbon dioxide (CO₂), along with small amounts of hydrogen sulfide (H₂S), nitrogen (N₂), oxygen (O₂), and water vapor (H₂O). This occurs under anaerobic conditions through the process of anaerobic digestion and fermentation, driven by a complex group of bacteria. This process offers dual benefits: it treats organic waste while simultaneously producing a usable energy source that can serve as an alternative to fossil fuels.

Bioenergy technologies based on biogas and biofuels continue to attract significant attention worldwide. Emerging countries have been striving for years to develop their technical and production capacities in this type of fuel. Their goal is to diversify local energy sources, meet the growing energy demands of their populations, and improve waste management. This is especially important in the context of climate fluctuations and the volatility of global energy markets.

Algeria still relies heavily on oil rent for its exports, despite its vast potential for renewable energy sources such as solar, wind, and waste. Bioenergy technology is not new in Algeria. The first biogas digester was designed in 1938 in El

Harrach (Algiers) by the French professors Isman and Doucelier. The main advantage of biogas technology lies in its ability to add value to biomass chains by closing material cycles and enhancing energy efficiency (Benaissa, 2020, p. 66). Considering the benefits mentioned, this represents a missed opportunity in Algeria to recover energy from fermentable organic waste and to produce biogas and biofuels. These can be converted into electricity to supply rural and isolated areas.

Algeria is currently planning to launch a national pioneering project to valorize waste by converting it into biogas similar to natural gas. This will be achieved by rehabilitating the Oued Es-Smar landfill in the capital, transforming it into a hub for converting waste into electrical energy and serving as a model for biogas valorization (Boudbia, 2024, pp. 10-36). However, the project remains under consideration, hindered by legislative, organizational, economic, and financial challenges.

b- Challenges and Obstacles to Effective Waste Management in Oran

Oran has great potential for investment in the management and exploitation of domestic waste (DMA). It also offers opportunities to support environmental entrepreneurship, such as startups in recycling, bioenergy production, and the application of the latest technological innovations, including artificial intelligence. However, these possibilities are currently limited by several obstacles and challenges, notably:

b-a Legislative and Regulatory Challenges:

Despite the existence of important legal texts governing waste management in Algeria, such as Law 01-19 dated December 12, 2001, on waste management, monitoring, and removal; Law 03-10 dated July 20, 2003, on environmental protection within sustainable development; Executive Decree 02-175 on the establishment, organization, and legal operation of the National Waste Agency; Law 11-10 concerning municipalities; and Law 12-07 concerning wilayas, there remain gaps and vague legal provisions that require revision and amendment. For example, Law 01-19 does not provide a clear definition of waste management but rather lists the stages it undergoes (Sharif, 2020, p. 114). It also fails to address mechanisms for sustainable and integrated management of domestic waste and similar materials. The law assigns the head of the Municipal People's Assembly the responsibility to prepare a municipal waste management plan. However, it does not specify the financial and technical mechanisms needed for preparation, implementation, monitoring, and evaluation. It also does not account for disparities and financial support between municipalities within the same wilaya. Additionally, Article 51 of Law 01-19, related to household waste management, mandates the collection of a waste removal tax (TEOM: *Taxe d'Enlèvement des Ordures Ménagères*) for local authorities. However, coverage remains low and below expectations. This is largely due to the absence of implementation regulations clarifying the practical aspects of tax collection. Tax inspectorates face difficulties enforcing fees on municipalities that cannot impose charges commensurate with the public services provided to citizens.

The application of environmental taxation (the green tax) is considered an economic tool to address environmental problems under the “polluter country” principle. This principle monitors industrial entities and how they handle their waste, obligating them to treat their residues properly. However, in practice, the green tax mostly serves as a financial contribution toward landfill centers. This is due to the lack of proper legal backing and weak administrative effectiveness in monitoring and enforcement. The environmental pollution effects are often only observable over time, complicating immediate action.

Investment Law 22-18 Related to Investment in Algeria: Known as the new investment law dated July 24, 2022, this legislation repealed the provisions of Law 16-09 on investment development. The new law outlines the regulatory procedures applied to both domestic and foreign investments. It also includes incentive systems, particularly affecting the renewable and new energy sectors (Investment Law 22-18, Official Gazette No. 50, July 28, 2022, p. 8). The law establishes principles and guarantees to encourage investment and attract foreign capital to support the national economy. It aims to provide an effective investment environment in Algeria through transparency, digitalization, equality among investors, combating all forms of bureaucracy, and guaranteeing freedom of investment.

However, some gaps and clear points remain. These include the need to detail the legal provisions and their implementation mechanisms, clarify guarantees for foreign investors, establish a real estate agency for industrial property, and develop logistics and transport sectors to enhance efficiency and economic flow.

b-b Technical Aspect and Sector Digitalization:

Urban administration in Algeria suffers from significant delays in personnel training in digital skills and software management. Public spaces and streets lack sufficient surveillance cameras. Coordination between municipal technical departments, urban police units, and environmental protection agencies remains weak in addressing violations affecting environment, cleanliness, and public health through official reports.

Furthermore, the shortage, types, specialization, and poor distribution of waste containers in some neighborhoods have contributed to accumulated problems. This situation persists due to the absence of a guiding plan or technical standards.

Nevertheless, the National Waste Agency has developed the National Waste Information System (SNID). On June 5, 2015, it launched an industrial waste exchange platform online. This platform connects waste producers and recyclers across Algeria and is accessible via the website bourse.and.dz, available in both French and Arabic. The platform includes advertising space for companies, technical waste cards, and pricing information.

Additionally, the agency launched the “Nadhif” (Clean) application, enabling citizens to report illegal dumping sites (“black spots”). This allows municipalities to respond by removing waste. However, some municipalities delay intervention due to the lack and deterioration of waste collection vehicles and frequent breakdowns.

There is also a beneficiary application designed for regular users, serving as a digital platform for waste valorization and recycling promotion. It offers comprehensive solutions for collecting and sorting recyclable waste and facilitates communication between waste producers, consumers, professional collectors, and collection centers.

Despite these initiatives, the sector remains far from full digitalization and the creation of comprehensive data sets necessary for smart, effective management and decision-making.

lack of Awareness and Enforcement Among Citizens (Decline of Civil Society's Role):

The German philosopher Hegel defined civil society as the link between the state and the family. (Ghano, 2021, p. 812).

Civil society holds immense power in decision-making, both positively and negatively. It acts as a social, political, economic, and cultural partner that carries the aspirations and goals of society. It exerts pressure on the state, especially when effective environmental associations lead the discourse. In waste management, environmental governance results from interaction between the state and its institutions, the private sector, and civil society in decision-making and law enforcement related to environmental dimensions and outcomes (Siham, 2023, p. 233). Germany achieved leadership in waste management after more than 25 years of integrated studies and efforts.

In Algeria, the National Observatory for Civil Society was established in 2020 by constitutional amendment, and its tasks and organization were defined by Presidential Decree No. 21-139 dated April 12, 2021. This relatively new body suffers from numerous shortcomings, most notably: The difficulty of selecting its members due to the large and diverse number of associations in Algeria, and the very limited representation of trade unions, which is minimal compared to their vital role in the world of work, reliance on the authorities, which restricts its independence and dynamism in its work, a lack of financial resources, legal constraints, and challenges related to transparency and management. a lack of accountability regarding the misuse of funds.

8. Case Studies of Northern Mediterranean Coastal Cities (Barcelona, Spain and Marseille, France):

The Mediterranean Sea is a biodiversity hotspot, containing 7.5% of the world's marine animal wealth and 18% of its marine plant resources. However, it is an ecologically fragile area because it is a semi-enclosed basin with a population estimated at 444 million. The average annual waste generation in Mediterranean Union municipalities is about 500 kg per capita, while in Maghreb countries it is around 250 kg per capita. This makes it one of the most polluted marine regions worldwide, and heavy metals and persistent organic pollutants threaten human health and marine life, especially along coastal areas that receive high levels of industrial liquid waste and household garbage, (Madan, 2021). The worsening environmental problems in the region have led to conflicts that threaten security and stability. Therefore, cooperation in environmental matters gained importance, resulting in the establishment of the Barcelona Convention (1976). This agreement was supplemented by six protocols aimed at protecting the Mediterranean Sea, preventing waste dumping, and conserving biodiversity. It emphasizes continuous joint action and cooperation between parties to monitor and assess environmental conditions, support scientific and technical cooperation, and exchange information within the region.

We selected two European Mediterranean cities, Marseille (France) and Barcelona (Spain), to study their waste management systems. These cities share many urban characteristics with Oran. Each is the second most important city in their respective countries in terms of economic significance and population density. They also share geographical similarities (climate, vegetation cover, agricultural crops, demographic traits, geological structure, ports), as well as cultural and culinary intersections and strong artistic and cultural exchanges. All three are cosmopolitan cities with diverse populations from various ethnic and national backgrounds.

Oran could potentially cooperate with these cities in waste management, benefiting from their expertise within the framework of decentralized local governance and city twinning programs.

8.1 The Waste Management Experience in Marseille:

Marseille is a coastal city and one of the most significant cities on the northern Mediterranean. It is the second-largest urban and economic center in France after Paris. It is part of a metropolitan union comprising six major cities under one regional authority: La Métropole d'Aix-Marseille-Provence (AMP), located in the Bouches-du-Rhône department, according to France's 2014 administrative division.

As of January 1, 2016, AMP was established, comprising 92 municipalities and housing about 1.9 million residents. The metropolitan area features a multi-core urban network, meaning decision-making is decentralized (Daniel, 2014).

Marseille boasts vast natural resources, strong infrastructure, and continuous activity in hosting economic, sports, environmental, and business events. It is a prominent global tourist destination. In 2023, Marseille welcomed 16.2 million tourists, according to the Tourism Office and the Marseille Entertainment and Conference Center.

This urban and economic importance places Marseille at the center of challenges, notably environmental conservation and sustainable waste management.

The city has adopted plans and programs aiming to make Marseille more resilient and sustainable by 2030. For example, there is a joint program to enhance and preserve biodiversity as part of preparing the city of tomorrow.

A. Waste Management and Governance Mechanisms in Marseille: The AMP metropolitan area covers 3,173 km² and generates approximately 1.8 million tons of residual household waste annually from its 92 municipalities, averaging 621 kg per person per year.

Waste management follows the metropolitan waste management plan (Schéma Métropolitain de Gestion des Déchets de la Métropole (AMP)), which is based on five fundamental principles known as the “5Rs”: prevention, reduction, reuse, redirection, and recycling/composting, along with recovery and other disposal methods.

Marseille's waste management encourages sorting at the source. Specific days are allocated for waste collection, ranging from three to seven times per week depending on neighborhood waste volume. Waste is then transported to treatment centers such as sorting facilities, storage sites, and incineration plants.

The strategy focuses heavily on promoting source sorting and minimizing waste production as much as possible. Municipalities provide households with colored bags and containers to facilitate sorting, aiming to engage citizens and raise their awareness, recognizing them as primary waste producers. Recycling rates are high: 80% for cardboard and paper, and 100% for glass waste.

B. Infrastructure for Waste Management in Marseille: France, through its 2015 Energy Transition Law, focuses on promoting the growth of the green economy, developing the circular economy, enhancing renewable energy production, reducing greenhouse gas emissions, and achieving energy independence. The region includes 58 waste collection sites equipped with specialized containers for plastics, cardboard, glass, furniture, and more. These containers vary in size according to districts and neighborhoods to accommodate the volume of household waste. Citizens can use smart applications to easily find the nearest disposal points.

Waste management is overseen by inter-municipal public cooperation institutions (Établissements Publics de Coopération Intercommunale, EPCI), which coordinate waste handling among the municipalities within the metropolitan area.

There are six public EPCI bodies responsible for waste collection, transport, and treatment. Their revenues are supported by waste collection taxes (Final Observation Report of the Aix-Marseille-Provence Metropolitan Area (Bouches-du-Rhône), p. 41).

The area contains 19 waste transfer stations, two of which connect to the rail network. There are four composting plants that convert 65% of household organic waste into organic fertilizers, with a goal to increase this to 85% by 2030. Facilities also include storage centers for recovered household and special waste and a multi-sector treatment center.

The Fos-sur-Mer center plays a crucial role in waste management. It receives about 410,000 tons of waste annually, 40% of which is recyclable. The center houses two technical units for incineration and energy generation.

Waste incineration at this facility emphasizes recovery and environmental protection. It is operated by EveRé, a subsidiary of the international group Urbaser, one of the leading actors offering effective waste management solutions. These combine sorting, storage, composting technologies, and biogas utilization through advanced sustainable development techniques.

EveRé holds a patented technology for converting methane into a valuable resource and recovering energy through incineration. The energy generated supplies electricity for a population of approximately 50,000 residents. Around 20% of this electricity is used internally, while the remaining 80% is sold back to the ENEDIS grid. The resulting ash is treated and reused in construction and public works.

The Aix-Marseille-Provence metropolitan area produces green energy from biogas. The SUEZ group has invested €2.31 million to exploit biogas production, generating 2.3 million cubic meters annually. This energy covers the domestic needs of about 2,500 households and power long-distance buses, aiming to reduce ecological footprints and dependency on oil (Press kit, March 8, 2018, Marseille).

The AMP metropolitan area seeks to improve waste management efficiency by implementing RFID technology. This system tracks container locations and monitors their fill levels to optimize truck routes, reduce costs, and enhance recycling effectiveness.

8.2 Waste Management Experience in Barcelona:

Barcelona is a Mediterranean city bordered by the Mediterranean Sea to the southeast. It covers an area of 636 km² and has an estimated population of 1.6 million. As the vibrant and dynamic capital of Catalonia, it is one of the world's

earliest smart cities. Barcelona ranks as the second-largest city in Spain in terms of population and economic importance. It is among the top ten tourist destinations worldwide, receiving around 18 million visitors in 2023.

A. The Metropolitan Area of Barcelona (AMB):

The metropolitan area of Barcelona consists of a cluster of cities comprising 36 municipalities with a total population exceeding 5.2 million. Each municipality is responsible for governing and managing its city. The municipalities operate under the metropolitan council, which includes elected officials from the member municipalities. Additionally, a governing board handles daily administration.

Established in 2010, the metropolitan area serves as a tool to implement large-scale strategic projects. It aims to become a cohesive urban structure and an inspiring model for addressing urban challenges. It also represents a global urban vision through the Urban Development Plan (PDU) and the "Corridors" project.

Barcelona was among the first cities to transition into a smart city by actively involving its citizens in public policy, under the principle that "there is no smart city without smart citizens." Thanks to these policies, Barcelona was awarded the title of "European Capital of Innovation" by the European Commission in 2014.

The city's digital success is summarized in a set of guiding principles, referred to as the "Ten Commandments" (Josep-Ramon Ferrer, 2017, p. 72). Ten Commandments were developed collaboratively between the City Council and the consulting firm Doxa Innova and Smart. They can serve as a guide for other cities to integrate digital technologies aimed at transforming and improving their organization and engagement with citizens to meet their needs and interests. This approach has positioned Barcelona as a global capital of architecture, recognized by UNESCO and the International Union of Architects for the period 2024-2026.

Citizens play a central role in advancing intelligence in Barcelona. They participate openly, inclusively, and collaboratively in shaping the city's programs and public policies. They also take part in implementing and evaluating these policies. Barcelona won the European Capital of Innovation award from the European Commission since 2014.

B. Waste Management in Barcelona:

Barcelona's waste management model is considered one of the most efficient and advanced in the world. It applies smart management systems, uses clean energy, and reduces carbon dioxide emissions (Shehira Ben El Nia & Fouad Nahwi, 2025).

The approach is integrated, combining technology, selective waste collection, the circular economy, and citizen involvement to build a more sustainable future. The goal is to achieve a compact, low-carbon city. The Internet of Things (IoT) and big data technologies have contributed to the city's economic growth, transformed citizens' lifestyles, and improved their quality of life.

In 2023, the Barcelona metropolitan area (AMB) generated 1.49 million tons of waste. This equates to 444.3 kilograms per person annually. Of this, 42.1% of waste was sent to recycling centers, 35.1% was organic waste, 26.7% underwent energy recovery, and 26% ended up in landfills. Collecting organic waste is essential to improving recycling rates. In 2023, Barcelona is firmly committed to environmental transformation through waste management. Source separation is a priority, supported by:

1. Simplifying the sorting and collection process using a color-coded bin system:

- o Green bin: for glass (bottles, jars, etc.).
- o Blue bin: for paper and cardboard (newspapers, magazines, packaging, etc.).
- o Yellow bin: for plastic and metal packaging (plastic bottles, cans, tins, etc.).
- o Brown bin: for organic waste (food scraps, peels, etc.).
- o Gray bin: for non-recyclable waste (diapers, garbage bags, cigarette ashes, etc.).

Barcelona was among the first cities to adopt smart bins that use vacuum technology to move waste underground, reducing odors and visual pollution. These bins are equipped with sensors and are widely distributed across streets, monitored via interactive maps available on the AMB website. Citizens can also access this service by downloading the "Barcelona Residus" mobile app.

Furthermore, the Catalan Waste Agency established the "Residuonvas" website to support waste management efforts

A. Recycling:

The public policy on waste management focuses on adopting the R5 approach as a technique to achieve zero waste. Accordingly, the Barcelona City Council developed the "Barcelona Zero Waste Plan 2021-2027." This plan serves as a tool to address strategic challenges and objectives related to waste prevention and management for the coming years.

B. Energy Recovery from Waste:

Waste is considered the third source of renewable (clean) energy after solar and wind power. The Barcelona Metropolitan Area (AMB) has adopted an integrated solution for waste treatment. It goes beyond sorting and reuse, employing landfill technologies and advanced fourth-generation incinerators for energy production. These incinerators are highly efficient and environmentally safe, operating under the supervision of specialists from the Catalan Waste Agency under the Ministry of Environment.

C. Local Solid Waste Treatment and Energy Production Center – Ecopark 3:

Ecopark 3 is a public facility covering three hectares in the Sant Adrià de Besòs area, north of Barcelona. It is technologically advanced and located near residential buildings by one of Barcelona's beaches. It borders the gas and electricity company, the Besòs River, Parc de la Pau, and the Marina Forum. The site is six kilometers from the International Conference Center, where the Barcelona Convention and its protocols for protecting the Mediterranean Sea from pollution were signed in 1976.

The facility is operated by TERSA, a public company jointly owned by the City of Barcelona and the Barcelona Metropolitan Area. Ecopark 3 performs multiple functions, including mechanical and biological treatment, material recovery, thermal decomposition, and incineration. Its annual production capacity is estimated at 108 million cubic meters of biogas and 20.5 gigawatts of renewable electrical energy (Abbas Ibrahim Zahrudin).

9. Use of Artificial Intelligence in Waste Management:

Cities have transitioned from traditional management and planning to an era where technology and artificial intelligence (AI) are employed to support decision-making, reduce costs, enhance environmental sustainability, and improve citizens' quality of life amid the Fourth Industrial Revolution.

The rapid pace of technological development has pushed the world toward smart cities. These cities represent the path to digital transformation and global integration by finding technological solutions to protect the environment and promote sustainability.

A smart city is broadly defined as a digitally interconnected urban area that employs information and communication technologies across sectors such as the economy, education, urban management, and governance. The goal is to produce a localized information society (Léonidas G. Anthopoulos, 2014, p. 03).

Statistics indicate that the urban population worldwide is continuously increasing. It is expected to reach 6.7 billion by 2050. This growth makes smart cities essential to meet the rising demands of urban residents. Smart cities are equipped with modern technologies that help solve urban problems, enhance citizens' quality of life, and increase efficiency in managing resources and public services.

Experts argue that the move toward smart cities and the use of AI technologies will solve many issues, especially waste management, by:

1. Digitizing the waste sector and utilizing big data:

The most advanced countries have made significant achievements in digitizing the waste sector and using AI as an effective tool. Switzerland, Austria, the Netherlands, Sweden, and many other European countries apply advanced technologies for waste collection, sorting, and treatment, which promote more efficient and sustainable management.

9-1. Use of Artificial Intelligence in Recycling Processes and Promoting the Circular Economy:

The use of robots equipped with sensors and machine learning algorithms helps reduce pollution and improve overall efficiency to achieve zero waste. These technologies assist in sorting and recycling, lowering labor costs while increasing speed and accuracy in the sorting process.

The Finnish company ZenRobotics is a pioneer in applying artificial intelligence to develop robots that perform various waste sorting tasks. Their robots can separate 3,000 items per hour and identify over 25 types of waste, including plastics, paper, metals, glass, and textiles. They are capable of sorting 2,000 tons of waste continuously within 24 hours, which equals the work of 48 human laborers (Electronic Components Field, Amnesty International's Advantages in Waste Sorting, 2019).

Additionally, European Union-funded research has developed smart robotic systems capable of identifying and independently handling old radioactive waste in nuclear facilities. This technology aims to safely dispose of 4.9 million tons of legacy nuclear waste in the United Kingdom, including by-products from Cold War weapons production. Professor Rustam Stolkin notes that cleaning the UK's nuclear waste is the largest environmental remediation project in Europe. It is expected to last over 100 years and cost more than 200 billion euros. At least 20% of the operational work is carried out by robots.

The EU-funded RoMaNS project coordinates advanced robotic technologies designed to perform critical tasks in hazardous environments safely and cost-effectively. These systems have surpassed the latest advances in robotic vision, motion planning, control, and human-robot interfaces. For the first time, these technologies are being applied to address important societal challenges posed by nuclear environments (Dr. Rustam Stolkin et al., "Robots that Learn: Nuclear Robotics Meets Machine Learning," Royal Society and Susannah Odell, April 27, 2017).

9-2. Employing Artificial Intelligence in Biological Innovations:

Plastic recycling remains one of the greatest challenges faced by scientists in addressing major environmental problems linked to climate change. Recent research has made significant progress in discovering and engineering enzymes capable of breaking down plastics. These enzymes show promising potential for sustainable enzymatic biodegradation and recycling of plastic waste.

Researchers at the University of Portsmouth and the US Department of Energy have developed an enzyme that can consume plastic. This enzyme could greatly reduce pollution and plastic waste accumulation. The scientists discovered this enzyme while examining a natural enzyme structure found years ago in a plastic recycling center in Japan.

According to a CNN report, the enzyme, named *Ideonella sakaiensis*, can degrade polyethylene terephthalate (PET), a plastic material first developed in the 1940s. PET is widely used in millions of plastic bottles. This discovery aims to contribute to recycling efforts and reduce plastic pollution, particularly in oceans and seas.

The enzyme was identified using computational metagenomic screening of databases with a Markov hidden model-supported search algorithm (Baotong Zhu, Dong Wang, and Na Wei, 2022, p. 23). This metagenomic screening is relatively fast and cost-effective for enzyme extraction. However, its success depends on the size and quality of gene annotations in current databases of known plastic-degrading enzymes.

9-3. Carbon Capture Technologies:

Carbon capture is one of the most important technological applications in environmental science. It involves separating carbon dioxide, a major pollutant, from gases produced during electricity generation. The captured CO₂ is then transported through a network of pipelines and stored in geological formations beneath the Earth's surface.

9-4. Applications of Nanotechnology:

Nanotechnology plays a significant role in protecting the environment from pollutants. Its applications include:

- Removing environmental pollution by using microscopic machines to break down toxic and radioactive substances.
- Air quality monitoring.

CONCLUSION:

Waste management is a fundamental and priority issue for supporting environmental governance. It is also a key mechanism for advancing the principles and goals of sustainable development. Moreover, it serves as an indicator of how well countries and cities can adapt to and engage with the Fourth Industrial Revolution. This adaptation is essential for achieving effective and flexible waste management.

Green technology offers powerful tools to maximize the benefits derived from waste. However, the city of Oran remains far from implementing smart management and artificial intelligence technologies in this field. There are obvious gaps in the management chain at the levels of municipalities, civil society, and citizen behavior, which often disregards environmental considerations. This is largely due to the lack of enforcement of regulatory frameworks such as the TEOM (Waste Collection Tax) and green taxation.

These factors have contributed to delays in achieving effective waste management. Nevertheless, this does not diminish the current management efforts, which rely heavily on the significant technical role of landfill centers in waste treatment.

The remarkable progress made by cities in developed countries was neither accidental nor immediate. It took decades—up to a quarter of a century—to build effective and flexible waste management systems. These systems encourage innovation in green technology, establish diverse partnerships, and facilitate the exchange of knowledge and expertise. Oran has a golden opportunity to build an integrated information system for waste management. It can benefit from the experience of pioneering neighboring cities in smart waste management, such as Barcelona. This opportunity will materialize if financial resources and qualified personnel are allocated to develop an effective recycling system. Engaging citizens in the process by encouraging leaving at home is crucial. This can be supported by expanding applications that convert waste into funds and by enforcing financial penalties on environmental violations that burden citizens' finances. Additionally, developing and digitizing infrastructure can reduce costs, save time, and conserve effort. Activating media channels and social media platforms to foster a culture of recycling and waste reduction will undoubtedly halt environmental violations that have persisted for decades.

In conclusion, Oran deserves an integrated and effective management system that highlights its regional importance and connects it to the Mediterranean and global urban network.

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