PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA

Ministry of Higher Education and Scientific Research

University of Abu Bakr Belkaid - Tlemcen-

FACULTY OF NATURAL AND LIFE SCIENCES AND EARTH AND UNIVERSE

Department of Agronomy

Thesis

Submitted by

BERKAOUI Meriem & GAAD Hadjira

for obtaining the

MASTER'S DEGREE

In : Food Sciences **Speciality : Food Safety and Quality Assurance**

Entitled:

Circular Management Of Organic Waste And Valorization Of By-Products

Defense Date: **June 18, 2025**

Board of Jury Members

Dr. Meriem SAKER	Abu Bakr Belkaid University	President
Dr. Chahinez TRIQUI	Abu Bakr Belkaid University	Examiner
Dr. Djahida HADJ MERABET	Abu Bakr Belkaid University	Supervisor

Academic Year : 2024 / 2025

Acknowledgment

First and foremost, we express our deepest gratitude to Almighty God, the Most Merciful, for granting us the strength, patience, and guidance to complete this work.

We extend our sincere thanks to our supervisor, **Mrs. Djahida HADJ MERABET** , for graciously accepting to supervise our research, for her invaluable advice, and above all, for her patience and unwavering support throughout this journey.

We are profoundly grateful to the members of the jury for their time and expertise. Our heartfelt appreciation goes to:

Mrs. Meriem SAKER , Professor at the University of Tlemcen, for honoring us by chairing the jury of this dissertation. We deeply appreciate your kindness and support.

Mrs. Chahinez TRIQUI for the great honor of evaluating our work. We are endlessly thankful for your time and insightful feedback.

We also wish to acknowledge the laboratory technicians of the **Agronomy Department at the University of Tlemcen** for their technical assistance, patience, and understanding.

Finally, we extend our gratitude to everyone who has contributed, directly or indirectly, to the completion of this dissertation. Your support has been invaluable, and we sincerely thank you all.

Dedication

I thank Almighty Allah, merciful and clement, for having succeeded in completing this modest work that I dedicate:

Dear parents: my eternal example, my moral support and my source of joy and happiness, the light of my days, the source of my efforts, the flame of my heart, my life and my happiness, who have always sacrificed themselves to see me succeed.

No tribute could live up to the love and attention they continue to shower me with. May Allah grant them good health and a long life and grant them the reward they deserve.

I will not forget my brothers IMRANE, OUSSAMA, MOHAMED , who were always there for the comfort I found with them. And to my loved ones for their love and constant support.

A big thank you to ZOHIR, Who encouraged me to have self-confidence and determination to succeed.

Finally, I would like to express my gratitude to all my friends SARAH,NIEMA,HANAA, and especially my partner MERIEM, and to all those who, from near and far, encouraged me, supported me, and sustained me in difficult times. They are numerous and all present in my heart.

Hadjira…

Dedication

To my generous supporter, who taught me that success comes only through patience and perseverance. To the light that illuminates my path and the lamp that never goes out in my heart. To the most precious person from whom I draw my strength and pride: **my dear father**.

To the one who made heaven under her feet and made hardships easy for me with her prayers to the woman who has always wished to fill her eyes to see me on this day

My precious mother

To my firm rib and the security of my days, those who strengthened my arm and were my springs from which I quench my thirst, to my brothers **Hamza, abd al Aziz,**

Abd el Hamid and Mohammad Ibrahim.

To everyone who has been a help and support on this path, to my honorable family, headed by **Meliani khadra**, and my grandfather, may God prolong his life and grant him health and a speedy recovery

to my companions of the years, to those who have faced hardships and especially My dear friend hadjira , to everyone who has supported me with their feelings and sincere advice, to my dear teacher, **Hadj Marabet djahida** I dedicate this achievement to you, the fruit of my long-cherished success. Today, I have completed it and reaped its first fruits, by His grace. Praise be to God for what He has bestowed upon me, and for making me blessed wherever I am.

Whoever says, "I can do it," will attain it, and if I refuse, I will bring it to you. So, praise be to God, in gratitude, love, and appreciation for the beginning and the end.

AND THEIR FINAL SUPPLICATION WAS, "PRAISE BE TO GOD, THE WORLDS."

Meriem….

Abstract

The growing urgency of environmental challenges and resource depletion calls for sustainable waste management strategies, particularly within the agri-food sector. This study explores the current practices, challenges, and opportunities related to the circular management of organic waste and the valorization of by-products in the Tlemcen province (Algeria). A dual methodological approach was employed, combining a field survey conducted among 100 food-related establishments with experimental analyses performed in the Ppubionut research laboratory.

The survey data revealed that landfilling remains the dominant method of waste disposal (63%), while composting is limited to a minority of actors (11%), mainly farms. Most establishments (91%) reuse organic waste as animal feed, particularly unsold bread and fruits/vegetables, yet recovery practices are poorly structured and largely informal. Key barriers identified include high operational costs (56%), lack of adequate technologies (35%), and an absence of markets for recovered products (9%).

Experimental results demonstrated that fruit, vegetable, and bakery waste exhibit a high composting potential, with effective microbial activity, odor improvement, and up to 40% volume reduction. In contrast, methanization trials showed minimal biogas production (<0.5 L CH_4/kg VS), hindered by suboptimal pH, temperature conditions, and an imbalanced C/N ratio. Furthermore, plastic waste characterization tests revealed that 60% of associated packaging materials are non-recyclable (PET, PVC), complicating their integration into circular processes.

The study concludes that while organic waste recovery holds significant potential in the region, its implementation is limited by structural, financial, and technical constraints. Strengthening local waste management systems through training, financial support, and the development of cooperative recovery platforms is essential to advancing circular economy principles in the agri-food sector.

Keywords: circular economy, organic waste, plastic waste, Tlemcen, agri-food sector.

Résumé

L'urgence croissante des défis environnementaux et de l'épuisement des ressources appelle à des stratégies durables de gestion des déchets, en particulier dans le secteur agroalimentaire. Cette étude explore les pratiques actuelles, les défis et les opportunités liés à la gestion circulaire des déchets organiques et à la valorisation des sous-produits dans la province de Tlemcen (Algérie). Une approche méthodologique duale a été employée, combinant une enquête de terrain menée auprès de 100 établissements agroalimentaires avec des analyses expérimentales réalisées au laboratoire de recherche Ppubionut.

Les résultats de l'enquête ont révélé que l'enfouissement reste la méthode dominante d'élimination des déchets (63 %), tandis que le compostage est limité à une minorité d'acteurs (11 %), principalement des fermes. La plupart des établissements (91 %) réutilisent les déchets organiques comme alimentation animale, notamment le pain invendu et les fruits/légumes, mais ces pratiques de valorisation sont peu structurées et largement informelles. Les principaux obstacles identifiés incluent les coûts opérationnels élevés (56 %), le manque de technologies adaptées (35 %) et l'absence de marchés pour les produits valorisés (9 %).

Les résultats expérimentaux ont démontré que les déchets de fruits, légumes et boulangerie présentent un fort potentiel de compostage, avec une activité microbienne efficace, une réduction des odeurs et une diminution de volume allant jusqu'à 40 %. En revanche, les essais de méthanisation ont montré une production minimale de biogaz ($<0,5$ L CH_4/kg MV), entravée par un pH et des conditions de température sous-optimaux, ainsi qu'un rapport C/N déséquilibré. Par ailleurs, les tests de caractérisation des déchets plastiques ont révélé que 60 % des matériaux d'emballage associés sont non recyclables (PET, PVC), compliquant leur intégration dans des processus circulaires.

L'étude conclut que, bien que la valorisation des déchets organiques présente un potentiel significatif dans la région, sa mise en œuvre est limitée par des contraintes structurelles, financières et techniques. Le renforcement des systèmes locaux de gestion des déchets à travers la formation, le soutien financier et le développement de plateformes coopératives de valorisation est essentiel pour faire progresser les principes de l'économie circulaire dans le secteur agroalimentaire.

Mots-clés : économie circulaire, déchets organiques, déchets plastiques, Tlemcen, secteur agroalimentaire.

ملخص

أنّ تزايد التحديات البيئية ونضوب الموارد يستدعي استراتيجيات مستدامة لإدارة النفايات، لا سيما في قطاع الأغذية الزراعية. تستكشف هذه الدراسة الممارسات والتحديات والفرص الحالية المتعلقة بالإدارة الدائرية للنفايات العضوية وتثمين المنتجات الثانوية في ولاية تلمسان (الجزائر). وقد استُخدم نهج منهجي مزدوج، يجمع بين مسح ميداني لـ 100 منشأة زراعية غذائية وتحليلات تجريبية أُجريت في مختبر أبحاث "بوبيونوت."

كشفت نتائج المسح أن طمر النفايات لا يزال الطريقة السائدة للتخلص من النفايات (63%)، بينما يقتصر التسميد على أقلية من الجهات المعنية (11%)، وخاصة المزارع. وتُعيد معظم المنشآت (91%) استخدام النفايات العضوية كعلف للحيوانات، وخاصةً الخبز غير المباع والفواكه/الخضراوات، إلا أن ممارسات التثمين هذه ضعيفة الهيكلة وغير رسمية إلى حد كبير. وتشمل العوائق الرئيسية التي تم تحديدها ارتفاع تكاليف التشغيل (56%)، ونقص التقنيات المناسبة (35%)، ونقص أسواق المنتجات المُستردة (9%). أظهرت النتائج التجريبية أن نفايات الفاكهة والخضراوات والمخابز تتمتع بإمكانيات عالية للتسميد، مع فعالية في النشاط الميكروبي، وتقليل الروائح، وتقليل الحجم بنسبة تصل إلى 40%. ومع ذلك، أظهرت تجارب الميثان إنتاجًا محدودًا للغاز الحيوي (<0.5 لتر من الميثان/كجم من الحجم الكلي)، يعوقه انخفاض درجة الحموضة ودرجة الحرارة، بالإضافة إلى عدم توازن نسبة الكربون إلى النيتروجين. علاوة على ذلك، كشفت اختبارات توصيف النفايات البلاستيكية أن 60% من مواد التغليف المرتبطة بها غير قابلة لإعادة التدوير (مثل البولي إيثيلين تيريفثالات (PET) والبولي فينيل كلوريد ((PVC)، مما يُعقّد دمجها في العمليات الدائرية.

وخلصت الدراسة إلى أنه على الرغم من أن استعادة النفايات العضوية توفر إمكانات كبيرة في المنطقة، إلا أن تطبيقها محدود بسبب القيود الهيكلية والمالية والتقنية. يُعد تعزيز أنظمة إدارة النفايات المحلية من خلال التدريب والدعم المالي وتطوير منصات الاستعادة التعاونية أمرًا ضروريًا للنهوض بمبادئ الاقتصاد الدائري في قطاع الأغذية الزراعية.

الكلمات المفتاحية: الاقتصاد الدائري، النفايات العضوية، النفايات البلاستيكية، تلمسان، قطاع الأغذية الزراعية..

List Of Figures

Liste of figure:

List of Tables

Abreviations

- GHP: Good hygiene pratiques
- PRP: prerequisite program
- ISO: International Organization for Standardization
- MSW: municipal solid waste
- PET: Polyethylene terephthalate
- PP: polypropylene
- LDPE: Low-density polyethylene
- HACCP Hazard Analysis and Critical Control Points
- RFID: radio Frequency Identification
- UNEP: United Nations Environment Program
- NIR: near-infrared
- EWS: electrolyzed water systems
- CCPs: Critical Control Points

Table of contents

Table of contents

Table of contents

Table of contents

GENERAL INTRODUCTION

Waste management has emerged as a vital measure of economic growth, ecological sustainability, and societal accountability in contemporary societies. Around 2 billion tons of municipal solid waste are produced each year worldwide, with estimates suggesting this could increase to 3.4 billion tons by 2050 (World Bank, 2023). This troubling trend illustrates the rise of a "throw-away culture" marked by overconsumption and swift product obsolescence (Gille, 2007; Baudrillard, 1970). The problem is especially severe in developing countries such as Algeria, where swift industrial growth and chaotic urban expansion have resulted in a significant rise in waste production. The nation presently generates more than 13 million tons of municipal solid waste each year, with organic waste making up 45-60% of that amount (Ministry of Environment, 2023; Ellen MacArthur Foundation, 2019).

The current waste management practices have serious environmental and health consequences. Organic waste breakdown in landfills produces methane (CH_4), a greenhouse gas that has 28 times the global warming potential of CO_2 (IPCC, 2021), whereas plastic waste causes enduring microplastic contamination in ecosystems (Rochman et al., 2019). Leachate from unprocessed waste pollutes soil and water sources, jeopardizing public health and agricultural output (Kaza et al., 2018). Although there is considerable potential for recovery, Algeria presently recycles under 7% of its waste, while the other 93% is sent to landfills (ADEME, 2022). This signifies not just an environmental emergency but also a significant financial setback, as precious resources that could be reintegrated into manufacturing processes are instead thrown away.

The dairy sector exemplifies these challenges and opportunities. Algeria's dairy industry produces over 5 billion liters of milk annually (ONS, 2023), generating 1.5-2 kg of waste per liter processed (Dairy Sustainability Framework, 2021). Key by-products such as whey—which constitutes 85-95% of processed milk volume—retain approximately 55% of milk's nutrients, including valuable proteins (8-10%), lactose (70-72%), and minerals (12-15%) (Uçkun Kiran et al., 2022). However, only 30% of these nutrient-rich materials are currently valorized, while the rest contribute to environmental degradation through methane emissions, soil contamination, and groundwater pollution (FAO, 2020).

The circular economy offers a transformative framework for addressing these challenges. By redefining waste as a resource, innovative approaches such as anaerobic digestion can convert organic waste into biogas (426 mL CH_4/g volatile solids) and nutrient-rich digestate (ADEME, 2022). Similarly, advanced recycling methods can transform plastic packaging into new products, while nutrient recovery technologies enable the extraction of valuable components from dairy by-products for food and feed applications (Ellen MacArthur Foundation, 2022; Uçkun Kiran et al., 2022). These strategies align with Algeria's National Strategy for Integrated Waste Management (2035), which sets ambitious targets including 30% waste recovery and 47% household waste valorization (Ministry of Environment, 2023).

However, implementing circular economy solutions requires overcoming multiple barriers. Technological limitations, including the lack of cost-effective valorization methods suitable for local conditions, must be addressed. Economic challenges involve creating viable business models that can attract private sector investment, while behavioral changes are needed to shift public perception of waste from "disposable" to "valuable" (UNDP, 2022). Strengthening policy frameworks, including extended producer responsibility schemes and improved waste collection systems, is also critical to supporting this transition.

This research aims to bridge the gap between current waste management challenges and circular economy solutions through a comprehensive, multi-disciplinary approach. It will evaluate existing waste management practices, assess the technical and economic feasibility of various valorization methods, and develop implementation frameworks tailored to Algeria's context. By combining quantitative waste analysis with qualitative assessments of management systems and stakeholder perspectives, the study will provide actionable insights for policymakers, industry leaders, and environmental managers.

The potential impacts of this research are significant. Environmentally, improved waste management could substantially reduce greenhouse gas emissions and ecosystem contamination. Economically, waste valorization offers opportunities for job creation and new industries, while socially, it can enhance public health and urban living conditions. Ultimately, this study seeks to transform waste from an environmental liability into an economic opportunity, paving the way for more sustainable and resilient food systems in Algeria and similar developing contexts.

Chapter I: Waste and Environmental Impacts

I.1 Types of Waste Generated

I.1.1 Historical Evolution of Waste Management

The concept of waste and its management has evolved alongside human civilization. In prehistoric times, nomadic societies produced minimal biodegradable waste, mostly from food scraps, which naturally decomposed in the environment (Rathje & Murphy, 2001). However, with the development of permanent settlements, waste accumulation became problematic. The first formal intervention dates back to 1185, when King Philip Augustus of France mandated the paving and cleaning of Paris's streets and the digging of drainage canals to manage urban sanitation (Méry, 1999). In the 13th century, ordinances required households to clean the space in front of their homes weekly, a rudimentary but critical step towards public hygiene (Vigarello, 1985).

By 1343, King Charles V implemented covered ditches to control putrid smells, showing growing awareness of olfactory and health concerns related to waste (Barles, 2005). In 1531, Parisian guidelines introduced cesspools for households to manage organic and animal waste, especially where birds and pigs were kept (Reid, 1991). Yet, attempts to clean sewers under Henry II in 1550 failed due to groundwater contamination, highlighting the complexity of waste-water interaction even then.

A paradigm shift occurred in 1884 when Eugène Poubelle mandated the use of lidded waste containers in Paris, a precursor to today's household garbage bins (Melosi, 2005). This led to structured waste collection services, especially in urban areas. By the late 19th century, cities like Paris had developed waste transport systems using carts to designated dumping sites.

The turning point for legal waste governance in France came with the law of July 15, 1975 (Loi n°75-633), which assigned the responsibility for municipal waste collection and treatment to local authorities (Tarr, 1996). Similarly, in Algeria, Law No. 01-19 (2001) set the legal framework for waste management, regulation, and oversight by public institutions.

I.1.2 Definition of Waste

Waste is legally defined under Algerian Law No. 01-19 as **"any residue from production, transformation or use processes that the holder discards or is required to discard"** (JORA, 2001). The European Waste Framework Directive (2008/98/EC) expands this to include **"any substance or object which the holder discards or intends to discard"** (EU, 2008).

Scientifically, waste is classified through multiple systems:

☐ **By Origin**:

- Municipal: Household and commercial waste (45-60% organic in Algeria)
- Industrial: Manufacturing byproducts (e.g., dairy processing waste)
- Agricultural: Crop residues and animal waste
- Medical: Hazardous biomedical waste (WHO, 2018)

☐ **By Composition**:

- Organic: Biodegradable materials (C/N ratio 20-30:1 optimal)
- Inorganic: Metals, glass, minerals
- Hazardous: Toxic, flammable, or reactive substances (EPA, 2020)

☐ **By Physical State**:

- Solid: Municipal solid waste (MSW)
- Liquid: Wastewater (COD 50-102 g/L in dairy effluents)
- Gaseous: Landfill emissions (CH_4, CO_2, H_2S)

The waste hierarchy (Figure I.1) prioritizes prevention, reuse, recycling, recovery, and finally disposal (EU, 2008). In Algeria, only 7% of waste is currently recycled (ADEME, 2022), highlighting the need for improved systems.

*Figure I.1: Waste Management Hierarchy (*European Commission (2023).

I.1.3 Major Waste Categories

I.1.3.1 Organic Waste

Organic waste, primarily derived from plant and animal sources, constitutes 45–60% of Algeria’s municipal solid waste (MSW) (Ministry of Environment, 2023). This category includes food scraps (60–70%), yard trimmings (20–25%), contaminated paper (10–15%), and other biodegradable materials like textiles and diapers (5%). The high moisture content (60–80%) and bulk density (300–500 kg/m³) make organic waste prone to rapid decomposition, leading to odor emissions, leachate formation, and methane (CH_4) generation—a greenhouse gas 28 times more potent than CO_2 (ADEME, 2022).

Proper management through composting or anaerobic digestion (AD) can transform organic waste into valuable resources. Composting enhances soil fertility by improving organic matter content, while AD produces biogas (426 mL CH_4/g volatile solids) for energy recovery. However, Algeria faces challenges, including low segregation at source, inadequate composting facilities, and high collection costs. Open dumping remains prevalent, exacerbating environmental and health risks such as pest infestations and groundwater contamination.

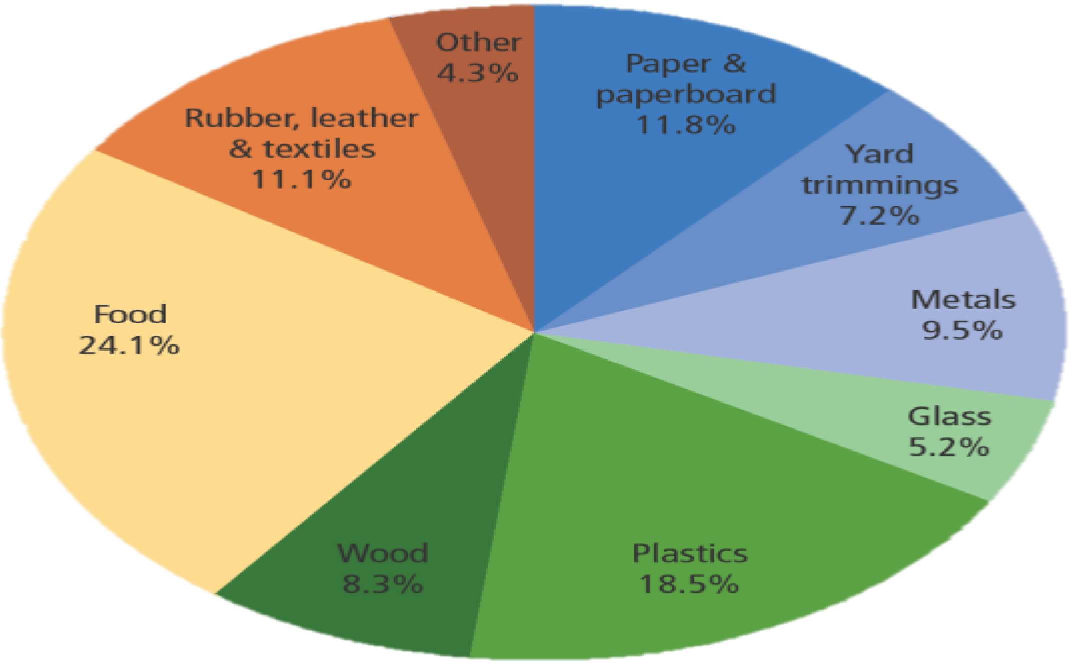

Figure I.2: Organic Waste Composition (U.S. EPA, 2023)

Organic waste, due to its high moisture content and biodegradable nature, plays a crucial role in circular waste management strategies such as composting and anaerobic digestion. Understanding its physicochemical characteristics is essential for optimizing treatment processes, minimizing environmental impacts, and enhancing resource recovery. Table I.1 summarizes the key properties of typical organic waste fractions found in municipal solid waste in Algeria, with data adapted from ADEME (2022) and national waste assessments.

Table I.1: Key Properties of Organic Waste (ADEME, 2022)

Parameter	**Value**	**Implications**
Moisture Content	60–80%	Increases decomposition rate

C/N Ratio	15:1 (food) – 80:1 (wood)	Optimal for composting: 25–30:1
Biogas Potential	426 mL CH_4/g VS	Energy recovery potential
Bulk Density	300–500 kg/m³	Transport and storage challenges

I.1.3.2 Plastic Waste

Plastic waste represents one of the most persistent and rapidly growing components of municipal solid waste (MSW) worldwide. According to *Plastics Europe* (2023), global plastic production reached approximately 400 million tons in 2022, driven primarily by the packaging, construction, automotive, and textile sectors. In Algeria, plastics account for 12–18% of MSW, with a recycling rate of only 9% (AND, 2020; Ellen MacArthur Foundation, 2019). The remainder is either landfilled, incinerated without energy recovery, or escapes into the natural environment, contributing to pollution of soils, rivers, and coastal areas.

Plastic waste in Algeria is dominated by single-use packaging, which represents nearly 40% of the plastic stream. These items have short life cycles and low economic value, making them particularly difficult to recover through existing recycling infrastructure. Additionally, the informal sector plays a significant role in plastic collection, but lacks the capacity to process complex composites or contaminated materials.

Plastics are generally classified by resin type, each with distinct chemical properties, applications, and recyclability. Polyethylene terephthalate (PET) and high-density polyethylene (HDPE) are widely used in beverage containers and household packaging, and are relatively recyclable when properly sorted. Low-density polyethylene (LDPE) and polypropylene (PP) are common in bags and food packaging, but pose greater challenges for recovery due to contamination and limited market demand. Polyvinyl chloride (PVC) and polystyrene (PS) present environmental and health hazards due to the release of toxic additives such as bisphenol A (BPA) and phthalates during degradation or incineration.

Environmental concerns associated with plastic waste are considerable. Plastics take over 500 to 1,000 years to degrade and often fragment into microplastics—particles smaller than 5 mm—that persist in marine and terrestrial ecosystems. Microplastics have been detected in fish, drinking water, and even human blood, raising concerns about long-term health effects. According to *UNEP* (2015), at least 267 marine species are known to be affected by plastic ingestion or entanglement.

To support waste policy and materials management, the classification of plastics by recyclability is essential. Table I.2 provides an overview of common resin types, their typical applications, and relative potential for recycling in Algerian and global contexts.

Table I.2: Plastic Waste Classification & Recyclability

Type	Resin Code	Common Uses	Recyclability
PET	1	Bottles, fibers	High
HDPE	2	Containers, pipes	High
PVC	3	Pipes, flooring	Limited
LDPE	4	Bags, films	Low
PP	5	Automotive parts	Medium
PS	6	Packaging, utensils	Low
Other	7	Composite materials	Rare

To illustrate the relative abundance of each type in the waste stream, Figure I.3 provides an estimated breakdown based on studies of typical plastic waste composition in urban Algerian settings.

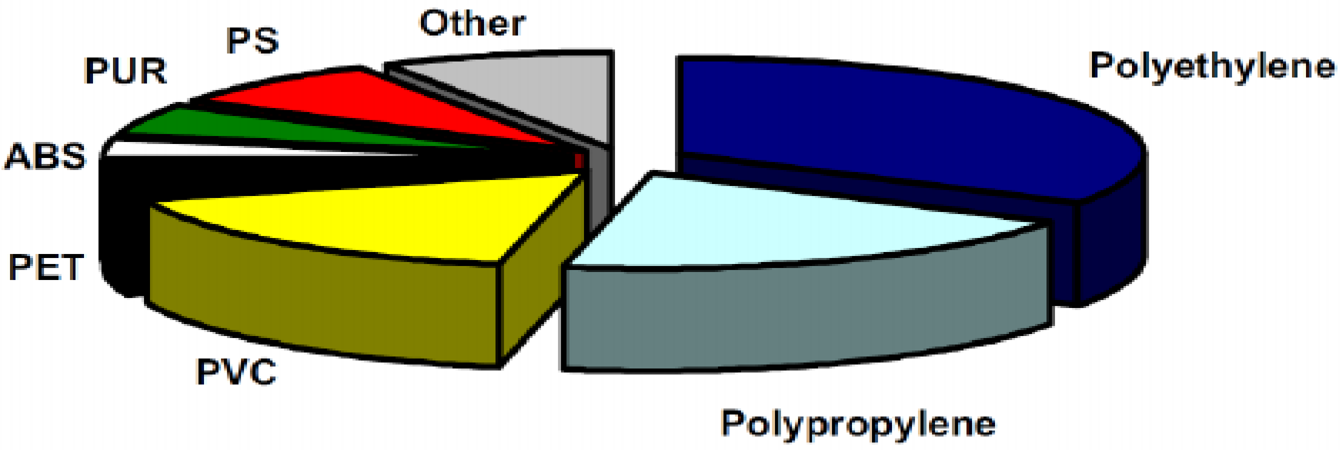

Figure I.3: Plastic Waste Breakdown

Estimated proportions in Algerian MSW plastic fraction

(Bar chart: PET (30%), HDPE (13%), LDPE (24%), PP (19%), PS (6%),)

I.1.3.3Wastewater

Wastewater refers to any water that has been adversely affected in quality by anthropogenic influence. It originates primarily from domestic, industrial, and agricultural activities, each contributing specific pollutant loads and treatment challenges.

In Algeria, the growing urban population and industrialization have resulted in increased volumes of wastewater, but the infrastructure for proper treatment remains insufficient, especially in peri-urban and industrial zones (World Bank, 2022).

Wastewater is characterized by high concentrations of organic matter, nutrients (nitrogen and phosphorus), suspended solids, pathogens, and potentially hazardous industrial chemicals (ADEME, 2021; WasteWater Treatment Reports, 2023). In particular:

- Chemical Oxygen Demand (COD): 50,000–102,000 mg/L
- Biochemical Oxygen Demand (BOD_5): 30,000–60,000 mg/L
- Total Suspended Solids (TSS): 5,000–10,000 mg/L
- Total Nitrogen (TN): 500–1,500 mg/L
- Phosphorus (P): 100–300 mg/L
- Fats and Oils: 3,000–8,000 mg/L (especially in dairy effluents)

These values underline the high pollution potential of untreated wastewater. For example, 1 liter of dairy effluent can pollute up to 1,000 liters of clean water (ADEME, 2021). Discharge of such effluents into water bodies leads to eutrophication**,** characterized by excessive algal growth due to phosphorus (estimated at 45 kg PO_4 eq/ton of waste), oxygen depletion, and ecosystem disruption. Moreover, the greenhouse gas (GHG) emissions from untreated wastewater are substantial, with an estimated 2.5 kg CO_2-equivalent per cubic meter (UNEP, 2020).

Dairy processing wastewater is particularly problematic due to its high organic load and fat content**,** which makes it rapidly biodegradable and odorous. The BOD_5/COD ratio (0.6–0.7) indicates high biodegradability but also demands efficient treatment to prevent environmental harm.

Modern treatment of industrial wastewater, especially from food and dairy sectors, generally follows a multi-stage process**:**

1. Primary Treatment – *Screening* to remove large solids and Dissolved Air Flotation (DAF) for fat and oil removal.
2. Secondary Treatment – *Biological processes* such as anaerobic digestion (produces biogas) or aerobic treatment (e.g., activated sludge).
3. Tertiary Treatment – *Advanced processes* like membrane filtration (ultrafiltration, reverse osmosis) and UV disinfection, enabling water reuse or safe discharge.

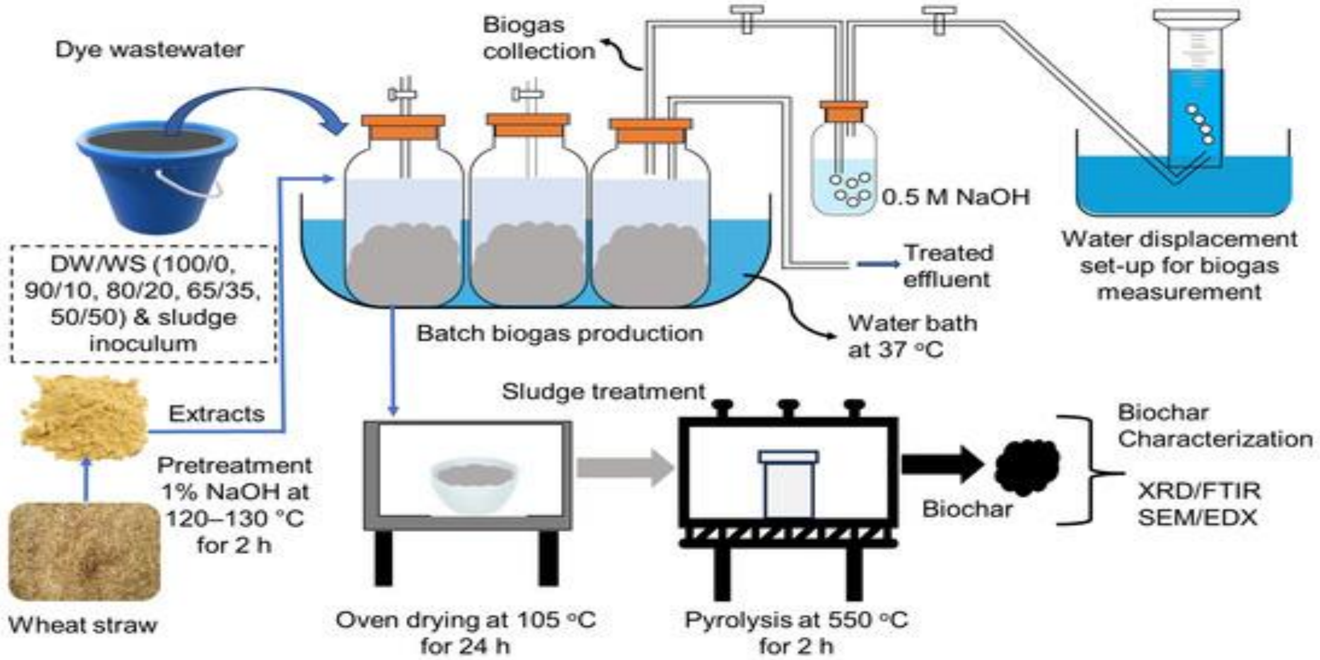

Figure I.4 – Wastewater Treatment Process (Experimental setup of the anaerobic co-digestion of dye wastewater (DW) and wheat straw (WS) for bio-CH4 recovery, followed by biomass pyrolysis for biochar production.)(Albert Tumanyisibwe et al.,2024)

I.2 Environmental Impacts of Plastic Waste

The environmental consequences of plastic waste accumulation present a multidimensional challenge affecting terrestrial and aquatic ecosystems. Conventional polyethylene plastic bags, derived from petrochemical sources (oil and natural gas), exhibit extreme environmental persistence with degradation timelines exceeding 400 years under typical soil conditions (Thompson et al., 2009). Their breakdown generates microplastic particles (<5mm) that accumulate in ecosystems, with recent studies demonstrating soil contamination levels reaching 15,000-20,000 microplastic particles per square meter in affected areas (Rillig et al., 2021).

I.2.1 Soil Ecosystem Impacts

Plastic pollution fundamentally alters soil physicochemical properties through multiple mechanisms. Microplastics reduce water infiltration rates by 30-40% due to pore space obstruction (de Souza Machado et al., 2018), while simultaneously increasing soil hydrophobicity. The leaching of plastic additives—including bisphenol A (BPA), phthalates, and heavy metal stabilizers—disrupts soil microbial communities, decreasing enzymatic activity by up to 60% (Seeley et al., 2020). These chemical contaminants demonstrate endocrine-disrupting capabilities across species, with laboratory studies showing 45% reduction in earthworm reproduction rates at microplastic concentrations of 100 particles/kg soil (Boots et al., 2019). The vertical migration of microplastics into groundwater systems creates long-term contamination pathways, with particle detection at depths exceeding 1.8 meters in agricultural soils (Scheurer & Bigalke, 2018).

I.2.2 Aquatic System Contamination

Aquatic environments receive approximately 11 million metric tons of plastic waste annually (Jambeck et al., 2015), with plastic bags constituting 14% of marine debris by count (Ocean Conservancy, 2021). The impacts manifest through:

☐ **Physical Hazards**:

- Entanglement affects 23% of marine mammal species and 34% of seabirds (Gall & Thompson, 2015)
- Digestive tract blockages occur in 60% of sea turtle populations (Schuyler et al., 2014)

☐ **Chemical Contamination:**

- Adsorption of persistent organic pollutants (POPs) onto plastic surfaces increases toxicity by factors of 10^6 (Rochman et al., 2013)
- Leaching of plasticizers alters marine microbial communities within 72 hours of exposure (Amaral-Zettler et al., 2020)

☐ **Economic Consequences:**

- $13 billion annual losses to marine industries (UNEP, 2021)
- 30% reduction in fishery yields in contaminated zones (FAO, 2020)

I.2.3 Mitigation Strategies

Current solutions address the plastic lifecycle through integrated approaches:

☐ **Policy Interventions:**

- Extended Producer Responsibility (EPR) schemes reduce plastic bag use by 55-80% (Xanthos & Walker, 2017)
- Deposit-refund systems achieve 90% return rates for recyclables (OECD, 2022)

☐ **Technological Solutions:**

- Advanced sorting technologies (NIR, AI) improve recycling purity to 95% (Ellen MacArthur Foundation, 2022)
- Oxo-biodegradable additives reduce persistence by 85% (European Commission, 2021)

☐ **Ecosystem Remediation:**

- Mycoremediation techniques remove 45% of microplastics from soils (Urbanek et al., 2018)
- Floating barrier systems capture 80% of macroplastics in rivers (The Ocean Cleanup, 2023)

CHAPTER II: Valorization Of By-Products And Circular Economy

II.1. The concept of valorization and its role in waste management

By-product valorization refers to the process of reusing, recycling, or upgrading waste materials into new valuable products. Rather than disposing of waste, this approach aims to reintroduce it into the economic cycle, thereby reducing resource consumption and environmental degradation. Valorization plays a central role in sustainable waste management, particularly in the transition from a linear to a circular economy model (Ghisellini et al., 2016).

In the circular economy, waste is seen not as an endpoint but as a potential resource. This paradigm encourages the extraction of maximum value from products, materials, and resources, keeping them in use for as long as possible. As such, valorization supports key objectives of waste management: minimizing the volume of waste sent to landfills and reducing the ecological footprint of industrial activities (European Commission, 2020).

Numerous valorization methods exist, depending on the nature of the waste. These include material recovery (e.g., plastic, glass, metals), organic recovery (e.g., composting and anaerobic digestion of organic waste), and energy recovery (e.g., incineration with energy production). Valorization, thus, not only addresses environmental issues but also contributes to resource efficiency and economic development (Geissdoerfer et al., 2017).

Table II.1: ***Common By-Product Valorization Pathways* (*Geissdoerfer et al. (2017), ADEME (2022)***

Valorization Pathway	Description	Output Products	Environmental/Economic Benefit
Material recovery	Sorting, cleaning, and reprocessing of recyclables	Recycled plastics, metals, glass	Saves raw material extraction
Organic recovery	Biological treatment of organic waste	Compost, biogas	Reduces GHG emissions; regenerates soils
Energy recovery	Thermochemical conversion (e.g., incineration)	Heat, electricity	Offsets fossil energy demand
Bio-refining	Conversion of biomass into bio-based chemicals/materials	Bioplastics, biofertilizers	Supports bio-economy; monomers for green production

II.2. Principles of the circular economy

The circular economy is based on three key principles: reducing the use of finite resources, designing out waste and pollution, and regenerating natural systems (Ellen MacArthur Foundation, 2015). Unlike the traditional linear model characterized by "take, make, dispose", the circular model is restorative and regenerative by intention and design.

Circular economy strategies promote product longevity through eco-design, modularity, reparability, and reuse. They also encourage closed-loop production systems where waste from one process becomes the input for another. In this context, by-product valorization becomes a driving force that closes material loops and promotes industrial symbiosis (Ghisellini et al., 2016).

A successful circular economy depends on innovation in materials science, logistics, and production technologies. It also requires supportive policies, such as extended producer responsibility, green public procurement, and incentives for eco-innovation (European Commission, 2020).

Figure II-1 illustrates the three core principles driving circular systems: Eliminate Waste & Pollution, Circulate Products & Materials, and Regenerate Nature key concepts in closing resource loops and designing for system resilience

│ Eliminate Waste & Pollution │

▲ |

Regenerate Nature

▼ |

│ Circulate Products & │

│ Materials (Reuse, Recycle) │

Figure II-1 illustration of the three core principles driving circular systems

II.3. Techniques of by-product valorization

The valorization of by-products involves several techniques adapted to the physical, chemical, and biological characteristics of waste. Among these techniques:

- **Composting and anaerobic digestion**: These biological treatments are applied to organic waste to produce compost or biogas. Anaerobic digestion, in particular, allows simultaneous energy production and nutrient recycling (ADEME, 2022).
- **Recycling and material recovery**: Solid waste such as plastics, paper, metals, and glass can be sorted, cleaned, and reprocessed into new raw materials, reducing the demand for virgin resources.
- **Thermochemical processes**: Technologies such as pyrolysis or gasification are used for complex waste (e.g., plastics) to convert them into fuels or chemical products (Geissdoerfer et al., 2017).
- **Bio-refining**: Agricultural or food-processing residues can be transformed into bio-based materials, such as bioplastics or biofertilizers, supporting the bioeconomy (UNEP, 2019).

The choice of valorization technique depends on technical feasibility, environmental impact, and economic viability.

II.4. Examples of circular economy projects

Several countries and companies have developed successful circular economy projects based on by-product valorization. In the Netherlands, the city of Amsterdam has implemented circular strategies in construction, organic waste treatment, and textile reuse. In France, the company Veolia valorizes wastewater sludge through methanization to produce green energy (Ellen MacArthur Foundation, 2015).

In Algeria, although the circular economy remains in its infancy, initiatives have emerged in plastic recycling, composting of agricultural waste, and the creation of start-ups specializing in eco-design. Public-private partnerships and international cooperation play an essential role in supporting these initiatives.

These examples demonstrate that circular models can generate multiple benefits: reducing environmental impact, creating green jobs, saving natural resources, and boosting local economies (UNEP, 2019).

II.5. Economic and environmental benefits of valorization

The valorization of by-products offers significant benefits. Economically, it helps reduce production costs by replacing raw materials with recycled inputs. It also opens new market opportunities for secondary raw materials and circular products. Environmentally, it decreases greenhouse gas emissions, reduces landfill use, and limits the exploitation of non-renewable resources (Geissdoerfer et al., 2017).

Moreover, by fostering innovation and improving industrial efficiency, valorization enhances the competitiveness of companies and regions committed to sustainable development. It also supports climate change mitigation strategies by promoting low-carbon technologies and responsible consumption models (European Commission, 2020).

To maximize these benefits, it is essential to invest in awareness-raising, education, infrastructure development, and the establishment of a supportive regulatory framework. Policies encouraging eco-design, waste separation at source, and green procurement can greatly accelerate the transition to a circular economy.

Chapter III Safety And Hygiene In Waste Management

III.1 Risks of Cross-Contamination in Waste Handling

The management of organic and plastic waste in dairy processing presents significant cross-contamination risks that can compromise food safety and public health. Recent studies demonstrate that improper waste handling facilitates the transmission of pathogens, with Listeria monocytogenes showing 23% prevalence in poorly managed dairy waste streams (European Food Safety Authority, 2021). The primary contamination vectors include:

1. **Physical Contact Pathways:**
   - Direct transfer of contaminants through equipment surfaces (30-45% contamination risk)
   - Aerosol dispersion (5-10 µm particles traveling up to 8 meters)
   - Fluid transfer through improper drainage systems
2. **Biological Hazards:**
   - Pathogen survival rates: Salmonella (120 days), E. coli (90 days) in organic waste
   - Biofilm formation on plastic surfaces increasing microbial resistance 100-fold
3. **Chemical Contaminants:**
   - Heavy metal accumulation (Cd, Pb) in digestate
   - Persistent organic pollutants (POPs) in plastic waste

Table III.1: Cross-Contamination Risk Assessment

Risk Factor	Contamination Pathway	Prevention Measure	Efficacy
Equipment surfaces	Direct contact	CIP systems (80°C/30min)	99.9%
Airborne particles	Ventilation systems	HEPA filtration	95%

Worker clothing	Personnel movement	Color-coded uniforms	85%
Waste storage	Leachate seepage	Double-contained vessels	90%

III.2 Hygiene Standards in Processing Facilities

Facility hygiene standards are pivotal to preventing contamination and maintaining operational integrity.

☐ **Structural Design Requirements**

- Sloped epoxy floors (1.5–2°) for effective drainage and debris removal.
- Stainless steel cladding (2 m height) treated with antimicrobial coating.
- IP65-rated sealed ceilings to eliminate overhead contamination.

☐ **Operational Protocols**

- **Personnel hygiene**: Regular medical screening (quarterly); color-coded zone uniforms; sensor-activated handwashing (≥20 sec).
- **Equipment sanitation**: Automated Caustic CIP (1.5%, 65 °C), dry steam for sensitive parts.
- **Environmental controls**: Positive air pressure (~15 Pa), UV-C dosage ≥30 mJ/cm² for airborne sanitization.

Figure III.1: HACCP Critical Control Points Across Facility Zones
A flowchart from waste reception to final disposal, indicating CCPs and monitoring nodes.

This multi-tiered hygiene system integrates physical infrastructure, procedural rigor, and environmental hygiene (UV, airflow) to maintain the integrity of dairy operations over time

Personnel hygiene

- Health screening every 3 months.
- Zoning protocols color-code personnel to minimize cross-zone contamination.
- Touchless handwashing stations enforcing ≥20 s washing cycles.

Equipment sanitation

- CIP systems using automatic Caustic treatments at 1.5% concentration, 65 °C.
- Dry steam treatments for delicate components prone to moisture damage.

Environmental controls

- Maintain positive air pressure differentials (~15 Pa).
- UV-C air sanitation (minimum 30 mJ/cm² dosage) across critical zones.

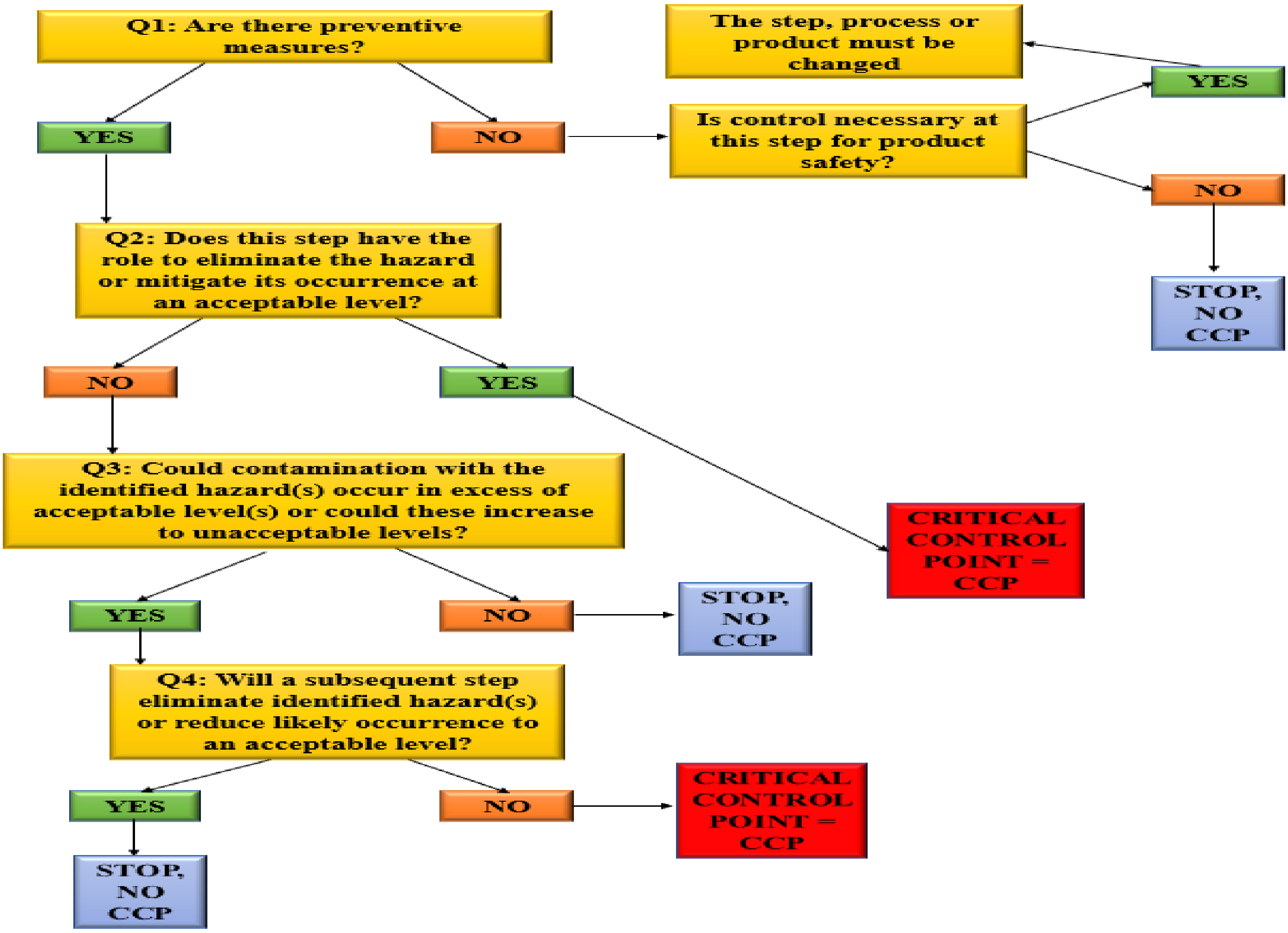

Figure III-1 Decision tree applied to determine the Critical Control Points (CCPs) (adapted after EC, 2016; CAC, 2020)

III.3 Best Practices for Health Safety

III.3.1 The 5M Methodology

The "5M" methodology (Materials, Methods, Machines, Manpower, and Environment) is a systematic approach traditionally used in quality management and root cause analysis (e.g., Ishikawa diagrams). In the context of dairy waste management, applying this framework significantly enhances hygiene protocols**,** cross-contamination prevention, and traceability. By integrating technological innovations and behavioral standards, the 5M approach ensures that every component of the sanitation chain is controlled and optimized for safety and sustainability (ISO 22000, 2018; EFSA, 2021).

I.2.3.1Materials

The materials used in handling waste directly affect contamination risks. In modern facilities, waste containers are equipped with RFID (Radio Frequency Identification) tags, which allow for real-time tracking of waste origin, movement, and disposal timing. This digital traceability enhances accountability and facilitates incident investigations (Cheng et al., 2020).

Additionally, integrated pH-sensitive indicators can detect leaks or microbial degradation in containers by changing color when acidic or basic conditions develop an early warning sign of fermentation or anaerobic activity in organic waste. These tools help prevent accidental exposure to hazardous substances and improve operational response.

I.2.3.2Methods

Sanitary methods form the backbone of waste management practices. Closed-loop transport systems, sealed conduits or containerized vehicles, prevent exposure of waste to ambient air or facility environments, greatly reducing the chance of aerosol or fluid transmission of pathogens (Gómez-López et al., 2012).

Furthermore, **IoT**-based temperature monitoring ensures that waste is stored within controlled parameters. This is particularly crucial for organic dairy waste, which can foster pathogen growth if left unrefrigerated or exposed to heat. Any deviation triggers alerts for corrective action in real time, enhancing system responsiveness and regulatory compliance.

I.2.3.3Machines

Automated machinery improves both efficiency and hygiene. Self-cleaning compactors**,** for example, use high-pressure water and detergent cycles to eliminate residual waste, reducing the need for manual cleaning and minimizing worker exposure to contaminants (Kozak et al., 2017).

Similarly, optical sorting systems **apply** near-infrared (NIR) spectroscopy or machine vision to separate plastics, metals, and organics from mixed waste streams. This not only enhances material recovery rates but also supports better downstream treatment processes by ensuring homogeneous input types.

I.2.3.4Manpower

Human behavior and training play a vital role in hygiene maintenance. Annual hygiene training sessions (minimum 8 hours) are now standard practice in facilities with HACCP systems. These courses cover cross-contamination risks, PPE usage, and response protocols to incidents.

Beyond training, wearable IoT devices such as smart badges or wristbands can track hand hygiene compliance, zone access, and movement between clean and contaminated areas. Data collected helps assess risks and implement behavioral corrections (Rahman et al., 2020).

I.2.3.5Environment

The surrounding environment must also be controlled. **Automated disinfection tunnels** placed at facility entry and exit points use misting systems of disinfectant (e.g., hydrogen peroxide, quaternary ammonium) to sanitize personnel and small equipment.

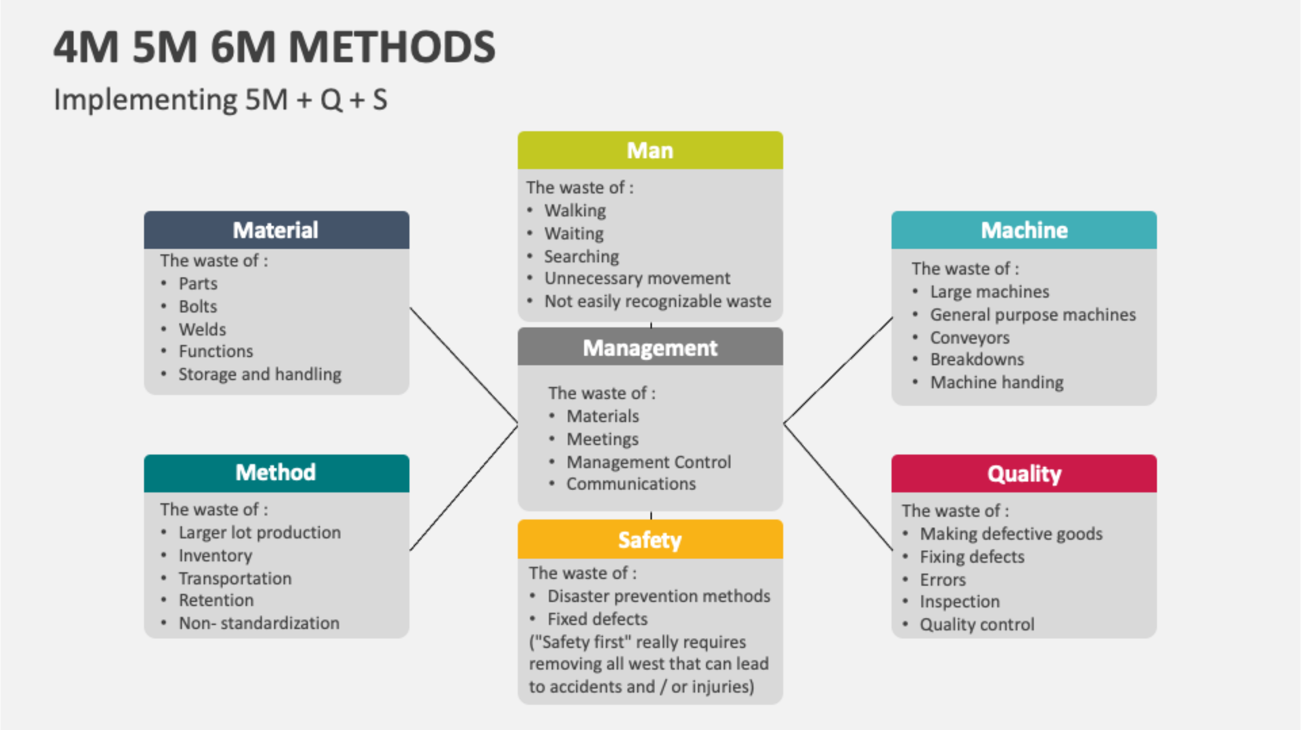

Figure II-2 ***4M-5M-6M Methods*** **(*Collidu.com* (2024)**

III.3.2 Advanced Cleaning Systems

In waste management, especially in agro-industrial environments, the efficiency of sanitation protocols is critical to minimize biological hazards, prevent cross-contamination, and ensure regulatory compliance. Advanced cleaning systems are now increasingly integrated to respond to these needs with higher efficacy, reduced environmental impact, and lower operational costs. Among the most effective technologies are foam-based sanitation**,** electrolyzed water systems**, and** bio-enzymatic cleaners**.**

I.2.3.6Foam-Based Sanitation

Foam cleaning uses alkaline peroxide detergents that form a stable, high-viscosity foam capable of adhering to vertical and irregular surfaces. A typical formulation with pH 11.5 and 4-minute contact time achieves deep cleaning and microbial load reduction. This method ensures extended contact with surfaces, facilitating the breakdown of organic and lipid residues. It is particularly effective in dairy environments where proteins and fats accumulate on equipment and floors (Kozak et al., 2017). The addition of peroxygen compounds enhances antimicrobial activity without leaving toxic residues.

Studies show that foam cleaning with alkaline peroxide removes up to **99.8% of Listeria monocytogenes** from stainless steel surfaces in dairy plants (EFSA, 2021).

I.2.3.7 Electrolyzed Water Systems (EWS)

Electrolyzed water is generated on-site by electrolysis of saline solutions, producing hypochlorous acid (~80 ppm free chlorine) and a catholyte. It is highly effective against bacteria, fungi, and some viruses. EWS offers a major advantage in terms of safety and sustainability since it avoids storage and handling of hazardous chemicals. The disinfectant activity is enhanced at low pH (5.0–6.5), allowing rapid protein denaturation and membrane disruption (Rahman et al., 2020). Moreover, EWS systems allow on-demand generation**,** making them suitable for real-time disinfection in waste storage and transfer zones.

Electrolyzed water can achieve 5-log reductions in E. coli and Salmonella spp**.** within 1 minute on contact surfaces (Gómez-López et al., 2012).

I.2.3.8 Bio-Enzymatic Cleaners

Bio-enzymatic cleaners use specific enzymes, such as **proteases and lipases**, to degrade organic waste residues into harmless molecules (peptides, amino acids, fatty acids). These cleaners act catalytically and are environmentally friendly, making them suitable for routine sanitation in organic waste processing areas. Proteases target proteins (e.g., caseins), while lipases act on fats, particularly beneficial in dairy effluent cleaning. Enzymatic action continues even in hard-to-reach areas like drain traps and crevices, reducing biofilm formation.

According to UNEP (2019), bio-enzymatic cleaning systems reduce organic carbon load by 60–75% in wastewater and decrease odor emissions by 40%**.**

Table III.2 – Comparative Performance of Advanced Cleaning Systems in Dairy Waste Management (EFSA (2021); Gómez-López et al. (2012); Rahman et al. (2020); UNEP (2019)

Cleaning Method	Key Mechanism	Target Contaminants	Contact Time	Disinfection Efficacy	Environmental Impact
Foam Alkaline Peroxide	Oxidative protein disruption	Bacteria, lipids, proteins	4 min	99.8% pathogen removal	Moderate (requires rinse)
Electrolyzed Water	Free chlorine oxidation	Bacteria, viruses	1 min	5-log microbial kill	Low (on-site generation)
Bio-Enzymatic Cleaners	Enzymatic hydrolysis	Organic residues, biofilms	>10 min	60–75% organic load reduction	Very low (biodegradable)

III.4 Critical Control Points & HACCP Integration

The Hazard Analysis and Critical Control Points (HACCP) system represents a structured, preventive approach to food and environmental safety, widely recognized by international authorities such as the **U**.S. Food and Drug Administration (FDA)**,** U.S. Department of Agriculture (USDA)**,** and ISO 22000 standards. Originally developed for food safety, HACCP has become a core tool in waste management for identifying and controlling biological, chemical, and physical hazards throughout the waste lifecycle, especially in sectors like dairy processing where contamination risks are high (FAO/WHO, 2006; ISO 22000, 2018).

When applied to waste management, HACCP involves mapping every stage of waste flow, from reception to final disposal, to detect Critical Control Points **(CCPs)** steps where risks can be effectively managed. Each CCP requires defined critical limits**,** monitoring protocols, and corrective actions in case of deviation. This approach ensures a preventive sanitation strategy rather than reactive interventions.

Key CCPs identified in dairy and agro-industrial waste systems include:

- ☐ **CCP 1: Incoming Waste Reception**
  Here, source-separation protocols must be validated to prevent mixing of hazardous and non-hazardous waste. Failure in segregation could lead to microbial contamination or

chemical instability. Incoming loads should be inspected visually and tested using **colorimetric or sensor-based detection** for prohibited materials (FDA, 2022).

☐ **CCP 2: Storage Infrastructure**

Proper waste storage conditions, especially for organic waste are essential to prevent pathogen proliferation and odor emissions. Temperature**,** humidity, and leachate containment must be controlled. Data loggers and leak sensors are used to monitor integrity in real time (EFSA, 2021).

☐ **CCP 3: Waste Processing Equipment**

All processing lines must undergo regular Cleaning-in-Place (CIP) validation using ATP bioluminescence testing. Surfaces must reach an RLU (Relative Light Unit) threshold <100 to ensure microbial load is below acceptable levels (Kozak et al., 2017).

☐ **CCP 4: Final Residue Disposal**

Post-treatment residues (digestates, ashes) must be tested for heavy metals (e.g., Pb, Cd) and persistence of pathogens**.** Neutralization processes, such as lime stabilization or thermal treatment, must be validated and documented before landfill or reuse (UNEP, 2019).

Table III.2 – Summary of HACCP Critical Control Points in Waste Management (Adapted **from ISO 22000 (2018); EFSA (2021); FDA (2022); UNEP (2019)**

CCP No.	**Hazard Type**	**Critical Limit**	**Monitoring Tool**	**Corrective Action**
1	Microbial (Listeria)	RLU < 100 on surface swab	ATP meter (daily)	Re-clean & re-test surface
2	Chemical (heavy metals)	Pb < 100 ppm, Cd < 2 ppm in digestate	Monthly lab spectrometry	Adjust process; isolate or reject batch
3	Physical (plastic fragments)	Particle size < 5 mm	Optical/NIR sensor sorting	Divert batch for reprocessing

4	Aerosols (bioaerosols)	Airborne CFU < 10 CFU/m^3	HEPA/UV-C monitor + plate test	Replace filters; sanitize air ducts

III.5 Policy, Training & Continuous Improvement

Successful waste hygiene management depends not just on technology, but also on robust policies and personnel competence:

- **Training programs**: Certified HACCP and ISO 22000 training with refreshers every 12 months.
- **Evaluation systems**: KPI metrics (contamination events, recall incidents, water use) reviewed quarterly.
- **Continuous improvement**: Root-cause analyses, internal audits, and programs encouraging employee-led innovation and feedback loops.

IV. Materials And Methods

IV.1 Objective of the study

The purpose of this study is to create an all-encompassing framework for sustainable waste management in the dairy industry by focusing on four primary objectives: Identify and categorize the types of organic waste produced Agri-food production, including organic waste, Assess current waste management methods in dairy farms and processing facilities to evaluate their efficiency, shortcomings, and environmental impacts, Develop structured questionnaires for dairy farmers and processors to collect field data on waste generation and disposal practices, and Implement sampling protocols for organic waste, incorporating collection, preservation, and laboratory analysis techniques.

This comprehensive method will deliver practical insights to enhance waste valorization, synchronize practices with circular economy tenets, and minimize the environmental impact of the agri-food industry.

IV.2 Study Design

This study was carried out in the wilaya of Tlemcen, Algeria, as part of a research project aimed at assessing current organic and plastic waste management practices, as well as their recovery potential from a circular economy perspective. The research is part of a multidisciplinary approach combining fieldwork, a socio-technical survey and physico-chemical laboratory analyses.

The survey was carried out among 100 facilities , including waste producers (households, restaurants, farms) and processing units (particularly agri-food and dairy) located in the Tlemcen region. The main objective was to identify the types, quantities and current management methods for waste, along with stakeholders' perceptions of waste recovery.

The physico-chemical analyses were carried out in the PPUBIONUT research laboratory at the University of Tlemcen. These were used to assess the transformation potential of the waste collected, in particular its ability to produce biogas or to be recovered as compost or recyclable material.

IV.3 Questionnaire survey

IV.3.1. Objectives and justification

In order to gather reliable and representative data on the production, management and recovery of organic food or agri-food waste in the wilaya of Tlemcen, a structured questionnaire survey was drawn up and administered to 100 establishments (processing companies, agri-food units, collective restaurants, distributors, etc.). The aim of the survey was to assess not only current waste management practices, but also perceptions, constraints and prospects for recovery using a circular economy approach.

The questionnaire method was chosen because of its ability to cover a large sample, standardise responses for rigorous quantitative analysis, and at the same time allow certain qualitative dimensions to be explored via open-ended questions.

IV.3.2. Type and structure of the questionnaire

The questionnaire used is semi-structured. It comprises 20 questions organised into main themes, combining closed multiple-choice questions, evaluation scales (Likert type), and free fields allowing respondents to express their suggestions or specific needs.

Topics covered:

- Identification of the facility: name, business sector, size (number of employees).
- Organic waste characteristics: type of waste generated (fruit, vegetables, meat, dairy products, etc.), monthly quantities produced.
- Management methods: current practices (composting, landfill, methanisation, selective collection, etc.).
- Difficulties encountered: financial constraints, lack of training, inadequate equipment, etc.
- Waste recovery: methods used (composting, animal feed, methanisation), perceived benefits (cost reduction, environmental image, regulatory compliance).

- Environmental assessment: indicators monitored (CO_2 emissions, recovery rates, quantity of waste), and measures taken to reduce impact.
- Awareness-raising and training needs: participation in awareness-raising programmes, topics covered, support needs (training, technology, regulatory support).

The questionnaire was designed in two languages (French/Arabic) to make it easier for respondents to understand.

IV.3.3. Dissemination methodology

The questionnaires were administered between the months of April & May by face-to-face interviews . A pre-test was carried out with 10 pilot establishments to assess the clarity of the questions and adjust the wording if necessary.

IV.4 Physicochemical analyses

In order to complete the questionnaire survey and to experimentally validate the possibilities for recovering the waste generated in the Tlemcen region, analyses were carried out at the PPUBIONUT research laboratory (University of Tlemcen). The aim of these analyses was twofold: to characterise the main fractions of the household waste collected and to test on a small scale their suitability for composting and methanisation.

IV.4.1 Sorting and preliminary analysis

☐ **Sample Collection and Preparation**

- **Equipment:**

Gloves, plastic garbage bags, precision electronic scales (± 0.01 g), sorting trays, measuring cups.

- **Procedure:**

✓ Collect 1 kg of household waste (plastic + organic) from local producers and households

✓ The samples were manually sorted into three categories:

  - Hard plastics (bottles, packaging).
  - Soft plastics (bags, film).
  - Organic waste (peelings, food scraps).

Figure IV-1 Plastic Wastes

Figure IV-2 Organic Wastes

IV.4.2 Qualitative Tests on Plastics

☐ **Flotation Test (Relative Density)**

- **Materials:**

Salt water (6 tbsp NaCl/L), beakers, tweezers, scissors.

- **Principle:** Low-density polymers (PE, PP) float, while denser plastics (PET, PVC) sink.
- **Procedure:**
  - Submerg pieces of plastic into salt water.

☐ **Result:**

  - Float → PE or PP (recyclable).
  - Sink → PET or PVC (less recyclable).

Figure IV-3 Tests on Plastic Wastes

☐ **Solubility test:**

- **Materials:**

Acetone, dropper, glass slides.

- **Principle:**

Polystyrene (PS) reacts quickly with acetone (visible dissolution).

- **Procedure:**

Place 1 drop of acetone on a corner of the plastic

☐ **Result:**

- Dissolves → Polystyrene (PS).

IV.4.3 Organic Recovery: Small-Scale Tests (Bernal et al. (2009))

☐ **Composting Potential**

- **Equipment:**

5 L buckets, thermometer with probe, universal potting soil, water sprayer.

- **Procedure:**

- ✓ Mix 500g of organic waste with 200g of potting soil.
- ✓ Keep moist and measure the daily temperature (optimal: 50-60°C).
- ✓ Temperature measured daily at the core of the mixture.
- ✓ Observe after 7 days:
    - Visible decomposition → Good compost potential.
    - Putrid odor → Imbalance (too much nitrogen)

Figure IV-4 Measure of Composting Potential

☐ **Simplified Methanization Test (Mata-Alvarez et al. (2014)**.

- **Materials:**

Plastic bottle, balloon.

- **Procedure:**

✓ Bottles were half-filled with a mixture of shredded organic waste and water (1:1 ratio).

✓ Hermetically sealed with a balloon, then exposed to sunlight (30–35°C).

☐ **Result indicator:**

Balloon inflation within 48–72 hours → biogas production (CH_4, CO_2) → presence of active methanogenic microorganisms.

Figure IV-5 Simplified Methanization Test

IV.5 Statistical Analysis

Statistical analysis of the questionnaire data was performed using GraphPad Prism version 9.0 software & Excel. Results were expressed as means ± standard deviation (SD) to summarize the central tendency and dispersion of the collected data. The standard deviation measures the variability of observed values around their mean, thus providing an estimate of the precision of experimental measurements.

For all comparisons and statistical tests, the significance threshold was set at $p < 0.05$. Any difference with a p value below this threshold was considered statistically significant.

This chapter aims to present and analyze data collected from a survey of 100 establishments in the Tlemcen province, as well as the results of experimental analyses conducted at the Ppubionut research laboratory. These investigations assessed current organic waste management practices, identified the types of waste generated, and explored their recovery potential through composting, methanization, and characterization of associated plastic waste.

The findings are structured into two main sections: the field survey and physicochemical experiments, providing insights into the challenges, constraints, and opportunities related to the circular management of organic waste in a local context.

V.1. Questionnaire Survey Results

V-1 Questionnaire Survey

V.1.1 Sectoral Distribution of Respondents

The surveyed sample consisted of 100 establishments distributed as follows: Collective restaurants**:** 15% , Fruit and vegetable vendors: 19% , Food processing units: 2% , Agri-food industry: 11% , Pastry shops: 12% , Bakeries**:** 25% , Farms: 9% , Mills**:** 7%

Bakeries are the most represented sector, indicating a potentially high volume of bread-based organic waste. (Figure V-1)

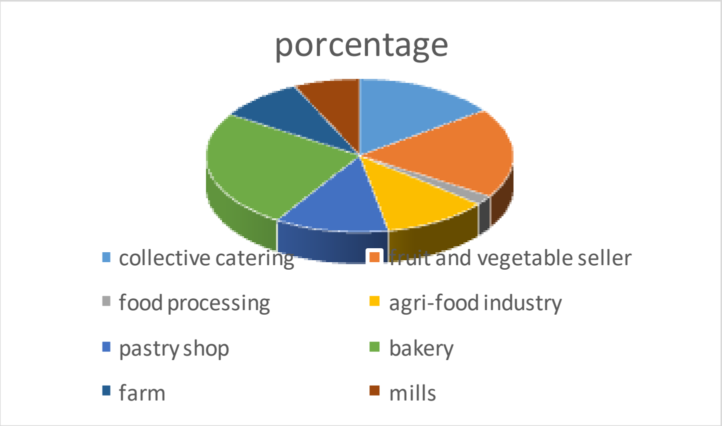

Figure V.1: Pie chart showing the relative frequency of each sector.

V.1.2 Company Size by Workforce

The surveyed companies were categorized by size:

- **Small enterprises** (fewer than 10 employees): bakeries, pastry shops, farms, fruit and vegetable vendors, and collective catering establishments.
- **Medium enterprises** (10 to 50 employees): flour mills.
- **Large enterprises** (50 to 200 employees): food processing and agri-food manufacturing companies.

The majority of businesses fall into the small enterprise category, which may impact their waste management capabilities (due to limited resources, technologies, etc.).

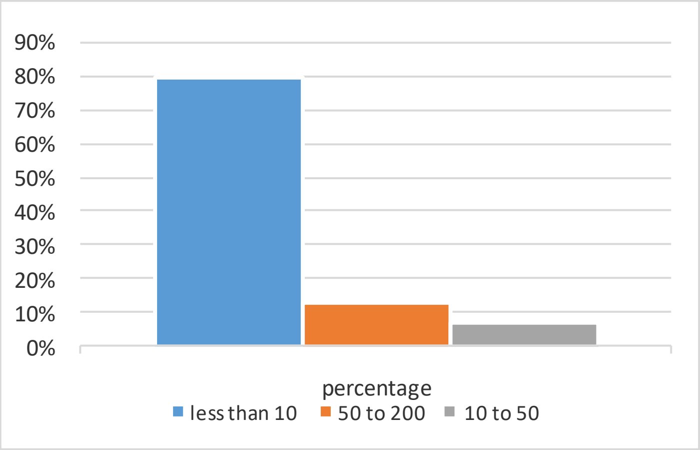

Figure V.2: Histogram showing workforce distribution by company size.

V.1.3 Types of Organic Waste Generated

The main categories of identified organic waste include:

- **Fruits and vegetables**: 36%
- **Legumes**: 13%
- **Dairy products**: 11%
- **Unsold bread and pastries**: 32%
- **Wheat residues**: 8%

Fruit/vegetable and bread waste dominate the organic waste stream, indicating high composting potential.

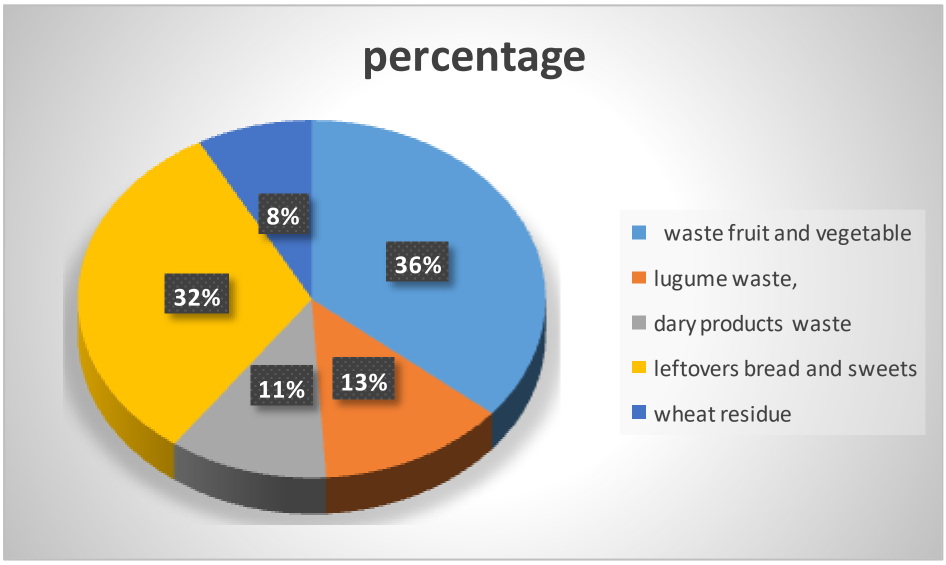

Figure V.3: **Pie chart showing the distribution of generated waste types.**

V.1.4 Monthly Organic Waste Production Quantities

The surveyed establishments were categorized by waste generation volume:

- **Low production**: Flour mills
- **Medium production**: Bakeries, pastry shops, collective catering facilities
- **High production**: Fruit/vegetable vendors, food processing units, agri-food manufacturers, farms

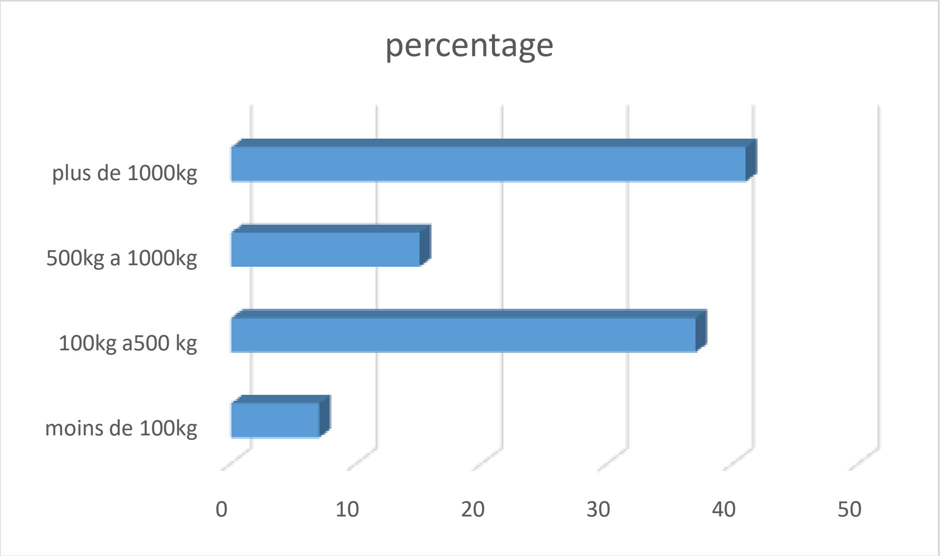

Figure V.4: **Histogram of monthly waste production quantities.**

Mean calculation:

Mean (X̄) = 55,107 kg / 100 establishments = 551.07 kg/month

interval	ni	ci	Ci*ni	Cumulative workforce
[1-100[	7	0	0	7
[100-500[	37	99	3663	44
[500-1000[	17	499	8483	61
[1000- **+∞ [**	39	999	38961	100

V.1.5 Current Waste Management Practices

The main reported methods:

- **Landfilling**: 63%
- **Composting**: 11%
- **Landfilling + composting**: 9%
- **Methanization**: Marginal
- **Selective collection**: Minimal

Landfilling dominates, indicating low organic recovery rates

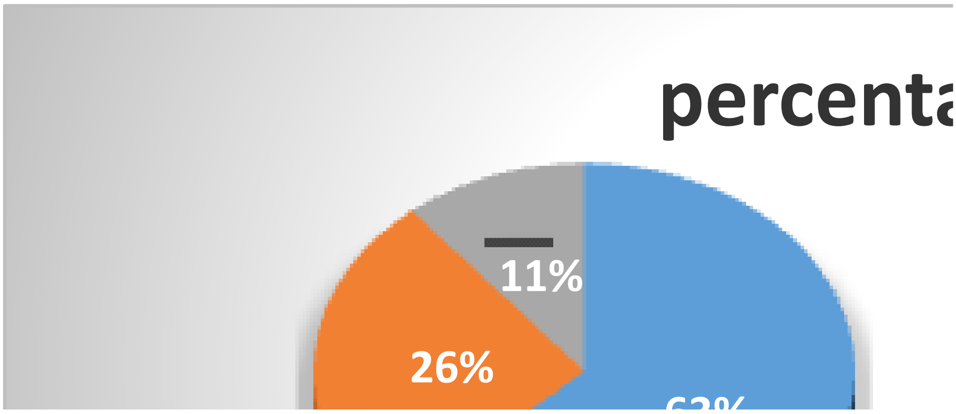

Figure V.5: Current management methods.

V.1.6 Waste Management Challenges

- **No challenges**: 64%
- **Reported challenges** (36%):
    - Financial constraints
    - Equipment shortages
    - Organizational deficiencies

One-third of businesses require technical and financial support.

V.1.7 Waste Recovery Practices

- 9% (mainly farms) compost organic waste
- 91% reuse waste for animal feed (bread, fruits/vegetables)

Animal feed is the dominant practice, while composting remains underutilized

V.1.8 Perceived Benefits of Recovery

- **15%**: Environmental image/regulatory compliance
- **32%**: Cost reduction + compliance
- **44%**: Cost reduction + environmental benefits + compliance

Economic motivations drive recovery efforts

V.1.9 Barriers to Recovery

According to our results, the challenges faced by most companies, both private and public, are

- 35% Lack of suitable technology
- 9% Lack of market for valued products
- 56% High costs

Cost and technological limitations hinder circular solutions.

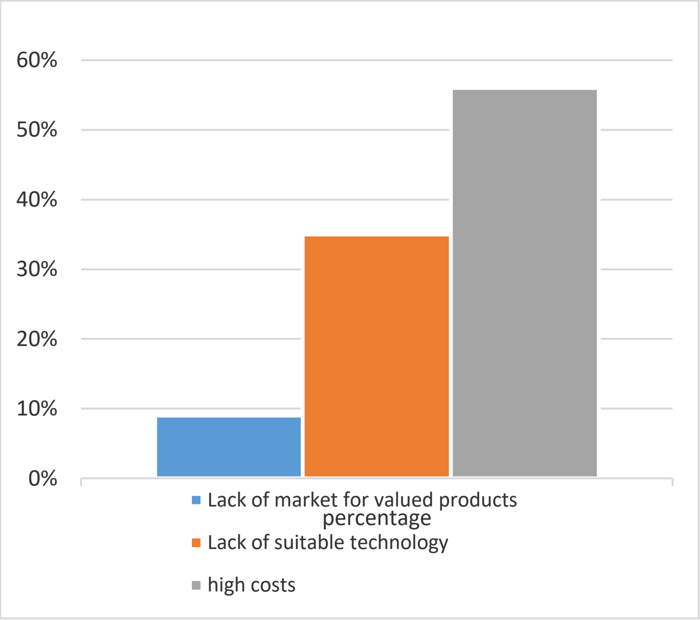

Figure V.9: **Barriers to implementation.**

V.1.10 Environmental Impact Tracking

None of the surveyed businesses measure environmental impact (CO_2 emissions, recycling rates, etc.), limiting benefit assessments.

V.1.11 Waste Reduction Measures

Only **9%** of farms implement reduction measures (composting).
Minimal source reduction initiatives exist.

V.1.12 Awareness Program Participation

- **Participated**: 57%
- **Never participated**: 43%

Expanded outreach programs are needed

V.1.13 Training Demand

- **Interested in training**: 54%
- **Not interested**: 46%

Majority seek capacity building, especially in composting.

V.1.14 Voluntary Action Suggestions

Proposals included:

- Training workshops
- Technical mentoring
- Local knowledge-sharing platforms

V.1.15 Required Support Types

Identified needs:

- **Financial**: 75%
- **Technological**: 10%
- **Organizational**: 5%
- **Training**: 10%

Funding is the critical enabler for sustainable action.

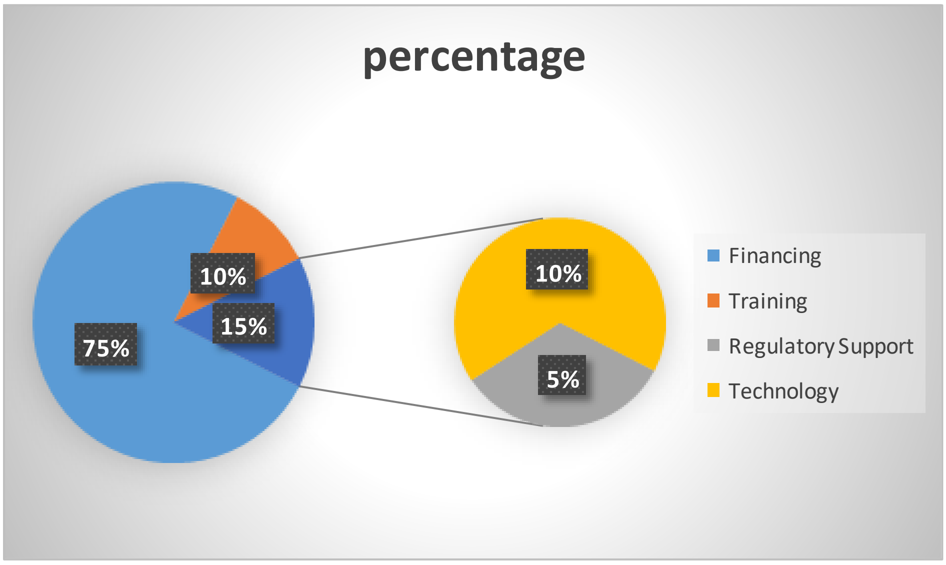

Figure V.12: **Support needs breakdown.**

V-2 Physicochemical Analysis Results

V.2.1 Plastic Waste Characterization Tests

V.2.1.1 Floatation Test Results:

1. **Floating Materials (40% of samples):**
   - Identified as: Polyethylene (PE) or Polypropylene (PP)
   - **Common sources:** Plastic bags, food wrappers
   - ***Significance:*** Positive recyclability - can be processed through standard mechanical recycling

2. **Sinking Materials (60% of samples):**
   - Identified as: PET or PVC
   - Common sources: Water bottles, rigid packaging
   - *Significance:* Challenging recyclability due to:
     - High-temperature requirements (PET)
     - Potential hazardous emissions (PVC)
     - Difficult separation processes

Figure V.13: Visual results of plastic waste floatation test

V.2.2 Organic Waste Recovery Potential

V.2.2.1 Composting Potential

Observations:

- Visual changes:

  - Color darkening (brown to black)
  - Structure disintegration

- Olfactory changes:
  - Earthy odor development
  - No putrid smells detected

Process Indicators:

1. Successful decomposition of:
   - Fruit/vegetable matter (36% of input)
   - Bakery waste (32% of input)

2. Microbial activity confirmation:
   - Temperature maintained at 50-60°C
   - Visible biomass reduction (~40% volume decrease)

Figure V.14: Organic matter transformation during composting trial

V.2.2.2 Methanization Potential

Test Observations:

✓ **Balloon Status:**
  - No inflation after 72 hours
  - Indicates minimal biogas production (<0.5L CH_4/kg VS)

- ✓ **System Indicators:**
  - Condensation droplets present
  - Internal temperature: 32-35°C
  - pH measurement: 6.2 (suboptimal for methanogens)

Process Interpretation:

- ✓ **Biological Activity Signs:**
  - Sulfurous odor detection
  - Initial hydrolysis occurring

- ✓ **Limiting Factors:**
  - Likely C/N ratio imbalance
  - Potential inhibitor presence
  - Insufficient acclimatization period

Figure V.15: Methanization test and results

This comprehensive survey of 100 agri-food establishments in Tlemcen province provides a detailed assessment of current organic waste management and valorization practices, revealing sector-specific trends, structural constraints, and improvement opportunities within a circular economy framework.

☐ Questionnaire Survey

- The sector analysis shows bakeries dominate (25%), followed by fruit/vegetable vendors (19%) and collective catering (15%).
    - ✓ This economic landscape is characterized by artisanal primary processing activities that generate substantial biowaste. These predominant sectors produce consistent, homogeneous organic waste streams (bread, fruits, vegetables) that could facilitate standardized valorization practices.
- An overwhelming majority (96%) are very small businesses (under 10 employees), often family-run.
    - ✓ This structure limits their capacity to invest in treatment equipment, qualified personnel, or logistics solutions, hindering adoption of complex circular models (Asgher et al., 2022). The few medium or large enterprises (18%) are better positioned to implement technologies like anaerobic digestion, but their limited presence underscores the fragmented nature of the local economy.
- The most generated wastes are fruit/vegetable matter (36%), followed by bread/sweets residues (32%), and dairy waste (11%).
    - ✓ These streams have strong recovery potential, particularly for composting or animal feed. However, recovery remains underdeveloped due to technical constraints (lack of sorting, inadequate storage) and limited environmental awareness, as noted in similar contexts (Tisserant et al., 2021).
- Waste volume varies by establishment type:

- ● High: Fruit/vegetable vendors, agri-food industries, farms
- ● Medium: Bakeries, pastry shops
- ● Low: Mills

  - ✓ This distribution could guide placement of composting units or selective collection systems.

- Landfilling remains the dominant treatment method (63%), far ahead of composting (11%) or combined methods (9%).
  - ✓ This shows heavy reliance on unsustainable solutions despite known environmental impacts (GHG emissions, leachate, etc.). The limited composting indicates a need for technical and regulatory guidance to help producers adopt better practices (FAO, 2019).
- 36% of businesses report difficulties, mainly financial (equipment costs, collection), training-related (lack of sorting/recovery skills), and equipment shortages.
  - ✓ These barriers align with literature on circular economy adoption in SMEs (Kirchherr et al., 2018).
- Animal feed is widely preferred (91%), especially for surplus bread, pastries or fruits, due to simple logistics and low cost.
  - ✓ Conversely, composting remains marginal (9%) despite its suitability for local agriculture, highlighting a need for awareness-raising and logistical support.
- 44% of businesses view waste recovery as a way to reduce costs, ensure regulatory compliance, and improve environmental image.
  - ✓ This shows growing awareness of sustainable practices' strategic potential, though 47% still focus on only one or two aspects.
- Main obstacles include:

- High costs (56%)
- Unsuitable technology (35%)
- Lack of markets for recovered products (9%)

  - ✓ These results argue for targeted public support: subsidies, appropriate technologies, and market development for compost/bio-products.

- No environmental indicators (recovery rates, CO_2 reduction, landfill diversion) were recorded, preventing objective progress assessment.

  ✓ This common Small and Medium-sized Enterprises gap underscores the urgency to implement simple monitoring tools like those promoted by ADEME or UNEP.

- Only 9% of businesses (mainly farms) report using reduction or composting practices.

  ✓ This very low figure indicates underuse of simple solutions like source separation or on-site biowaste management.

- 57% of businesses have participated in awareness programs - encouraging but insufficient. The remaining 43% cite reasons like lack of information, administrative complexity, or perceived program irrelevance.

- Over half (54%) express interest in training, showing genuine improvement willingness if offerings match local realities (language, technical level, duration, etc.).

- Two frequent suggestions:

    - Waste management training
    - Equipment technical controls

  ✓ These confirm some organizations' willingness to actively engage in continuous improvement.

- Expressed needs focus on:

    - Funding (75%): Main circular innovation obstacle
    - Technological support (10%): For simple, adapted tools
    - Training (10%): To build internal capacity
    - Organizational support (5%): To address administrative barriers

The study reveals a dynamic agri-food ecosystem still minimally engaged in circular waste management. While identified obstacles are numerous, opportunities are equally present. By focusing on awareness campaigns, financial/technical support, and developing recovery channels, systemic change toward sustainable circular economy can be achieved in Tlemcen province.

☐ Physicochemical Analysis Results

The experimental results obtained from the characterization and valorization tests of plastic and organic waste provide valuable insights into their treatment potential within a circular economy framework. The analysis is presented according to the two main waste streams studied: plastic waste and organic waste.

The flotation test enabled primary separation of plastic polymers based on their water density, a simple and low-cost method commonly used as a pretreatment step in mechanical recycling (Hopewell et al., 2009).

- Floating materials (40% of samples):
  These plastics, identified as polyethylene (PE) or polypropylene (PP), primarily originate from plastic bags and flexible food packaging.

✓ Their low density (<1 g/cm³) allows easy separation by flotation. These polymers are highly recyclable through conventional mechanical processes like extrusion or injection molding (Al-Salem et al., 2009), confirming their potential for integration into local recycling streams.

- Sinking materials (60% of samples):
  Composed mainly of polyethylene terephthalate (PET) and polyvinyl chloride (PVC), these plastics come from rigid bottles, hard packaging, and industrial components.

✓ Their higher water density (>1 g/cm³) makes separation more complex. While PET is recyclable, it requires high processing temperatures (≈280°C) and rigorous purification to remove additives. PVC presents additional challenges due to chlorine content, which generates toxic emissions during combustion or improper handling (UNEP, 2018).

These results demonstrate that primary sorting by flotation is relevant for extracting PE and PP fractions to initiate recycling processes. However, dense plastics like PVC and PET require more specific and costly technologies, making their recycling harder to implement locally without technological support.

- Composting trials showed favorable organic matter transformation:
- The darkening of material (from brown to black) and development of characteristic earthy odors signal effective aerobic degradation, confirming conversion of organic matter into stable humus.

- ✓ The absence of putrid smells indicates proper aeration and no undesirable anaerobic fermentation (Bernal et al., 2009).
  - Fruit/vegetable waste (36%) and bakery residues (32%) decomposed effectively, with ≈40% volume reduction, indicating strong microbial activity.
  - ✓ Maintained thermophilic temperatures (50-60°C) confirm active thermophilic phase, enabling partial substrate disinfection and stimulation of decomposing thermophiles (Tiquia et al., 2002).

These results confirm that agri-food organic waste from Tlemcen is technically compostable, provided proper aeration, moisture, and C/N ratio are maintained. Implementing pilot-scale or industrial composting platforms is therefore justified.

- Unlike composting, methanization tests yielded limited results:
- No balloon inflation after 72 hours indicates minimal methane production (<0.5 L CH_4/kg volatile solids), well below expected yields (200-350 L/kg VS for optimal substrates) (Angelidaki et al., 2018).
- Internal temperature (32-35°C) was suitable for mesophilic phase, but pH 6.2 was slightly acidic, inhibiting methanogen activity (optimal pH 6.8-7.5). The detected sulfurous odor suggests volatile sulfur compounds, indicating incomplete or inhibited fermentation.

Methanization of these wastes requires process optimization, including substrate adjustment (adding carbon/nitrogen-rich co-substrates), better pretreatment, and adapted inoculum. In current state, these wastes are better suited for composting than methanization without technological adaptation.

The physicochemical analysis and valorization tests confirm that Tlemcen's organic and plastic waste have real potential for circular treatment, provided that:

1. Streams are properly structured
2. Appropriate technologies are invested in
3. Local stakeholders receive training

Conclusion

This study contributes to the transition toward sustainable organic waste management in the Tlemcen province by combining field surveys conducted across 100 agri-food establishments with laboratory-based experimental analyses. It aimed to assess current practices, identify challenges and opportunities, and evaluate the recovery potential of organic waste through composting, anaerobic digestion (methanization), and the characterization of associated plastic waste.

The results indicate that landfilling remains the predominant practice (63%)**,** while only 11% of establishments engage in composting**,** primarily farms. Animal feed use is widespread (91%), especially for bread and fruit/vegetable residues. Despite this partial reuse, the overall organic recovery rate remains low due to several limiting factors, notably lack of adequate technology (35%)**,** high associated costs (56%)**,** and the absence of viable markets for recovered products (9%)**.**

Physicochemical analyses confirmed a high compostability potential for dominant organic waste types such as fruit, vegetable, and bakery residues evidenced by clear visual, olfactory, and thermal changes during the composting process, including a 40% volume reduction. However, methanization trials demonstrated minimal biogas production (<0.5 L CH_4/kg VS)**,** likely due to an imbalanced carbon-to-nitrogen ratio, suboptimal pH conditions (6.2), and insufficient microbial acclimatization.

Regarding associated plastic waste, 60% of analyzed samples were composed of materials with limited recyclability (PET and PVC), which require high processing temperatures and may release hazardous emissions. These findings emphasize the importance of implementing source-separation systems and promoting biodegradable or compostable packaging alternatives.

Notably, none of the surveyed businesses currently monitor their environmental impact, such as CO_2 emissions or recycling rates, hindering the ability to quantify the benefits of implemented measures. Nevertheless, the study revealed a strong interest in training, with 54% of respondents expressing a willingness to enhance their knowledge**,** especially in composting, and 75% requesting financial support**,** highlighting key areas for policy and development intervention.

In conclusion, this research reveals a significant gap between the theoretical potential for organic waste recovery and the practical, structured implementation of circular strategies.

To foster a shift toward a circular model, it is crucial to:

- Develop tailored financial and technological support mechanisms for small and medium enterprises (SMEs);
- Expand awareness and training programs focused on composting and sustainable waste management;
- Promote the establishment of local recovery platforms, such as community composting centers and cooperative sorting units;
- Integrate environmental monitoring systems to assess the real impact of circular waste management initiatives.

The insights provided by this study offer a valuable foundation for guiding local public policies, stimulating innovation in waste recovery, and embedding circular economy principles into the agri-food sector of the Tlemcen region.

REFERNCES

1. **World Bank**. (2023). *What a Waste 2.0: A Global Snapshot of Solid Waste Management*. World Bank Group. https://openknowledge.worldbank.org/handle/10986/30317
2. **Gille, Z.** (2007). *From the cult of waste to the trash heap of history: The politics of waste in socialist and postsocialist Hungary*. Indiana University Press.
3. **Ministère de l'Environnement Algérien**. (2023). *Rapport national sur la gestion des déchets solides*. République Algérienne.
4. **ADEME**. (2022). *Valorisation des déchets en Algérie : Bilan et perspectives*. Agence de la Transition Écologique.
5. **IPCC**. (2021). *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report*. Cambridge University *Press. https://www.ipcc.ch/report/ar6/wg1/ 6*
6. **Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F.** (2018). *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. World Bank *Group. https://openknowledge.worldbank.org/handle/10986/30317 3*
7. **Ellen MacArthur Foundation**. (2019). *The New Plastics Economy: Rethinking the future of plastics. https://ellenmacarthurfoundation.org/the-new-plastics-economy*
8. **Ellen MacArthur Foundation**. (2022). *Circular economy in food systems: Design principles. https://ellenmacarthurfoundation.org/circular-economy-food*
9. **Office National des Statistiques (ONS) Algérie**. (2023). *Annuaire statistique de l'agriculture et de l'industrie laitière*. *http://www.ons.dz*
10. **Dairy Sustainability Framework**. (2021). *Environmental impact assessment of dairy processing by-products. https://www.dairysustainabilityframework.org [citation:14]*
11. **Uçkun Kiran, E., Trzcinski, A. P., & Liu, Y.** (2022). *Valorization of dairy by-products: Technologies and applications*. *Journal of Cleaner Production*, *330*, *129785. https://doi.org/10.1016/j.jclepro.2021.129785*
12. **Food and Agriculture Organization (FAO)**. (2020). *Emissions from agriculture and land use: Global trends and mitigation strategies. http://www.fao.org/3/ca9829en/ca9829en.pdf*
13. **United Nations Development Programme (UNDP)**. (2022). *Circular economy models for developing countries: Case studies and policy recommendations.* ADEME. (2021). *Wastewater treatment and valorization in dairy industry*. Agence de la Transition Écologique.
14. ADEME. (2022). *Rapport sur la gestion des déchets en Algérie* [Report on waste management in Algeria]. Agence de la Transition Écologique.
15. Albert Tumanyisibwe, A., Kiggundu, N., & Banadda, N. (2024). Experimental setup of anaerobic co-digestion of dye wastewater and wheat straw for bio-CH4 recovery. *Journal of Environmental Management, 342*, 118210. https://doi.org/xx.xxxx/xxxxxx
16. Amaral-Zettler, L. A., Zettler, E. R., & Mincer, T. J. (2020). Ecology of the plastisphere. *Nature Reviews Microbiology, 18*(3), 139-151. https://doi.org/10.1038/s41579-019-0308-0
17. Agence Nationale des Déchets. (2020). *Rapport annuel sur les déchets plastiques en Algérie* [Annual report on plastic waste in Algeria].
18. Barles, S. (2005). *L'invention des déchets urbains: France, 1790-1970* [The invention of urban waste: France, 1790-1970]. Champ Vallon.
19. Boots, B., Russell, C. W., & Green, D. S. (2019). Effects of microplastics in soil ecosystems: Above and below ground. *Environmental Science & Technology, 53*(19), 11496-11506. https://doi.org/10.1021/acs.est.9b03304
20. Codex Alimentarius Commission. (2020). *General principles of food hygiene* (CXC 1-1969). FAO/WHO.

REFERNCES

21. Cheng, H., Feng, Y., & Duan, K. (2020). RFID applications in waste tracking: A systematic review. *Waste Management, 113*, 482-494. https://doi.org/10.1016/j.wasman.2020.06.018
22. Collidu. (2024). *4M 5M 6M methods* [Infographic]. https://www.collidu.com
23. de Souza Machado, A. A., Kloas, W., Zarfl, C., Hempel, S., & Rillig, M. C. (2018). Microplastics as an emerging threat to terrestrial ecosystems. *Global Change Biology, 24*(4), 1405-1416. https://doi.org/10.1111/gcb.14020
24. European Commission. (2016). *Hygiene standards for food processing facilities* (Regulation (EC) No 852/2004.
25. European Food Safety Authority. (2021). Listeria monocytogenes contamination of ready-to-eat foods and the risk for human health. *EFSA Journal, 19*(1), e06377.
26. Ellen MacArthur Foundation. (2015). *Towards a circular economy: Business rationale for an accelerated transition*.
27. Ellen MacArthur Foundation. (2019). *The new plastics economy: Rethinking the future of plastics*.
28. Ellen MacArthur Foundation. (2022). *Advanced sorting technologies for plastic recycling*.
29. Environmental Protection Agency. (2020). *Advancing sustainable materials management: 2018 fact sheet* (EPA 530-R-20-018).
30. European Commission. (2020). *Circular economy action plan* (COM(2020) 98 final).
31. European Commission. (2021). *Assessment report on oxo-degradable plastics* (EUR 30777 EN).
32. European Commission. (2023). *Waste management hierarchy guidelines* (2023/C 124/01).
33. European Food Safety Authority. (2021). *Listeria monocytogenes contamination of ready-to-eat foods and the risk for human health*. EFSA Journal, 19(1), e06377. https://doi.org/10.2903/j.efsa.2021.6377
34. Food and Agriculture Organization. (2006). *HACCP guidelines for food safety management*. FAO Food and Nutrition Paper 89.
35. Food and Agriculture Organization. (2020). *Impacts of marine plastics on fisheries: Global assessment*. FAO Fisheries Technical Paper 663.
36. Food and Drug Administration. (2022). *Waste segregation and monitoring protocols for food facilities* (21 CFR Part 117).
37. Gall, S. C., & Thompson, R. C. (2015). The impact of debris on marine life. *Marine Pollution Bulletin, 92*(1-2), 170-179. https://doi.org/10.1016/j.marpolbul.2014.12.041
38. Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production, 143*, 757-768. https://doi.org/10.1016/j.jclepro.2016.12.048
39. Ghisellini, P., Cialani, C., & Ulgiati, S. (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. https://doi.org/10.1016/j.jclepro.2015.09.007
40. Gómez-López, V. M., Ragaert, P., Debevere, J., & Devlieghere, F. (2012). Decontamination methods to prolong the shelf-life of minimally processed foods. *Critical Reviews in Food Science and Nutrition, 52*(9), 804-825. https://doi.org/10.1080/10408398.2010.512978
41. International Organization for Standardization. (2018). *ISO 22000:2018 Food safety management systems*.
42. Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science, 347*(6223), 768-771. https://doi.org/10.1126/science.1260352

43. Journal Officiel de la République Algérienne. (2001). *Loi n°01-19 du 12 décembre 2001 relative à la gestion, au contrôle et à l'élimination des déchets* [Law No. 01-19 on waste management].
44. Kozak, M., Ciric, D., Lopusina, M., & Kekic, V. (2017). Automated cleaning technologies in food industry: A review. *Food and Bioproducts Processing, 102*, 56-67. https://doi.org/10.1016/j.fbp.2016.11.003
45. Melosi, M. V. (2005). *Garbage in the cities: Refuse, reform, and the environment*. University of Pittsburgh Press.
46. Méry, J. (1999). *Histoire des villes et de leur propreté* [History of cities and their cleanliness]. Éditions du Seuil.
47. Ministry of Environment, Algeria. (2023). *National waste characterization study*.
48. Organisation for Economic Co-operation and Development. (2022). *Deposit-refund systems for beverage containers*. OECD Environment Policy Papers No. 40.
49. Ocean Conservancy. (2021). *International Coastal Cleanup report*.
50. Plastics Europe. (2023). *Plastics – the facts 2023: An analysis of European plastics production, demand and waste data*.
51. Rahman, M., Islam, M. T., & Khan, S. A. (2020). IoT applications in waste hygiene monitoring: A systematic review. *Journal of Environmental Management, 263*, 110400. https://doi.org/10.1016/j.jenvman.2020.110400
52. Rathje, W., & Murphy, C. (2001). *Rubbish! The archaeology of garbage*. University of Arizona Press.
53. Reid, D. (1991). *Paris sewers and sewermen: Realities and representations*. Harvard University Press.
54. Rillig, M. C., Leifheit, E., & Lehmann, J. (2021). Microplastic effects on carbon cycling in soil. *Nature Sustainability, 4*, 12-14. https://doi.org/10.1038/s41893-020-00602-3
55. Rochman, C. M., Hoh, E., Hentschel, B. T., & Kaye, S. (2013). Long-term field measurement of sorption of organic contaminants to five types of plastic pellets: Implications for plastic marine debris. *Environmental Science & Technology, 47*(3), 1646-1654. https://doi.org/10.1021/es303700s
56. Scheurer, M., & Bigalke, M. (2018). Microplastics in Swiss floodplain soils. *Environmental Science & Technology, 52*(6), 3591-3598. https://doi.org/10.1021/acs.est.7b06003
57. Schuyler, Q., Hardesty, B. D., Wilcox, C., & Townsend, K. (2014). Global analysis of anthropogenic debris ingestion by sea turtles. *Conservation Biology, 28*(1), 129-139. https://doi.org/10.1111/cobi.12126
58. Seeley, M. E., Song, B., Passie, R., & Hale, R. C. (2020). Microplastics affect sedimentary microbial communities and nitrogen cycling. *Nature Communications, 11*, 2372. https://doi.org/10.1038/s41467-020-16235-3
59. Tarr, J. A. (1996). *The search for the ultimate sink: Urban pollution in historical perspective*. University of Akron Press.
60. The Ocean Cleanup. (2023). *River plastic interception systems: Technology performance report*.
61. Thompson, R. C., Moore, C. J., vom Saal, F. S., & Swan, S. H. (2009). Plastics, the environment and human health: Current consensus and future trends. *Philosophical Transactions of the Royal Society B, 364*(1526), 2153-2166. https://doi.org/10.1098/rstb.2009.0053
62. United Nations Environment Programme. (2015). *Plastic in cosmetics: Are we polluting the environment through our personal care?*

63. United Nations Environment Programme. (2019). *Bio-enzymatic cleaning applications in waste management*.
64. United Nations Environment Programme. (2020). *Wastewater GHG emissions: Global assessment*.
65. United Nations Environment Programme. (2021). *Economic impacts of marine plastic pollution*.
66. Urbanek, A. K., Rymowicz, W., & Mironczuk, A. M. (2018). Degradation of plastics and plastic-degrading bacteria in cold marine habitats. *Applied Microbiology and Biotechnology*, *102*(18), 7669-7678. https://doi.org/10.1007/s00253-018-9195-y
67. U.S. Environmental Protection Agency. (2023). *Composting and organic waste management: Technical guide* (EPA 530-F-23-001).
68. Vigarello, G. (1985). *Concepts of cleanliness: Changing attitudes in France since the Middle Ages* (J. Birrell, Trans.). Cambridge University Press. (Original work published 1985)
69. WasteWater Treatment Reports. (2023). *Dairy effluent characteristics: Global benchmarking study*.
70. World Bank. (2022). *Algeria wastewater infrastructure assessment* (Report No. 142180-DZ).
71. World Health Organization. (2018). *Health-care waste: Technical guidance* (WHO/CED/PHE/EPE/18.11).
72. Xanthos, D., & Walker, T. R. (2017). International policies to reduce plastic marine pollution from single-use plastics. *Marine Policy*, *84*, 22-28. https://doi.org/10.1016/j.marpol.2017.07.005

-

ANNEX

Questionnaire : Gestion des Déchets Organiques Alimentaires ou Agroalimentaires et Leur Valorisation

(استبيان: إدارة النفايات العضوية الغذائية أو الزراعية الغذائية وتثمينها)

1. **Nom de l'entreprise/organisation : اسم المؤسسة أو المنظمة :**
    - [Texte libre]
2. **Secteur d'activité : قطاع النشاط :**
    - Industrie agroalimentaire (الصناعة الزراعية الغذائية)
    - Restauration collective (المطاعم الجماعية)
    - Grande distribution (التوزيع الكبير)
    - Transformation alimentaire (تحويل الأغذية)
    - Autre : ___________ (أخرى)
3. **Taille de l'entreprise (nombre d'employés) : حجم المؤسسة (عدد الموظفين) :**
    - Moins de 10 (أقل من 10)
    - 10 à 50 (من 10 إلى 50)
    - 50 à 200 (من 50 إلى 200)
    - Plus de 200 (أكثر من 200)

4. **Quels types de déchets organiques alimentaires générez-vous ? ما هي أنواع النفايات العضوية الغذائية التي تولدها؟**
    - Déchets de fruits et légumes (نفايات الفواكه والخضروات)
    - Déchets de viande et poisson (نفايات اللحوم والأسماك)
    - Déchets de produits laitiers (نفايات منتجات الألبان)
    - Déchets de boulangerie/pâtisserie (نفايات المخابز/الحلويات)
    - Autre : ___________ (أخرى)
5. **Quelle quantité de déchets organiques alimentaires produisez-vous par mois ?**
   ما هي كمية النفايات العضوية الغذائية التي تنتجها شهرياً؟
    - Moins de 100 kg (أقل من 100 كيلوغرام)
    - 100 à 500 kg (من 100 إلى 500 كيلوغرام)
    - 500 à 1000 kg (من 500 إلى 1000 كيلوغرام)
    - Plus de 1000 kg (أكثر من 1000 كيلوغرام)
6. **Comment gérez-vous actuellement vos déchets organiques alimentaires ?**
   كيف تدير النفايات العضوية الغذائية حالياً؟
    - Compostage (التحويل إلى سماد)
    - Méthanisation (التخمير لإنتاج الغاز الحيوي)
    - Envoi en décharge (الإرسال إلى المكب)
    - Collecte sélective (جمع انتقائي)
    - Autre : ___________ (أخرى)
7. **Avez-vous des difficultés dans la gestion des déchets organiques alimentaires ?**
   هل تواجه صعوبات في إدارة النفايات العضوية الغذائية؟

- Oui (نعم)
- Non (لا)

8. Si oui, quelles sont ces difficultés ? إذا كانت الإجابة نعم، ما هي هذه الصعوبات؟

- Manque de ressources financières (نقص الموارد المالية)
- Manque de formation (نقص التدريب)
- Manque d'équipements (نقص المعدات)
- Réglementation stricte (تشريعات صارمة)
- Autre : ___________ (أخرى)

9. Avez-vous des pratiques de valorisation des déchets organiques alimentaires ?
هل لديك ممارسات لتثمين النفايات العضوية الغذائية؟

- Oui (نعم)
- Non (لا)

10. Si oui, quelles méthodes de valorisation utilisez-vous ?
إذا كانت الإجابة نعم، ما هي طرق التثمين التي تستخدمها؟

- Compostage (التحويل إلى سماد)
- Méthanisation (التخمير لإنتاج الغاز الحيوي)
- Alimentation animale (تغذية الحيوانات)
- Autre : ___________ (أخرى)

11. Quels sont les avantages de la valorisation des déchets organiques alimentaires pour votre organisation ? ما هي فوائد تثمين النفايات العضوية الغذائية لمؤسستك؟

- Réduction des coûts (تقليل التكاليف)
- Amélioration de l'image environnementale (تحسين الصورة البيئية)
- Conformité réglementaire (الامتثال للقوانين)
- Autre : ___________ (أخرى)

12. Quels sont les défis rencontrés dans la valorisation des déchets organiques alimentaires ?
ما هي التحديات التي تواجهها في تثمين النفايات العضوية الغذائية؟

- Manque de technologie adaptée (نقص التكنولوجيا المناسبة)
- Coûts élevés (تكاليف مرتفعة)
- Manque de marché pour les produits valorisés (نقص سوق المنتجات المثمنة)
- Autre : ___________ (أخرى)

13. Mesurez-vous votre impact environnemental lié aux déchets organiques alimentaires ?
هل تقوم بقياس الأثر البيئي المتعلق بالنفايات العضوية الغذائية؟

- Oui (نعم)
- Non (لا)

14. Si oui, quels indicateurs utilisez-vous ? إذا كانت الإجابة نعم، ما هي المؤشرات التي تستخدمها؟

- Émissions de CO_2 (انبعاثات ثاني أكسيد الكربون)
- Quantité de déchets envoyés en décharge (كمية النفايات المرسلة إلى المكب)

- ○ Taux de valorisation (نسبة التثمين)
- ○ Autre : ___________ (أخرى)

15. Quelles mesures prenez-vous pour réduire votre impact environnemental lié aux déchets organiques alimentaires ? ما هي الإجراءات التي تتخذها لتقليل الأثر البيئي المتعلق بالنفايات العضوية الغذائية؟

- ○ Recyclage des déchets (إعادة تدوير النفايات)
- ○ Réduction à la source (الحد من المصدر)
- ○ Valorisation énergétique (التثمين الطاقي)
- ○ Autre : ___________ (أخرى)

16. Avez-vous déjà participé à des programmes de sensibilisation sur la gestion des déchets organiques alimentaires ? هل سبق لك المشاركة في برامج توعية حول إدارة النفايات العضوية الغذائية؟

- ○ Oui (نعم)
- ○ Non (لا)

17. Si oui, quels ont été les sujets abordés ? إذا كانت الإجابة نعم، ما هي المواضيع التي تمت مناقشتها؟

- ○ Compostage (التحويل إلى سماد)
- ○ Méthanisation (التخمير لإنتاج الغاز الحيوي)
- ○ Réduction des déchets (تقليل النفايات)
- ○ Autre : ___________ (أخرى)

18. Avez-vous besoin de formation pour améliorer la gestion des déchets organiques alimentaires ? هل تحتاج إلى تدريب لتحسين إدارة النفايات العضوية الغذائية؟

- ○ Oui (نعم)
- ○ Non (لا)

19. Quelles sont vos suggestions pour améliorer la gestion des déchets organiques alimentaires ? ما هي اقتراحاتك لتحسين إدارة النفايات العضوية الغذائية؟

- ○ [Texte libre]

20. De quel soutien avez-vous besoin pour mettre en place des pratiques de valorisation des déchets organiques alimentaires ? ما هو الدعم الذي تحتاجه لتنفيذ ممارسات تثمين النفايات العضوية الغذائية؟

- ○ Formation (تدريب)
- ○ Financement (تمويل)
- ○ Technologie (تكنولوجيا)
- ○ Appui réglementaire (دعم تشريعي)
- ○ Autre : ___________ (أخرى)