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Topic

Advancing the Waste-Energy-Climate Nexus in Algeria: Circular Economy Potential and Challenges for Municipal Waste-to-Energy in El Oued

On June 2025 in front the jury committee:

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Abstract

Municipal waste management poses a significant challenge in Algeria, with traditional disposal methods contributing to environmental pollution and greenhouse gas emissions. In regions like El Oued, agricultural and urban waste streams offer an underutilized resource for energy generation. Adopting a circular economy framework presents a pathway to close waste loops, transforming waste into a valuable energy source and supporting Algeria's climate goals. Despite the huge number of studies carried out in this topic, only few works are done in the Algerian context.

This thesis aims to investigate the potential of circular economy principles to advance the waste-energy-climate nexus in Algeria, with a focus on municipal waste-to-energy (WtE) systems in El Oued. The main objective is to quantify WtE potential through the anaerobic digestion process, identify challenges, opportunities, and provide recommendations for stakeholders for promoting a sustainable WtE circular economy within the region. Both qualitative and quantitative methods will be used to achieve the goals of this work.

The findings of this thesis are promising and helpful for stakeholders (include policy makers, private sector, municipality…) to make best decisions on the municipal waste management with circular economy practices in El Oued and overall national territory of Algeria.

Key words: Municipal waste management, climate change, circular economy, waste to energy, waste-energy-climate nexus, anaerobic digestion, sustainability assessment.

ملخص

تُشكّل إدارة النفايات البلدية تحديًا كبيرًا في الجزائر، إذ تُساهم طرق التخلص التقليدية في تلويث البيئة وانبعاثات غازات الاحتباس الحراري. في مناطق مثل الوادي، تُشكّل مجاري النفايات الزراعية والحضرية موردًا غير مُستغلّ بالكامل لتوليد الطاقة. يُمثّل اعتماد إطار عمل الاقتصاد الدائري مسارًا لإغلاق حلقات النفايات، وتحويلها إلى مصدر طاقة قيّم، ودعم أهداف الجزائر المناخية. على الرغم من العدد الهائل من الدراسات التي أُجريت في هذا الموضوع، إلا أن الأعمال المُنجزة في السياق الجزائري قليلة.

تهدف هذه الأطروحة إلى دراسة إمكانات مبادئ الاقتصاد الدائري في تعزيز العلاقة بين النفايات والطاقة والمناخ في الجزائر، مع التركيز على أنظمة تحويل النفايات البلدية إلى طاقة (WtE) في الوادي. الهدف الرئيسي هو تحديد إمكانات تحويل النفايات إلى طاقة من خلال عملية الهضم اللاهوائي، وتحديد التحديات والفرص، وتقديم توصيات لأصحاب المصلحة لتعزيز اقتصاد دائري مستدام لتحويل النفايات إلى طاقة في المنطقة. سيتم استخدام كل من الأساليب النوعية والكمية لتحقيق أهداف هذا العمل. تُعدّ نتائج هذه الأطروحة واعدة ومفيدة لأصحاب المصلحة (بما في ذلك صانعي السياسات والقطاع الخاص والبلديات...) لاتخاذ أفضل القرارات بشأن إدارة النفايات البلدية من خلال ممارسات الاقتصاد الدائري في الوادي وعلى الصعيد الوطني الجزائري.

الكلمات المفتاحية: إدارة النفايات البلدية، تغير المناخ، الاقتصاد الدائري، تحويل النفايات إلى طاقة، العلاقة بين النفايات والطاقة والمناخ، الهضم اللاهوائي، تقييم الاستدامة.

Dedicated to

OUR PARENTS

OUR FAMILY

OUR COLLEGES

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Contents

Nomenclature and Abbreviations

WtE	Waste to Energy
MSW	Municipal solid waste
GHG	Green House Gas
WECn	Waste-Energy-Climate nexus
CE	Circular economy
AD	Anaerobic Digestion
WHO	World Health Organization
CO2	Carbon dioxide
MENA	Middle east and north Africa
NSIW	National Strategy for Integrated Waste Management
RDF	Refuse-Derived Fuel
LCA	Life Cycle Assessment
UK	United Kingdom
USA	United States of America

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Introduction

Background

In the face of rapidly increasing urbanization, population expansion, and inadequate infrastructure, Algeria, like many developing countries, has growing issues in handling growing municipal solid waste (MSW). Besides, inadequate disposal methods, primarily open dumping and uncontrolled landfilling, contribute to the mismanagement of MSW in the country. In addition to degrading the environment, these methods increase greenhouse gas (GHG) emissions, especially methane that leads to climate concerns and the spread of many diseases.

Meanwhile, Algeria is struggling to satisfy its climate mitigation obligations under the Paris Agreement, diversify its energy sources, and decrease its reliance on fossil fuels. Thus, waste-to-energy (WtE) technologies—processes that recover energy from trash, mainly organic waste through several technics such as incineration, anaerobic digestion, or gasification—offer a promising solution for addressing the stated issues and targets.

El Oued province, which located in the southeast and semi-arid climate of Algeria, as an example is characterized by increasing MSW quantities (mainly organic waste) due to rapid population growth and over availability foods, and accelerated rate of land use activities (urbanisation and agricultural activities), offers both a challenge and an opportunity for implementing WtE within a circular economy framework. A circular economy strategy based on WtE will contributing on enhancing the nexus of waste management, energy generation, and climate mitigation (Waste-Energy-Climate nexus or it is abbreviated to WECn) in this urbanised and active region.

Problem Statement

Although Algeria has embraced the ideas of a circular economy and sustainable waste management in theory and policy, these concepts have yet to be effectively put into practice. Moreover, WtE solutions are still not widely investigated by researchers in the Algerian context, not incorporated into local municipal planning, local stakeholders are rarely involved in decision-making processes and there's a noticeable gap when it comes to technical and financial feasibility studies at the community level, specifically in the southern regions. Moreover.

El Oued, as a case study province of Algeria, it's especially important to explore MSW management situation and investigate how WtE circular economy technics could be implemented —while taking into account the region's environmental, economic, and social challenges.

Aim and Objectives

The aim of this thesis is to evaluate the potential and challenges of implementing municipal waste-to-energy strategies in El Oued within the broader context of Algeria's circular economy transition, energy security and climate mitigation targets. The main objectives of this work are to: (1) Assess the current state of MSW management in El Oued, (2) Estimate the technical potential for energy recovery from MSW, (3) Analyse the environmental and climate implications of WtE integration, (4) Identify Political, Economic, Social and Technical (PEST) challenges hindering WtE deployment in El Oued, (5) Recommend strategies for promoting sustainable WtE circular economy in El Oued.

Research Questions

- How much municipal solid waste is produced in El Oued, what is it made up of, and how well does it lend itself to energy recovery?
- Which WtE technologies would be the best fit for the local conditions in El Oued? How much amount of energy could be generated from MSW in the area?
- What kind of environmental and climate-related benefits could come from adopting WtE solutions in the area?
- What are the main obstacles—that stand in the way of implementing WtE projects?
- And finally, how can WtE initiatives be effectively woven into a wider circular economy strategy for the region?

Method

To achieve these goals, this study uses a combination of quantitative and qualitative methods. On the quantitative side, it estimates the energy potential of municipal solid waste (MSW) based on the waste's quantity, composition, energy content and the WtE method. A simplified energy recovery model (e.g., lower heating value–based calculations) is applied to assess WtE potential. On the qualitative side, the research draws on literature review, surveys and in-depth interviews with key stakeholders—including municipal representatives, waste handlers, local actors and residents—to better understand the technical, economic, political and social challenges surrounding the adoption of WtE solutions in the region.

The focus of the study is the El Oued municipality and surrounding urban areas, with attention placed solely on household waste. Additionally, the research includes an examination of national and local policies to better grasp the governance and regulatory environment shaping WtE opportunities in the region.

Structure of the thesis

This thesis is organized as follows.

Chapter 1 presents a comprehensive literature review, discussing the key studies, theories, and concepts related to WtE systems, circular economy concept, and their implications for El Oued, and Algeria.

Chapter 2 outlines the research methodology, detailing the quantitative and qualitative methods employed for data collection, analysis, and assessment of WtE potential in the region.

Chapter 3 presents and discusses the obtained results, including waste analysis, stakeholder interviews, and environmental impact assessments.

Finally, key findings of this thesis as well as the main research limitations and suggestions for future work are highlighted in the conclusion.

Chapter 1: Literature Review

Chapter 1. Literature Review

1. Overview

The continuous development and expansion of cities is accompanied by an increase in the economic level through industry, trade and all economic activities with the aim of increasing the percentage of employment and absorbing a large number of residents, and thus improving the standard of living and developing living conditions, resulting from an increase in the income of individuals and thus driving the wheel of construction and building movement, which causes an increase in consumption and consequently an increase in the amount of waste produced, which constitutes a heavy burden in how to dispose of it, especially in large cities, which are witnessing a continuous increase and growing danger day after day. Due to the diversity of waste emitted in cities, methods of disposing of it have become diverse, and interest in it has increased, and cooperation between various international and global organizations and bodies to learn about all development experiences in waste disposal and treatment and benefit from it, and exchange experiences between countries.

In this first chapter, we will focus on previous studies of this project, mention some of its advantages, and provide an overview based on previous studies, books, and magazines that have addressed the study of waste, its recovery, and, most importantly, its conversion into energy.

2. Conceptual framework of waste

Waste is a fundamental concept in the environmental field, possessing significant importance and a direct impact on various aspects of economic, social, and other life. We will discuss this topic in detail in this research.

2.1. Definition of waste

Definitions of the term waste vary depending on the study, the perspective from which it is viewed, and the field in which it is defined. We find:

<u>First: The linguistic definition:</u>

Linguistically, "nafa" is the plural of "nafayya," which is derived from the word "nafa." The waste of something is its remnant and worst [1]. In Lisan al-Arab by Ibn Manzur, it states: "Waste" (with a damma) is what you discard of something due to its bad quality. [2]

<u>Second: Technical definition:</u>

The World Health Organization defines it as: "Those things that are no longer wanted by their owner in a particular place or time, and that no longer have any importance or value". [3]

- Waste is the various wastes resulting from direct use or consumption, such as household waste, waste from roads, shops, and public markets, animal waste, farm waste, tree waste, and waste from slaughterhouses and hospitals. [4]

Official waste management agencies in various countries define waste as a collection of heterogeneous waste, which includes:

Various natural wastes and household wastes, such as food scraps or food preparation waste, sweepings, commonly used items that are no longer usable, newspapers and various papers, metal cans, bottles, paper or plastic containers, linen and other textile waste [5]...etc.

As for international bodies, the World Health Organization (WHO) has come up with the following concept: It is something that its owner does not want at a given time and place, and this item has a market value. This concept is linked to a spatial and temporal context, a market value, and a benefit to the waste holder. [6]. In general, waste is materials that have lost their importance and no longer have any value at all levels.

Third: Legal Definition:

The Algerian legislator defined waste as: "All residues resulting from production, transformation, or use, and more generally, any material, product, or movable object that the owner or possessor disposes of, intends to dispose of, or is obligated to dispose of or remove [7].

It also defined waste as: everything left over from the stages of production, transformation, or use, and all neglected or abandoned objects, materials, and products. In general, it means any movable object that is abandoned or relinquished by its owner." [8]

2.2. Characteristics of waste and its classification

2.2.1. Waste's suceptibility to chemical reactivity

The spread of large quantities of household waste over large areas leads to chemical reactions resulting in a complex mixture of the waste's constituent materials. Because this waste is biodegradable and decomposable, it will certainly impact the environment, leading to the spread of unpleasant Odors that impact public health. Furthermore, it has a significant impact on the aesthetics of cities. [9]

2.2.2. Waste's ability to be converted into fertilizers

This property distinguishes household waste from other wastes by converting it into fertilizers, which provides numerous economic advantages, especially in agriculture.

The conversion in this case occurs through the decomposition of organic matter present in household waste, producing a relatively stable humic substance. [9]

2.2.3. Waste Recyclability

Recycling plays an important role in protecting and preserving the environment by conserving resources, reducing consumption, protecting agricultural land and waste dumping sites, and protecting the environment from toxic materials and emissions. [9]

2.2.4. The heterogeneity of its contents and classification

It includes food scraps, fruits, vegetables, paper, glass, plastic, metals, and other waste, leading to a high percentage of organic matter in household waste. It is highly humid and non-degradable, becoming a source of unpleasant Odors and breeding grounds for flies and insects. Fig.1 presents a misxt of waste in a trash can in Algeria

Figure 1. Classification of waste in algeria . [9]

And Tab.1.summarizing the classification of waste in Algeria based on Law No. 01-19 of 2001.

Table 1. Classification of waste in Algeria based on Law No. 01-19 of 2001. [10]

Waste Category	Description
Household and Similar Waste	Generated from daily activities in homes and similar waste from industrial, commercial, and other sectors.
Bulky Waste	Large items from households (e.g., furniture, large appliances) that cannot be collected with regular waste.
Special Waste	Includes waste from industrial, agricultural, medical, and service sectors, requiring specific handling.
Hazardous Waste	Includes chemical, nuclear, and other dangerous waste that poses risks to health and the environment. Needs special disposal methods.

Algeria's legislative framework includes this classification system to manage and lessen the environmental impact of garbage disposal.

3. The Waste-Energy-Climate Nexus

There are multiple series of waste management method that has been introduced from the past few decades. Waste management options have been evolved from linear to the circular method, which includes the traditional landfill approach to the advance option such as incineration and WtE. Despite this evolution, waste management still becomes a controversial issue that is still being discussed openly in the modern world. This is since improper waste management still becomes one of the main factors that contribute to the current environmental problem such as pollution and climate change [11]. Dutta et al. [12], have verified a significant linkage between waste management and climate change. Their finding showed that the lack of awareness, policy implementation, and supply chain are the factors that contributed to poor waste management. Fig.2 shows the waste management hierarchy that is currently practiced globally, which recommends sustainable practice as an important part of waste management. Based on the figure, the most sustainable way of managing waste is by minimizing or reducing waste at the source.

Figure 2. Waste management Hierarchy Adapted from Cristóvão. [13]

Unfortunately, people tend to choose an easier way such as disposal as a favourable practice. Some have agreed that reduction at source is quite difficult to implement [14].

In fact, Esa et al., [15] has emphasized that the 3R principle which includes reduce, reuse, and recycling practices is insufficient to mitigate the waste generation. Thus, the implementation of WtE may resolve this issue more properly. It is, in fact, an intelligent approach that allowed human behavior that keeps producing waste, to now become less burdened since this waste can generate positive output such as cleaner energy that will reduce the climate change effect.

This nexus framework highlights the interdependence between waste management, energy recovery, and climate change mitigation. WtE contributes to energy security by providing locally generated electricity or heat and helps reduce methane emissions from landfills—one of the most potent greenhouse gases. Aligning WtE with climate goals requires understanding trade-offs between emissions from combustion and benefits from avoided landfill use.

4. Circular Economy and Waste-to-Energy

WtE is increasingly framed as part of circular economy strategies that prioritize resource recovery and sustainability. While traditional WtE (e.g., incineration) has faced criticism for pollution, modern systems emphasize emission control and energy efficiency. In developing countries, WtE can reduce landfill use, recover valuable energy, and create jobs—though financial and technical constraints persist. WtE is recognized globally as a pathway to support circular economy goals, especially when integrated with waste reduction, reuse, and recycling strategies. It allows the recovery of energy from non-recyclable waste, thereby reducing the volume of waste sent to landfills and contributing to energy diversification. In a circular economy, WtE acts as a complementary process, ideally positioned after materials recovery efforts. And the Fig.3 shows the Principe of circular economy how it's work

Figure 3. The principe of circular economy. [16]

5. Waste-to-Energy Technologies and Methods

A range of Waste-to-Energy (WtE) technologies exist, each with varying levels of technological maturity, environmental impact, cost, and suitability depending on waste composition and local conditions. These methods fall broadly into thermal, biological, and chemical categories.

5.1. Thermal Methods

- **Incineration**: The most widely used WtE method globally, incineration involves the combustion of waste at high temperatures (~850–1100°C) to generate heat, which can be converted to electricity or used directly. It significantly reduces waste volume and is effective for mixed waste streams. However, it requires advanced emissions control systems (e.g., for dioxins and particulates) and is capital intensive.

- **Gasification**: This process converts carbonaceous waste into synthetic gas (syngas) through partial oxidation at high temperatures (700–1500°C). The syngas can be used for electricity generation or chemical production. Gasification is more efficient and cleaner than incineration but demands uniform feedstock and stable operating conditions.

- **Pyrolysis**: Conducted in the absence of oxygen, pyrolysis decomposes organic waste into bio-oil, syngas, and char. It is suited for plastic and rubber waste and has potential for fuel production. Pyrolysis is still emerging commercially and requires advanced handling and pre-processing.

5.2. Biological Methods

- **Anaerobic Digestion (AD)**: This method is ideal for high-moisture organic waste such as food and agricultural residues. Microorganisms break down the waste in oxygen-free environments, producing biogas (methane and CO_2) and digestate (usable as fertilizer). AD is environmentally friendly and can be implemented at small to medium scales but is unsuitable for mixed or dry waste streams common in El Oued, The Fig.4 shows to us the system of Anaerobic Digestion system.

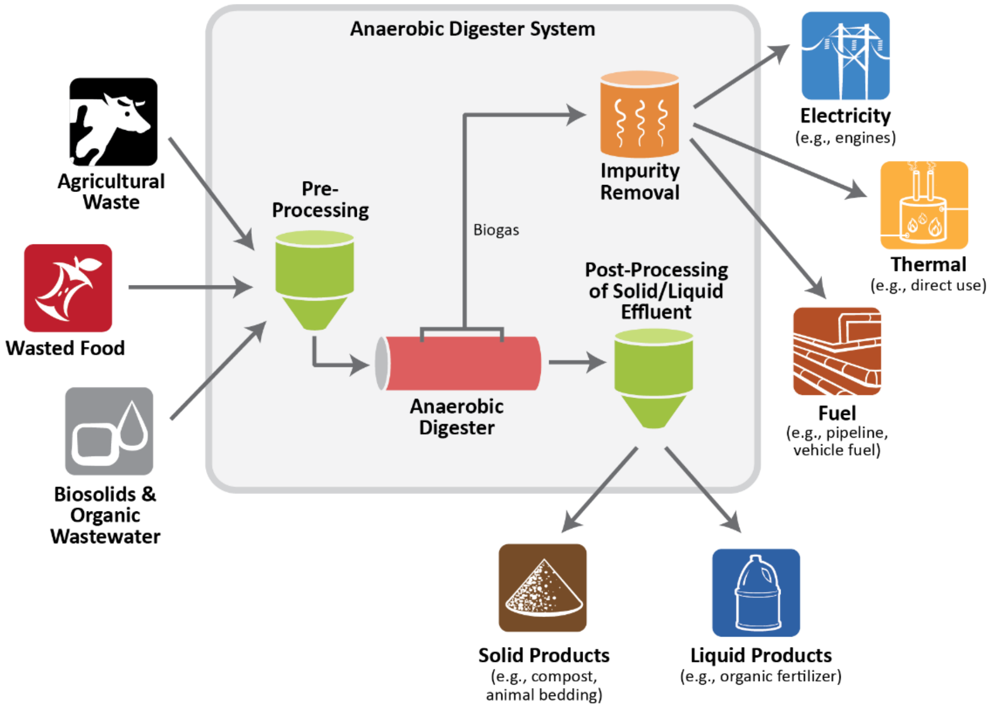

Figure 4. Anaerobic Digestion System. [17]

- **Composting**: While not an energy recovery method per se, aerobic composting of organic waste helps reduce landfill loads and provides soil amendments. Energy benefits are indirect, but it complements WtE strategies in source-separated systems.

5.3. Emerging and Hybrid Technologies

- **Refuse-Derived Fuel (RDF)**: Involves processing non-recyclable waste into a homogenized, high-calorific fuel used in cement kilns or power plants. RDF production requires pre-sorting and has logistical and market challenges in regions lacking industrial demand.
- **Plasma Arc Gasification**: Uses electrically generated plasma to achieve extremely high temperatures (>3,000°C), converting waste into syngas and vitrified slag. It offers near-complete waste destruction and minimal emissions but is costly and technically demanding.

5.4. Technology Suitability for El Oued

Given the **hot dry climate**, and **limited infrastructure** in El Oued, **modular incineration systems** (for dry organic waste) may be the most viable near-term option. **Anaerobic digestion (AD)** could be applied if we have high portion of Food waste or wet organics, and source-separation of organic waste is implemented, especially from households or agricultural residues. However, **Gasification and pyrolysis** remain medium-term options, requiring more detailed feasibility assessments. Tab.2 presents comparison of most popular WtE technologies. According to the table, Inceneration and AD are seems to be the most appropriate methods for El Oued context, which would be valifdted later.

Table 2. Comparison of most popular WtE technologies

Technology	Process Type	Waste Type Suitability	Energy Output	Maturity Level
Incineration	Thermal	Mixed MSW, dry waste	High (electricity/heat)	Commercial
Gasification	Thermal	Homogeneous, dry organic waste	High (syngas/electricity)	Emerging
Pyrolysis	Thermal	Plastics, rubbers, dried biomass	Medium (bio-oil, gas)	Emerging
Anaerobic Digestion	Biological	Food waste, wet organics	Medium (biogas)	Mature
RDF Production	Pre-processing	Non-recyclable, high-calorific	Indirect (used in kilns)	Mature
Plasma Gasification	Thermal (Plasma)	Hazardous, mixed, complex waste	High (syngas)	Experimental
Composting	Biological	Organics (non-energy)	None (soil amendment)	Mature

6. Global and Regional Trends in WtE Deployment

Many developed nations have integrated WtE into their national energy and waste strategies. In contrast, WtE in Africa remains underutilized due to financial, institutional, and technological barriers. However, pilot initiatives in Morocco, Egypt, and South Africa illustrate growing interest. In the MENA region, WtE is gaining traction in Gulf countries through large-scale projects, often supported by international financing.

Globally, WtE is widespread in Europe and parts of Asia, with countries like Sweden and Japan successfully integrating it into sustainable waste strategies. In North Africa, WtE remains nascent. Recent studies show Algeria has significant untapped potential, but investments and regulatory frameworks are underdeveloped.

6.1. Previous studies in the field of WtE

We have summarized some of the studies previously conducted in this field in a simple Tab.3

Table 3. Global studies in the field of waste-to-energy conversion

Researchers	Institution/Country	Study Topic	Key Findings
Rajeev Singh et al. (2019)	Banaras Hindu University – India	Analysis of modern WtE technologies (pyrolysis, gasification, anaerobic digestion)	Gasification is more efficient than incineration in thermal performance and carbon emissions; anaerobic digestion is best for moist organic waste.
Paola Lettieri et al. (2014)	University College London – UK	Life Cycle Assessment (LCA) of waste gasification for synthetic fuel production	Gasification significantly reduces greenhouse gas emissions compared to traditional incineration when the output is used as alternative fuel.
Veena Sahajwalla (2018)	University of New South Wales – Australia	Conversion of plastic waste to thermal energy for steel production	Developed "Green Steel" by replacing coal with waste, reducing carbon emissions by up to 30%.
Francis de los Reyes III	North Carolina State University – USA	Anaerobic digestion for biogas production from municipal waste	Optimizing temperature and waste mix increased methane yield by up to 60%.

6.2. WtE Market Growth:

The global WtE market is expected to expand at a compound annual growth rate (CAGR) of 7.1% through 2033, from its estimated USD 44.24 billion in 2025. Growing urbanization, stricter environmental laws, and the growing demand for renewable energy sources are the main causes of this expansion.

6.3. Technology Insights

The thermal segment dominated the market, with a revenue share of 81.7% in 2024, attributed to thermal technologies effectively reducing waste volume and converting it into ash and energy, which addresses the challenges municipalities face with landfill constraints. In addition to transforming non-recyclable waste into energy, these technologies manage waste effectively and support circular economy initiatives and sustainability goals. Moreover, research and development have led to advancements in efficiency and energy recovery, enhancing the viability of thermal solutions. As a result, these factors collectively increase the appeal of thermal technologies for waste management and energy production. Fig.5 shows the global market size of west to energy .

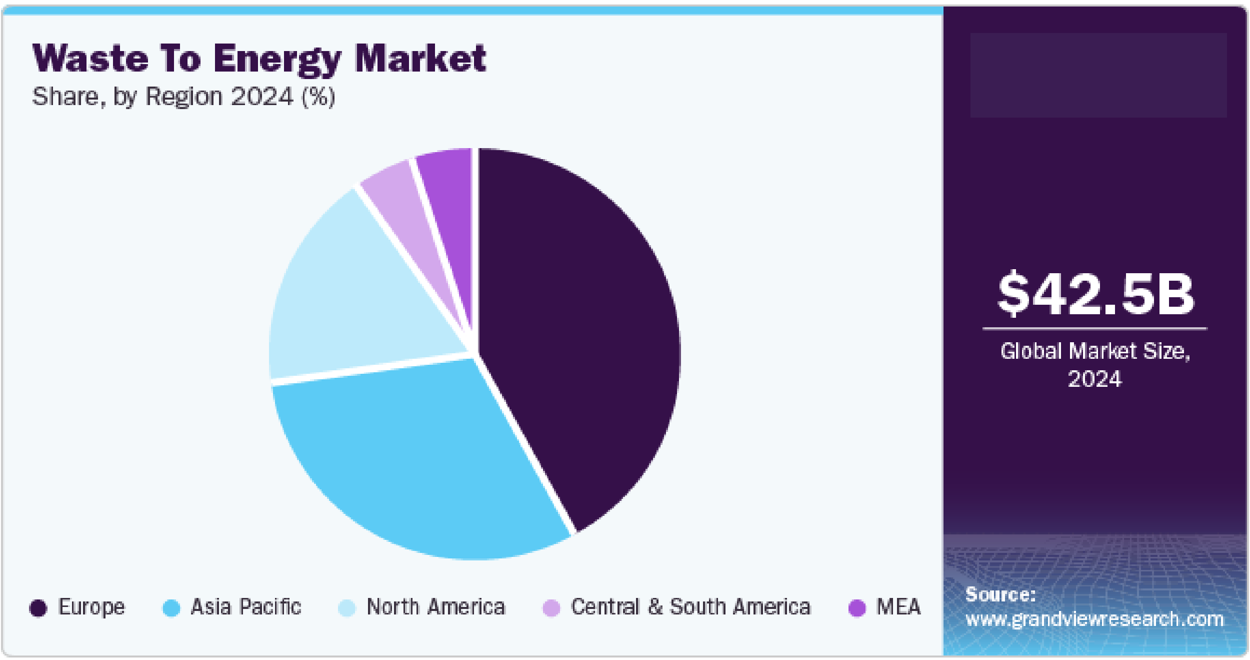

Figure 5. Global market size of west to energy [18].

The biological segment is projected to witness the fastest CAGR of 9.3% over the forecast period, attributed to its environmental advantages, regulatory support, economic efficiency, versatility in feedstock usage, nutrient recovery potential, and strong public acceptance. These factors collectively position biological solutions as preferred for sustainable energy and waste management. Moreover, biological systems typically incur lower capital and operational costs due to simpler construction and reduced resource requirements, leading to quicker payback periods. Therefore, the economic attractiveness of biological technologies reinforces their role as a preferred solution for sustainable energy and waste management. [18]

7. Barriers and Enablers for WtE in Developing Contexts

Key barriers include high initial investment costs, lack of waste segregation, limited public awareness, and weak regulatory frameworks. Enablers include international cooperation, public-private partnerships, technology transfer, and alignment with climate and energy policies.

In these two tables: Tab.4 and Tab.5 ، we explain in more detail the enabling factors and barriers:

Table 4. Barriers for Waste-to-Energy (WtE) in Developing Contexts: [19]

Category	Description
Financial Constraints	High capital and operational costs make WtE unaffordable for many governments.
Poor Waste Quality	Mixed, unsegregated, and high-moisture waste reduces energy recovery efficiency.
Policy Gaps	Weak or unclear regulations, lack of incentives, and inconsistent enforcement.
Technical Limitations	Lack of local expertise, inadequate infrastructure, and outdated technology.
Social Acceptance	Public resistance due to concerns about pollution, odors, and health risks.
Informal Sector Impact	Informal recyclers may divert high-calorific waste, reducing feedstock value.

Table 5. Enablers for Waste-to-Energy (WtE) in Developing Contexts: [19]

Category	Description
Policy and Regulatory Support	Clear regulations, waste disposal restrictions, and energy incentives (e.g., feed-in tariffs).
International Funding	Support from donors, climate finance (e.g., Green Climate Fund), and development banks.
Public-Private Partnerships	PPPs share risks, reduce public costs, and bring technical and managerial know-how.
Capacity Building	Training and education programs to develop local expertise in WtE technologies.
Technology Transfer	Partnerships with experienced countries for modern, scalable solutions.
Urban Growth and Demand	Rising waste volumes and energy shortages make WtE more relevant in fast-growing cities.
Climate Goals	WtE helps reduce methane from landfills and contributes to national climate targets.

7.1. Waste Management Challenges in Algeria

Developing countries in general face many challenges in managing their waste. We can summarize the most important difficulties faced by Algeria:

- Lack of surveys and statistics and thus data and information on waste.

- Weak enforcement of environmental legislation.

- Inadequate technical infrastructure, plans and strategies

- Limited financial resources with the high average cost of treatment and disposal, which ranged between 1500 and 2000 DzD per ton.

-Low level of public awareness.

-Lack of institutional structure.

-Limited participation of non-governmental organizations.

7.2. Legal and Policy Framework for WtE in Algeria

Resource recovery is mentioned in both the Renewable Energy and Energy Efficiency Development Program (REEDP) and Algeria's National Strategy for Integrated Waste Management (NSIW), however there is no operational alignment. WtE deployment is currently not supported by clear rules, and there are no feed-in tariffs or subsidies for energy-from-waste. There is very little institutional cooperation between the Ministry of Energy and the Ministry of Environment. [20]. This is what we have summarized in Tab.6.

Table 6. Legislative development related to waste management in Algeria [21]

Regulatory Texts		Laws	
Decree 84-378 specifying the.conditions for cleaning and disposing of solid waste	1984	Law No. 83-03 on the Protection of	1983
Executive Decree 02-175 establishing the National Agency	2002	Law 01-19 on the Management	2001
Executive Decree No. 03 specifying the methods for managing waste from treatment activities	2003	Law 03-10 on the Protection of the Environment within the Framework of Sustainable Development	2003
Executive Decree 04-188 regulating oil treatment	2004	Law 11-10 on the Municipality	2011
Executive Decree 04-199 specifying the methods for establishing the public system	2004	Law 12-07 on the State	2012
Executive Decree No. 04-409 specifying the methods for transporting waste	2004	//	
Executive Decree No. 04-410 specifying the general rules for the operation and exploitation of waste treatment facilities and the conditions for accepting waste at these facilities.	2004		
Executive Decree No. 06-104 specifying the list of waste, including hazardous waste	2006		
Executive Decree No. 07-205 specifying the methods and procedures for preparing, publishing, and reviewing the municipal plan for managing household waste and similar waste	2007		
Executive Decree No. 10-23 specifying the technical characteristics of wastewater filtration systems	2010		
Executive Decree No. 19-10 regulating the export of hazardous Go environmental waste	2019		

8. Contexts Assessment of WtE Technologies for Semi-Arid Contexts

Carefully assessing the composition, moisture content, and calorific value of local garbage is necessary when choosing suitable garbage-to-Energy (WtE) methods. These factors are especially affected by consumption habits, climate, and the lack of broad source segregation in semi-arid regions like El Oued.

In El Oued, municipal solid waste (MSW) frequently has a low intrinsic moisture content, little organic kitchen waste, and a comparatively high percentage of plastics, paper, and other dry combustibles—characteristics common in arid and semi-arid metropolitan settings. Anaerobic digestion (AD), which works best with wet, homogenous organic feedstock like food and agricultural waste, tends to be less efficient under these circumstances. AD produces less biogas in situations involving dry or mixed waste and may necessitate expensive preprocessing steps like mechanical separation or water addition. [22]

On the other hand, thermal conversion technologies like gasification and incineration are preferred because to the increased calorific value of the local waste stream, which is primarily composed of plastics and dry biomass. Energy may be efficiently recovered from dry, non-recyclable waste fractions using these techniques. For medium-sized Algerian municipalities without centralized infrastructure, these small-scale modular incinerators with flue gas cleaning systems are a viable alternative. These systems are small, reasonably simple to use, and, with the right emissions controls in place, can meet air quality regulations.

However, in addition to economic viability and long-term operational sustainability, the implementation of such technologies must consider local institutional capacity, technical skill, and community acceptance. Integrated techniques that include material recovery, trash reduction, and energy recovery may provide a more balanced and context-appropriate pathway in situations where plastic waste is prevalent but environmentally sensitive.

9. Previous Studies on WtE and Circular Economy in Algeria

Few academic or technical studies have evaluated the WtE potential in Algeria. Some feasibility assessments in Algiers and Oran focus on MSW incineration, suggesting that calorific values exceed 7 MJ/kg—adequate for thermal processes. However, these studies often lack environmental impact assessments, local stakeholder input, or circular economy integration, highlighting a gap this thesis aims to address in El Oued. Tab.7 presents example of research conducted on WtE and circular economy in Algeria.

Table 7. Example of research conducted on WtE and circular economy in Algeria

Reference	Focus Area	Key Findings	Relevance to our Study
Hassaine & Abrika (2024)	Circular Economy & Waste Management	Analyzed Algeria's waste management policies, highlighting the shift towards sustainable practices post-2016 with the National Integrated Waste Management Strategy (NSIWM-2035).	Provides a policy framework aligning with circular economy principles, essential for contextualizing WtE initiatives in El Oued.
Boukelia & Mecibah (2014)	Solid Waste as Renewable Energy	Discussed Algeria's biomass potential from solid waste, emphasizing the need for improved waste management and energy recovery systems.	Offers data on biomass energy potential, supporting the feasibility of WtE projects in Algeria.
Boubekeur & Argillos (2024)	Waste Management in Energy Companies	Explored the transition to a circular economy within Algerian energy companies, focusing on waste management strategies.	Highlights corporate approaches to waste management, relevant for understanding stakeholder roles in WtE projects.
National Waste Agency (2020)	Waste Statistics & Management	Reported that Algeria produced 13.5 million tons of household waste in 2020, with only 3% being recycled or composted.	Underlines the urgency for effective waste valorization methods like WtE to address low recycling rates.
RegASK (2025)	Waste Management Legislation	Detailed Algeria's new waste management law emphasizing circular economy goals, extended producer responsibility, and eco-design.	Indicates a supportive legal environment for implementing WtE solutions within a circular economy framework.

10. Conclusion

This chapter presents an overview of the most relevant concepts and literature conducted on circular economy through waste to energy, globally and in Algeria. This will be the base of our study, to perform validation and compare our results. According to the literature and the context of the region, incineration and AD could be suggested to converting waste to energy in El Oued.

Thus, both methods will be considered in this study and compared to recommend strategies for promoting circular economy in El Oued through WtE.

Chapter 2: Methodology

Chapter 2. Methodology

1. Overview

This chapter presents the methodology adopted to investigate the circular economy potential and challenges of implementing municipal WtE solutions in El Oued, Algeria. It integrates qualitative and quantitative techniques to assess waste availability, evaluate technology suitability, and analyse policy and socioeconomic implications.

The research employs a combined-method approach:

- **Quantitative analysis** includes the estimation of MSW composition and energy content using local data and literature-derived parameters. A simplified energy recovery model (e.g., lower heating value–based calculations) is applied to assess WtE potential.
- **Qualitative assessment** involves performing PEST analysis based on stakeholder interviews, literature and policy documents to identify key barriers. In addition, a simple data analysis approach is used to synthesize findings and develop strategic recommendations tailored to El Oued's local context.

The overall approach is multidisciplinary, drawing from energy systems analysis, waste management, environmental assessment, and policy studies.

2. Research Design

The research design follows a mixed-methods approach, consisting of four main components:

- We collected data on solid waste to understand current generation trends, composition, and customized practices.
- We evaluated waste-to-energy technologies best suited to the local context, based on simple technical and environmental factors.
- We assessed the potential environmental and climate impacts of waste-to-energy solutions within a broader economic context.
- We provided some advice and perspectives from the General Assembly and contributed to waste management and energy planning.

The research methodology allows for the integration of several data sources and methodologies, including waste composition analysis, technology evaluation, and stakeholder interaction, to ensure more reliable and credible results. Using these varied perspectives, the study offers a thorough and balanced assessment of El Oued's Waste-to-Energy (WtE) potential, taking into consideration not just technical feasibility but also social and environmental factors.

3. Data Collection and Sources

In this work we will use both types of data, primary and secondary.

✓ **Primary Data**

- Private and public visits to municipal waste collection sites across the state of El Oued.
- Interviews with officials involved in waste collection and handling, such as municipal officials, technical landfill officials, and private companies.
- Questionnaires targeting El Oued residents and local companies regarding waste patterns and their attitudes toward the possibility of converting waste to energy.

✓ **Secondary Data**

- Reports and data on waste from the National Waste Agency (AND)
- National waste statistics from the Ministry of Environment
- Local population and energy demand data from the National Office of Statistics (ONS)
- International standards, references, and previous studies on waste-to-energy technologies

4. Waste Characterization

The primary goal of waste characteristics is to gain a clear understanding of the composition of municipal fixed waste (MSW), especially to identify which types of waste are most widespread - such as organic matter, plastic, paper, metal, glass and other different materials. This information is necessary to assess viability and design of waste-to-energy technologies, as different waste fractions vary in energy material, humidity level and combustion properties.

In this study, a simplified but structured waste symptom was treated to provide a snapshot of the current waste profile in L O.ED. Work includes:

- Sampling at municipal fundraising points, and ensures representation in housing, commercial and institutional waste sources to reflect areas in the city's various waste-generating areas.
- Visual inspection of the samples collected and manual sorting, followed by the weight of each sequential fraction to determine the percentage of the weight of each waste category.

- Classification of waste in standard categories: Organic/biodegradable waste, paper and cardboard, plastic, metal, glass and other residues (eg textiles, ceramics or inert materials).

To estimate the energy capacity of the waste flow, the calorie value (CVS) - which represents the amount of energy issued during combustion - was used on each waste category. These values were well-established literature and database (eg Thmailis and Uloa, 2007; UNEP, 2019) and were adjusted to the Account of Regional References, including the specific moisture content and level of pollution seen in EL OUD's climate and waste management conditions. [23]

5. Assessing the technical potential for energy recovery from MSW

The evaluation of technical capacity for energy recovery from municipal fixed waste (MSW) is an important step in determining whether waste-to-energy (WTE) technologies can be effectively distributed and in each area. This evaluation involves analysing the physical and chemical properties of the waste flow, identifying appropriate conversion technologies and estimating the amount of energy that can really be extracted.

5.1. Waste Composition and Calorific Value

The energy capacity of MSW largely depends on its composition. High -energy water such as plastic, paper, cardboard and fabrics usually have a high calorie value, while the high humidity levels of organic waste are materials with low energy. To determine the technical capacity, the low heating value (LHV) is used for each waste component to estimate theoretical energy production.

For example: [24]

- Plastic: 30-45 mj/kg
- Paper and cardboard: 13-18 MJ/kg
- Organics: 4-6 MJ/kg (varies with moisture content)

These values are usually adjusted based on local waste properties, climate and consumed patterns. Fig.6 shows Calorific value of waste composition (Beigl et al., 2008) [25]

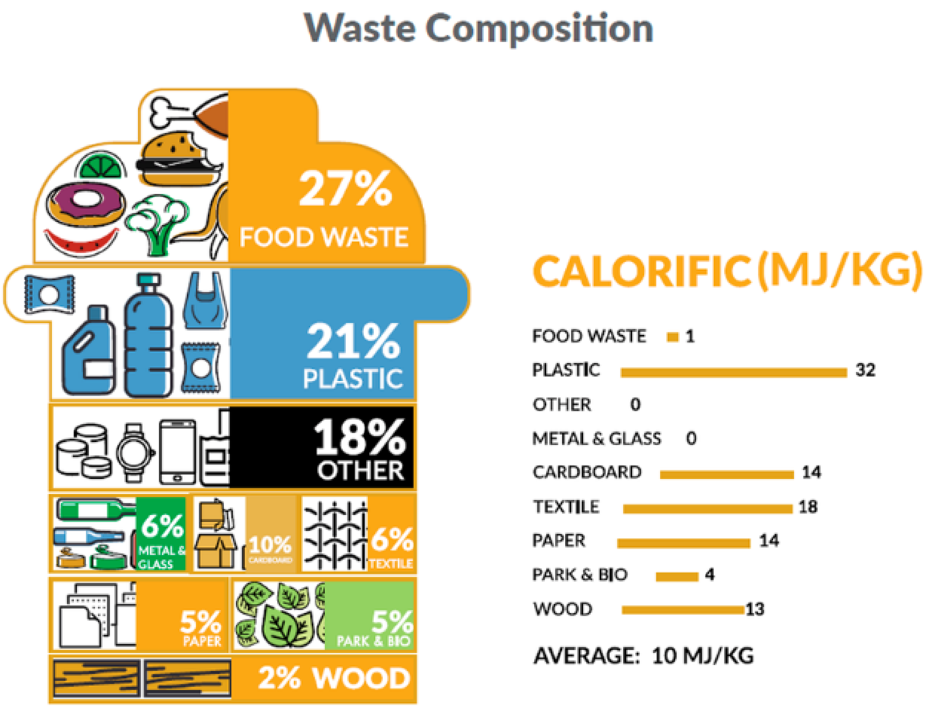

Figure 6 Calorific value of waste composition [25]

5.2. Selection of Suitable WtE Technologies

Choosing the technique suitable for converting waste into energy depends on the waste flow and the specific properties of the local infrastructure. General WTE -Technologies include: [26]

5.2.1. Conscience:

Dry, skilled for high calorie waste; Creates heat and electricity.

5.2.2. Anaerobic digestion:

Suitable for wet organic waste; Produces biogas and digestion.

5.2.3. Gasification and pyrolysis:

Thermochemical procedures ideal for selected waste types; Produce singing or bio -oil.

Each technique has separate energy efficiency rates, capital and operating costs and environmental concerns. Fig.7 shows Classification of WtE technologies regarding conversion pathways [27].

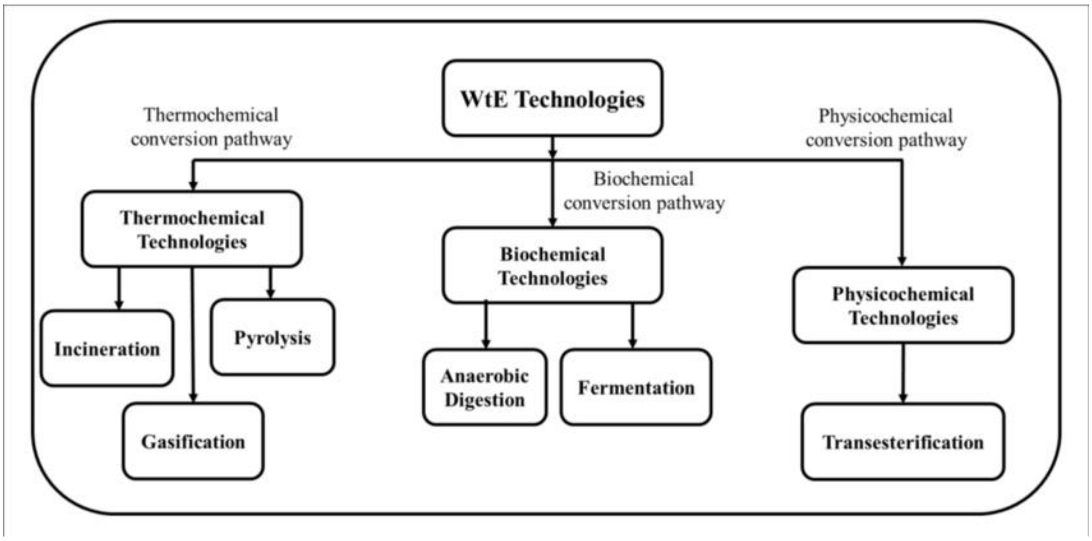

Figure 7 Classification of WtE technologies regarding conversion pathways. [27]

5.3. Estimating Energy Yield

When the waste composition and LHV are known, the energy yield can be estimated using mass and energy balance calculations. For example, Eq. 1. : [28]

$$Energy\ output\ (kWh/day) = \sum_{1}^{n} (mass\ of\ each\ waste\ type \times LHV) \times conversion\ efficiency \quad (1)$$

Conversion capacity is different:

-Combustion: 20-30% (current), up to 80% if combined heat and power (CHP) is used

- Anaerobic digestion: ~ 60% of methane biogas, ~ 30-40% with electrical efficiency

5.4. Local Infrastructure and Grid Integration

Technical capacity also depends on the possibility of using or distributing recycled energy. It also includes: [29]

- Near electric grid or district heating system

- Waste collection, sorting, and availability of ongoing infrastructure

- Effective labour and operating capacity

5.5. Environmental and Operational Constraints

Technically possible, the WTE system should also follow environmental rules. Emissions control, disposal of ash and public acceptance can affect all technical viability. [30]

This gives an estimate of how much energy could be recovered per day if WtE technologies were applied efficiently at the cast study region. In addition, this analysis helps to (1) Identify whether the **waste stream in El Oued has sufficient energy value** to justify investment in WtE infrastructure, (2) guide **technology selection** (e.g., incineration vs. anaerobic digestion), (3) estimate the **contribution of WtE to local energy supply and GHG reduction**.

6. Circular Economy and Climate Assessment

To understand the role of WtE within a broader circular economy and climate mitigation

Growing costs associated with energy sources and inappropriate disposal of waste materials are increasing public interest in improving environmental quality in the modern period. The economics of biomass conversion pathways are significantly influenced by the end products. Latent release of hazardous gases and substances like SOx, CO, and NOx, as well as unstable chemical compounds generated from combustion and insufficient oxidation are the key hazards [31]. All these dangerous gases are bad for the environment and human health. Therefore, seepage should be avoided during waste-to-energy conversion processes; a suitable conditioning system and an efficient gas clean-up are essential for this. Reducing the likelihood of incomplete oxidation during the conversion process is another effective strategy to lessen the risk of hazardous gases. For the generation of ethanol, a hybrid method of gasification coupled with fermentation has been compared to traditional enzymatic hydrolysis coupled with fermentation technology. The cost of producing ethanol through gasification and fermentation is significantly higher than that of producing ethanol through enzymatic hydrolysis and fermentation [32]. The primary reasons for this increased cost are the comparatively low ethanol yield, the high energy recovery costs, and the high capital cost. The use of land, the demand for equipment, and the amount of feed required all effect cost analysis. The labour and maintenance costs are included in the process's operational fee. These costs are all estimates, but the precise cost depends on the area's administrative requirements, incentives, feedstock accessibility, and skilled labour. However, gasification is not a good method for feedstocks with high moisture concentrations because it increases the cost of the entire process and needs the adoption of a pretreatment technology to boost processing efficiency [33]. But when it comes to reducing incineration-related process costs, techniques like pyrolysis or gasification are more beneficial. Among all the other thermal and biochemical processes, pyrolysis, as well as hybrid conversion techniques, are the most appealing methods from an economic evaluation standpoint.

The current waste management system depends a lot on landfill, with low recycling and minimal resource recovery. This linear approach leads to high greenhouse gas emissions and loses financial opportunities. A change to a spherical economy model can improve stability by promoting a change in waste, recycling, organic fertilizer and waste-to-energy (WTE).

These actions reduce methane emissions, displace the use of fossil fuels and contribute to Algeria's climate targets. Integration of combined circular practice with side rivers and infrastructure, the waste area can become a more climate-flexible and resource-developed system.

7. PEST analysis and challenges identification

Here PEST (Political, economic, social and technical) analysis was performed to identify the barriers for implementing WtE initiatives in Algeria and then in El Oued. These challenges are extracted from the primary and the secondary data (including literature, national wate and energy policy documents and interview data). This qualitative method is widely used to understand the context and identify challenges and opportunities for a given topic.

8. Conclusion

This chapter emphasizes the planned research method in this study describes the types of data used, processes followed for data collection and analytical approach that have been adopted. The function was designed to coordinate with careful research goals and provide a steady structure to evaluate the waste-to-energy capacity in El Oud. It attracts both primary and secondary data sources, which incorporate field observation, expert input and literature -based estimates where direct measurements were not possible.

Particular attention was paid to ensure openness and replication of analysis methods along with the validity and relevance of the data. However, many functioning boundaries are recognized:

- Data on waste composition was only partly based on direct samples. In some examples, estimates from secondary sources were used, which cannot completely capture seasonal ups and downs in waste production patterns.

- Estimate for greenhouse gas emissions was obtained using standard emission factors from the international guidelines (eg IPCC) rather than site -specific measurements, which may affect the accuracy of climate effect assessment.

- The stakeholder entrance was limited to a small selection of respondents available in El Oud. This may have interrupted the depth and diversity of the approaches involved in institutional and social analysis.

- Economic analysis and modelling of reliable local costs were not carried out due to lack of availability of local cost data, especially related to waste treatment infrastructure, energy prices and operating expenses.

Despite these restrictions, the proposed method in study is solid and comprehensive and could bring useful insights, especially about the technical feasibility and relevant challenges of using WTE solutions in El Oued. The obtained results, with important interpretations and implications, are presented in detail and discussed in the following Chapter.

Chapter 3: Case study, Results and Discussions

Chapter 3. Case study, Results and Discussions

1. Overview

After collecting all the necessary data, applying the proposed method, and communicating with those involved in the waste and energy sector in the state of El Oued, we obtained the results we wanted to apply in our study, which we will work on and confirm in our comprehensive theory for this project. In this chapter, we will present the numerical application of waste-to-energy methods. Having specialized and selected only two methods: incineration and anaerobic digestion, we will compare the results we find and determine which method will be more effective and more suitable for implementation or even for further study in the future at the level of the state of Oued. We will also address the real challenges facing the waste-to-energy transformation process, challenges encountered by experts in the state of El Oued and those encountered by institutions involved in waste collection and management.

Finally, we will present some solutions we deem appropriate and capable of overcoming the challenges present at the state level or the country in general.

2. Characterization of MSW in El Oued

After conducting numerous visits to private institutions involved in waste management (the Technical Landfill Institution EPWG-GET Eloued, the El Oued Municipality, etc.), we obtained very little quantitative information about the organic waste we wanted to calculate and which is required for this study. We found that the total waste entering in 2022 was estimated at 52,839.20 tons. [37]

In the Tab.8 , we see the amount of waste received at the center for the year 2022, detailed for each municipality separately. [37]

Since there are no official accounts related to the organic waste we need for this study, we obtained information from the Technical Landfill Center (EPWG-GET Eloued) that the percentage of organic waste entering the institution is 70% of the total waste entering the institution. Accurate calculations are only made for sorted waste, such as plastic, iron, and paper.

Table 8 Quantity of waste received at the center for the year 2022 [37]

Municipality	Waste amount (tons)
El Oued	38710.3
El bayadha	7443.68
warmass	1115.8
Wadi al alanda	1729.82
kouinin	2627.42
Ummiyah wa nssa	1221.18
Ghomar	6601.02

This percentage comes from the waste collection of seven municipalities affiliated with the Technical Landfill Institution in the El Oued Governorate (El Oued, Kouinine, El Bayada, Ghomar, Warmas, Ummiyah wa nssa, and Oued El Alanda). This means that 23 municipalities are not collected by the institution and are not included in these calculations and data. [37]

2.1. Assumptions and Data from real filed

- **Daily municipal waste generated in El Oued: 52839.20 tons/year (2022)**
- **Share of organic waste in MSW: 70%**
- **Organic waste generated: can be calculated through Eq. 2**

$$52839.20\ \frac{tons}{year} \times 70\% = \frac{36987.44\text{tons}}{\text{year}} = 36987440\ kg/year \qquad (2)$$

3. Technical WtE potential in El Oued

This section estimates the potential for energy recovery from municipal solid waste (MSW). This study focused only on the energy recovery potential of the organic fraction of MSW in the valley. Given the high availability of organic waste, especially in the state of Oued, and the lack of control over other types of solid waste, which are sometimes collected directly from households by private companies, two common waste-to-energy (WtE) methods were studied and compared: **incineration** and **anaerobic digestion**. The calculations are based on available waste data, assumed recovery efficiencies, and typical thermal energy and biogas yields reported in previous studies.

3.1. Method 1: Incineration of Organic Waste

In this method, used by many countries (Germany, Sweden, the Netherlands, Denmark, Japan, Singapore, etc.), we are required to handle dry waste. If dry waste is unavailable, a separate section is added specifically for drying organic waste to facilitate its handling during incineration. Assuming that 100% of organic waste is dry waste, this means that the amount of dry waste is 36,987,440 kg. Since the calorific value of organic waste ranges between 4-6 MJ/kg, a simple calculation can be performed Eq. 3 : [38]

$$Heat\ energy\ produced\ (MJ)\ =\ Mass\ (kg)\ \times\ Calorific\ value\ (MJ/kg) \tag{3}$$

By numerical application we find (Approximate calorific value) : Eq. 4

$$36987440\,\frac{kg}{year} \times \frac{5MJ}{kg} = 184937200\ MJ/year \tag{4}$$

Electricity potential (assuming 25% efficiency) Eq. 5:

$$184937200\,\frac{MJ}{year} \times 0.25 = 46234300\ MJ/year \tag{5}$$

Convert to kWh (1 MJ = 0.2778 kWh) Eq. 6:

$$46234300\,\frac{MJ}{year} \times 0.2778 = 12843888.54\ kWh/day \tag{6}$$

However, despite the high productivity of this method, it remains a very expensive and highly risky process. It must be carefully studied from all angles, as it produces toxic gases in very large quantities. Dealing with these gases requires significant resources and substantial financial support. Based on our study and previous studies of the incineration process, we conclude that incinerating organic materials produces less energy than other wastes, such as plastic. Therefore, it is an extremely difficult and unlikely process to implement within Algeria, especially in the state of El Oued.

3.2. Method 2: Anaerobic Digestion of Organic Waste

This method, also used by many countries (Germany, China, India, the United States, France, etc.), requires a greater use of wet organic waste, which is already abundant in the waste collected throughout the state of El Oued, reaching almost 100%. In this method, assuming a 100% wet organic waste ratio and a biogas production rate of between 100-200 m^3: [38]

- **Biogas yield from food/organic waste:** ~100 m^3/ton (wet weight)
- **Biogas energy content:** ~21–23 MJ/m^3

- **Total biogas produced Eq. 7:**

$$36987{,}44\,\frac{tons}{year} \times 100\,\frac{m^3}{ton} = 3698744\ m^3/year \tag{7}$$

Energy potential (thermal): can be calculated through Eq. 8**.**

$$\frac{3698744\ m^3}{year} \times 21\,\frac{MJ}{m3} = 77673624\ MJ/year \tag{8}$$

Electricity potential (with 35% CHP efficiency) Eq. 9:

$$77673624\ MJ/year \times 0.35 = 27185768.4\ MJ/year \tag{9}$$

Convert to kWh (1 MJ = 0.2778 kWh) Eq. 10:

$$27185768.4\ \frac{MJ}{day} \times 0.2778 = 7552206.46\ kWh/day \tag{10}$$

3.3. Comparative Summary of the WtE methods

With these results and according to previous studies, we note that it is a very large and very profitable percentage. This method will also be very effective with the organic waste we have, and compared to what other countries produce, this is a very large percentage and competitive with the largest biogas producing countries in the world. Tab.9 summarise the comparison between incineration and Anaerobic Digestion (AD) WtE methods in El Oued.

Table 9 comparison of incineration and Anaerobic Digestion (AD) WtE methods in El Oued [36]

Parameter	**Incineration**	**Anaerobic Digestion (AD)**
Energy form	Electricity (from heat)	Electricity (via biogas CHP)
Input waste (wet organic)	36987440kg/year	36987440kg/day
Total energy potential	46234300 MJ/year	77673624 MJ/year
Usable electricity (kWh)	~12843888.54 kWh/day	~7552206.46 kWh/year
Residues/by-products	Ash (10–15%), emissions	Digestate (usable as fertilizer)

Based on the technical potential comparison of both methods, we can conclude that:

• **Waste incineration** produces more electricity, but it is less environmentally friendly unless equipped with advanced flue gas cleaning systems. It emits highly harmful gases such as carbon dioxide (CO_2), nitrogen oxides (NO_x), dioxins, and heavy metals. It requires significant financial resources to fully address the emitted gases and prevent them from negatively impacting the environment.

• **Anaerobic digestion** is more sustainable, particularly for wet organic fractions (most of which are generated in the valley). It also produces very low carbon emissions and produces biomethane, which can be used as a clean fuel, reducing dependence on fossil energy sources. The byproduct of the process is used to improve the fertility of the valley's desert soil, providing agricultural and economic benefits, Although it produces less energy per ton of organic waste.

Therefore, we find that the first method (burning) is more suitable for the valley region if we look at it from the economic side, as it produces more electricity. However, if we also look at the environmental side and its impact, we will find that the second method (anaerobic digestion) is more suitable for the valley region due to its high organic content, as most of the organic waste is wet and the possibility of collecting waste in a decentralized manner, and the conditions of the region are also favourable for biological processes.

4. Challenges for WtE solutions in Algeria

Here PEST (Political, economic, social and technical) analysis was first performed to identify the barriers for implementing WtE initiatives in Algeria. These challenges are extracted from the literature, and policy documents.

4.1. Political factor

- Government support for renewable energy: Algeria has the goal of renewable energy, but specific policies for WTE are limited or unclear.

- Environmental regulations: The pressure increases to use landfill and reduce greenhouse gas emissions, which can support WtE when strengthening the regulatory structure.

- Institutional fragmentation: Many agencies (environment, energy, local authorities) can have an overlapping or vague role, which can be delayed.

- Permission and approval complexity: bureaucracy barriers and lack of experience with WtE technologies can slow down project implementation.

Strategies to overcome: With the correct adaptation of national waste, energy and climate policy, WTE can achieve political traction as a double purpose solution.

4.2. Economic factors

- **High capital investments are required:** WTE technologies are expensive for construction and operation compared to landfill.

- **Uncertain financial return:** Energy sales and tipping fees may not be sufficient without income deficit or long -term power purchase agreements (PPAS).

- **Limited access to green funding:** Many municipalities, including L.AD, can fight to attract personal investments without a guarantee at national level or international assistance.

- **Imported technology costs:** Most WTE systems need to be imported, which provides costs and complexity.

Strategies to overcome: Economic viability is improved with the scale, stable raw material supply and integrated waste currents (eg from the nearby municipalities). [34]

4.3. Social factors

- **Public opinion and acceptance:** misconceptions of provocative and emissions can lead to societal resistance.

- **Awareness of circular economy:** Resource extraction and low public understanding of WTE benefits can reduce sorting of waste or fertilizer participation.

- Work creation ability: WTE can offer new jobs in operation, maintenance and waste collections, especially if combined with recycling.

- Cultural approach: Traditional settlement habits and roles as informal waste choices must be considered in transitional plans.

Strategies to overcome: Social acceptance is improved with education, openness and involvement of local stakeholders in the scheme. [35]

4.4. Technical factor

- The suitability of technology: The high muscle limits the efficiency of the organic waste (al-order) limits the consumer's efficiency until pre-healing or other dry waste is combined.

- Lack of local expertise: Some technicians and engineers are trained to operate and maintain WtE facilities.

- Infrastructure expenses: Weak sorting, preprocessing and energy network compounds can reduce the efficiency of the WTE system.

- Technology that is not matching: The risk of using a system -friendly against local waste composition or climatic conditions.

Strategies to overcome: Small scale or modular WTE technologies (eg anaerobic digestion) can better suit local needs .[36]

Despite these challenges are general for the overall Algeria but will help us guiding our interviews with stakeholders in El Oued, and also for validating our results.

5. Challenges for WtE solutions in El Oued

After we discussed in the first and second chapters the challenges facing this process, which is converting waste into energy, and we mentioned many of them that we obtained through previous articles and studies that were conducted on this study, none of which were inside Algeria, and after we communicated with many officials who have a relationship with collecting and dealing with waste at the level of the state of El Oued, as well as the visits that we made at the level of the institutions that collect waste inside the state, we found a great similarity between the challenges facing the state or the country as a whole to work with this theory and apply it on the ground, and among the most important challenges that we found, we mention them:

5.1. Technical and technological challenges

Lack of infrastructure: There are no advanced waste treatment systems or WtE facilities (such as anaerobic digesters or incineration plants).

Lack of local technical expertise: A shortage of specialized personnel to operate and maintain technologies such as anaerobic digestion or gasification.

Poor waste separation efficiency: Waste is collected mixed (organic and inorganic), which hinders biological or thermal processes.

High humidity: Waste in the valley is often organic and moist, making it difficult to use in some technologies such as incineration without drying.

5.2. Economic and financial challenges

Lack of funding and investment: Projects in this field require significant initial capital (even small ones), and there is no financing facilities specifically targeted for this sector.

Lack of sustainable business models: Most municipalities do not have clear economic plans to recover the costs of WtE projects (such as selling energy or fertilizer).

Lack of government incentives: There are no tax exemptions or direct support for investors or farmers wishing to establish biogas units.

5.3. Administrative and organizational challenges

Poor coordination among agencies: Overlapping responsibilities between municipalities, directorates of the environment, agriculture, energy, and sanitation institutions hinder project implementation.

Lack of legal frameworks: There are no clear laws facilitating the establishment and investment of waste-to-energy projects at the local level.

Slow bureaucratic procedures: Licensing, such as operating permits, electricity connections, or environmental approvals, can take months.

6. Summary and recommendations

After conducting comprehensive and approximate calculations for converting waste into energy, approaching institutions responsible for collecting and handling waste, and conducting interviews with officials involved in all matters related to waste in the state of El Oued, we obtained the desired results for our project. All these findings will be used to recommend strategies for advancing WtE circular economy and enhancing the Waste-Energy-Climate nexus in El Oued.

6.1. Key results

6.1.1. Availability of large organic waste resources that can be converted into energy

The state produces large quantities of wet organic waste, such as:

- Food leftovers from markets and homes.

- Livestock manure from traditional farms.

- Agricultural waste (date pits, plant stems).

- These resources represent a high potential for biogas or compost production, enhancing energy and agricultural security.

6.1.2. Anaerobic digestion is the most suitable solution for the local environment.

- Due to the nature of the waste (wet, organic) and the desert climate, anaerobic digestion technology is more suitable than incineration or gasification.

- Small units can be used on farms or cooperatives, facilitating community adoption and reducing costs.

6.1.3. Energy production per ton of waste remains average, but it has a dual effect.

- Although anaerobic digestion produces less electricity than incineration (approximately 100–200 kWh/ton), the output includes bioenergy and organic fertilizer.

- This makes the project a dual benefit: energy and soil improvement.

6.1.4. Lack of specialized infrastructure and environmental awareness hinders implementation.

- There are currently no waste-to-energy plants in the valley.

- Poor source sorting and a lack of a recycling culture make it more difficult to adopt WtE technologies.

6.1.5. Financing and regulatory challenges hinder investment.

- Most municipalities lack sufficient funding to develop WtE projects.

- There are no clear incentives or laws to encourage investors or farmers to enter this sector.

6.2. Recommendations for advancing WtE circular economy in El Oued

Despite all these circumstances, there are many opportunities that enable us to move towards this project and implement it on the ground and give it great importance. Among these opportunities we mention:

- The abundance of organic waste (manure, agricultural waste, date residues) represents a free and stable resource.

- The strong agricultural character of the region could support the use of organic fertilizer produced by anaerobic digestion.

- Biogas can be used for cooking or electricity on farms.

- Small projects (home or cooperative biogas units) may be more viable than large-scale projects.

Also, after we have conducted studies and investigations, we can suggest some proposals with which we try to overcome the existing challenges. Some of the proposals that we suggest are:

- Launching small pilot projects, such as biogas plants on pilot farms or technical institutes.

- Raising awareness among residents and farmers through media campaigns about the benefits of waste sorting and bioenergy.

- Providing subsidized microloans to farmers wishing to use small anaerobic digestion units.

- Encouraging partnerships between municipalities and the private sector in bioenergy and compost projects.

- Updating the legal framework to allow customs and tax exemptions for WtE technologies.

7. Conclusion

This chapter presented and analyzed the case study of El Oued, offering valuable insights into the practical application of municipal waste-to-energy (WtE) strategies within the region’s socio-environmental and economic context. The results highlight a significant potential for integrating

WtE solutions into Algeria’s broader circular economy goals, especially in arid regions like El Oued where waste characteristics—such as low organic moisture and high combustible content—favor thermal treatment over biological processes.

Despite this technical feasibility, the discussion revealed several persistent challenges, including limited infrastructure, weak institutional coordination, and a lack of public awareness and stakeholder engagement. Policy gaps and inconsistent data availability further hinder effective planning and investment. Moreover, the financial viability of WtE remains uncertain without clear regulatory incentives or mechanisms to ensure long-term sustainability.

Overall, the case study underscores both the opportunities and constraints of implementing WtE in El Oued, reinforcing the need for an integrated approach that aligns waste management, energy policy, and climate action. Strengthening local capacity, enhancing data systems, and fostering multi-sector collaboration will be essential to transform waste from an environmental burden into a resource for sustainable development.

Conclusion

This thesis aimed to evaluate the potential and challenges of implementing municipal waste-to-energy strategies in the Oued, within the broader context of Algeria's transition to a circular economy, which offers many advantages over a linear economy, energy security, and climate mitigation objectives.

The results show that, by considering the economic aspect incineration may be more suitable, for El Oued. However, considering technical aspects and environmental impact, anaerobic digestion may be more appropriate for El Oued, due to high organic content (mostly wet), decentralized collection potential, and climate conditions favourable to biological processes.

The findings indicate that El Oued has significant untapped potential for implementing WtE initiatives. However, challenges such as limited technological infrastructure, financial constraints, and lack of public awareness were identified as barriers to WtE adoption. Stakeholder interviews further revealed institutional fragmentation and regulatory gaps that hinder effective MSW management in the region.

The findings of this work are significant and contribute effectively to local and national efforts aimed at sustainable development by examining the nexus of waste management, energy production, and climate policy. It offers actionable insights for policymakers, municipal authorities, and environmental planners to take appropriate decisions regarding MSW. Additionally, it aligns with Algeria's national climate objectives, supporting the country's commitment to reducing greenhouse gas emissions and advancing circular economy principles. The research also contributes to the global dialogue on sustainable development, particularly within the context of developing nations seeking to transition to cleaner, more resource-efficient economies.

And we find that the waste collection of seven municipalities affiliated with the Technical Landfill Institution in the El Oued Governorate (El Oued, Kouinine, El Bayada, Ghomar, Warmas, Ummiyah wa nssa, and Oued El Alanda) is : 52839.20 tons/year (2022) so from it we calculate with the famous mithode and we found Energy potential (thermal): 77673624 MJ/year and

Electricity potential (with 35% CHP efficiency) : 27185768.4 MJ/year and Convert to kWh (1 MJ = 0.2778 kWh) : 7552206.46 kWh/day all those in Method 1: Anaerobic Digestion of Organic Waste.

But in method 2: Incineration of Organic Waste we found By numerical application we find (Approximate calorific value) : 184937200 MJ/year and Electricity potential (assuming 25% efficiency) :46234300 MJ/year and Convert to kWh (1 MJ = 0.2778 kWh): 12843888.54 kWh/day

While this thesis presents useful information, it is limited by the availability and quality of local data, especially in terms of waste composition and energy recovery potential. Socioeconomic and institutional aspects were primarily assessed through stakeholder interviews and existing policy documents, which may not fully capture the broader public lifestyle and preferences. In addition, the study conducted only on specific region not at the overall country territory. Therefore, further works are needed to overcome these limitations and deliver more accurate results by conducting more extensive field studies and developing detailed techno-economic models, spatial analysis, multi-criteria decision analysis and social and environment lifecycle assessment to better assess the sustainability of WtE projects and select the optimal WtE solutions in the country. Moreover, in this work, a simple data analysis approach is used to synthesize findings and develop strategic recommendations tailored to the local context of El Oued. However, in future work advanced strategic development methods such as SWOT analysis will be employed to recommend strategies for promoting WtE solutions and circular economy for the overall country.

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Appendices

Appendix A Comparative Overview of Waste-to-Energy Technologies

Technology	Process Type	Waste Type Suitability	Energy Output	Emission Level	Capital Cost	Maturity Level
Incineration	Thermal	Mixed MSW, dry waste	High (electricity/heat)	Medium (needs control)	High	Commercial
Gasification	Thermal	Homogeneous, dry organic waste	High (syngas/electricity)	Low (cleaner than incineration)	Very High	Emerging
Pyrolysis	Thermal	Plastics, rubbers, dried biomass	Medium (bio-oil, gas)	Low	High	Emerging
Anaerobic Digestion	Biological	Food waste, wet organics	Medium (biogas)	Very Low	Medium	Mature
RDF Production	Pre-processing	Non-recyclable, high-calorific	Indirect (used in kilns)	Low	Medium	Mature
Plasma Gasification	Thermal (Plasma)	Hazardous, mixed, complex waste	High (syngas)	Very Low	Very High	Experimental
Composting	Biological	Organics (non-energy)	None (soil amendment)	Very Low	Low	Mature

Appendix B Waste Generation Data in El Oued (According to information provided by the Technical Landfill Centre of El Oued Province)

Year	Estimated Population	Total MSW Generated (tons/year)	Per Capita Waste (kg/day)
2015	647,548	180,000	0.71
2020	673,934	52505.53	0.72
2021	529,842	53527.68	0.72
2022	673,934	52839.20	0.73

Appendix C Comprehensive plan for managing household waste and similar waste in Algeria (Source: AND, 2020).