The Role of Eco-innovation in Waste Management in Algeria: Case Study of Green-Al Energy

دور الابتكار البيئي في إدارة النفايات في الجزائر: دراسة حالة مؤسسة Green-Al Energy

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Abstract: This study aimed at exploring the national context of waste management challenges in Algeria, and its governmental strategy and national support for startups to contribute with eco-innovation to manage waste. A case study examined Green-Al Energy, an Algerian eco-entrepreneurial venture designed to convert organic waste into biogas and bio-fertilizer. Findings showed that Green-Al Energy represents a locally adapted, low-cost eco-innovation pathway suitable for decentralized waste valorization, particularly in remote and rural regions where energy access and waste management remain problematic.

Keyword: Waste management; Eco-innovation; Green-Al Energy.
JEL classification code: Q53, Q55, O31.

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1. Introduction

In recent years, Algeria has increasingly recognized the importance of green entrepreneurship and eco-innovation as key drivers of sustainable development. Faced with environmental challenges such as resource depletion, pollution, and climate change, the country has begun to encourage startups and enterprises that integrate ecological practices into their business models. Green entrepreneurship with eco-innovation not only contributes to environmental protection but also fosters job creation, technological advancement, and social awareness. By supporting eco-innovative initiatives, Algeria is positioning itself within the global movement toward sustainability, highlighting the potential of local entrepreneurs to balance economic growth with ecological responsibility (Benmessaoud, 2022; Araar, Abaidia, & Mekahlia, 2024).

In addition, eco-innovation has become a strategic pillar in global sustainability transitions. In emerging economies such as Algeria, the need to address mounting environmental pressures—including rising solid–waste generation, low recycling rates, and dependence on fossil fuels—has accelerated interest in green technologies developed by local entrepreneurs. This introduction outlines the importance of eco-innovation, highlights its relevance for Algeria's environmental policy context, and presents the objectives of this case study.

1.1. Main question

For this study, we put the following main question to investigate: "*What is the role of eco-innovation in waste management in Algeria?*".

This problematic is followed by the following sub questions:

1. What challenges does Algeria face regarding waste management?

2. Are there any initiatives adopted by Algeria regarding waste management through eco-innovation?
3. How does Green-Al Energy contribute with eco-innovation to waste management?

1.2. Hypotheses

In order to find answers for the main question and sub questions of the study, the following main hypothesis was put for investigation: *"Algeria pays attention to the importance of eco-innovation for the sake of waste management"*.

The sub hypotheses were:

- **H_1:** Algeria still faces several challenges regarding waste management;
- **H_2:** There are several initiatives Algeria adopted regarding waste management;
- **H_3:** Green-Al Energy contributes with an eco-innovative solution help manage waste.

1.3. Research objectives

- To shed light on waste management reality in Algeria;
- To discover Algeria's institutional initiatives and strategies to manage waste for the future;
- To find out how eco-innovation can contribute to waste management.

1.4. Research methods

For the purposes of the study, the descriptive method was adopted to discover waste management and eco-innovation, as well as waste management reality in Algeria its and institutional initiatives and strategies to manage waste for the future. Moreover, the case study method was used to investigate Green-Al Energy, an Algerian

eco-entrepreneurial venture that used an eco-innovative product to manage waste through recycling domestic waste.

2. Waste Management

Waste management has been a serious issue and among major topics of sustainable development around the world. Governments, organizations and people are meant to deal with waste, each from their positions.

2.1. Definition of waste management

According to United Nations Environment Programme (UNEP) (2024): "Waste management refers to the collection, transport, recovery, and disposal of waste, including the supervision of such operations and after-care of disposal sites, with the aim of minimizing adverse impacts on human health and the environment".

World Bank defines it as: "Solid waste management is a universal issue affecting every single person in the world. It encompasses the generation, collection, transportation, treatment, and disposal of waste, as well as monitoring and regulation, with the goal of reducing adverse impacts on health, the environment, and the economy" (World Bank, 2022).

In addition, OECD (2019) defines it as: "Waste management refers to the activities required to handle waste materials in ways that reduce environmental impacts, promote resource efficiency, and support circular economy transitions".

2.2. Types of waste

"Common wastes are municipal solid waste, agriculture waste, industrial waste, biomedical waste, and e-waste" (Kumar & Kanwar, 2026, pp.5-6). The main types of waste are as follows:

a. **Municipal solid waste**: Municipal solid waste is produced from domestic residences, hospitality establishments, commercial offices, retail outlets, and educational institutions. Its principal constituents encompass organic waste, synthetic materials, glass items, and debris resulting from construction and demolition activities (Kumar & Kanwar, 2026, pp.5-6);

b. **Agricultural waste:** Agricultural waste is the by-product of various farming activities. It includes animal waste, straw, coir fiber, paddy husk, and other crop residues (Kumar & Kanwar, 2026, pp.5-6);

c. **Industrial solid waste:** This type of waste is generated from manufacturing processes in restaurants, eateries, cafeterias, diners, and other food establishments (Jain et al., 2025, p.4);

d. **E-Waste:** Electronic waste consists of discarded and unusable electronic and electrical equipment such as bulbs, batteries, electronic toys, computers, mobile phones, and televisions. E-waste contains both valuable and hazardous materials requiring special handling and recycling (Kumar & Kanwar, 2026, pp.5-6).

2.3. Importance of waste management

Managing waste has become crucial today to save environment and support sustainable development. So, it is necessary to manage waste for: (Lenka et al., 2025, p.12-13)

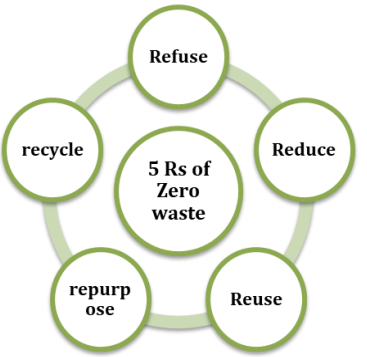
- **Environmental Protection:** Proper waste management helps prevent pollution of air, water, and soil. It reduces the release of harmful substances into the environment, minimizing negative impacts on ecosystems, wildlife, and human health (Lenka et al., 2025, p.12);

- **Resource Conservation:** It involves recycling and reusing materials, reducing the need for new raw materials. This conserves natural resources and energy, leading to more sustainable production processes (Lenka et al., 2025, p.12);
- **Energy Savings:** Many waste management practices, such as recycling and waste-to-energy technologies, generate renewable energy or recover energy from waste. This reduces the reliance on fossil fuels and helps combat climate change (Lenka et al., 2025, p.12);
- **Health and Safety:** It can lead to disease transmission, water contamination, and air pollution. It minimizes health risks for communities and workers in the waste industry (Lenka et al., 2025, p.13);
- **Economic Benefits**: It creates job opportunities in recycling, waste collection, processing, and related industries. It also reduces the costs of waste clean-up, disposal, and environmental remediation (Lenka et al., 2025, p.13);
- **Compliance with Regulations:** Many countries and regions have strict regulations for waste management to protect the environment and public health. Proper waste management ensures compliance with these regulations, avoiding legal and financial penalties (Lenka et al., 2025, p.13);
- **Sustainable Development:** Integrating waste management into sustainable development goals ensures the well-being of current and future generations by preserving resources and minimizing the environmental footprint (Lenka et al., 2025, p.13).

2.4. Waste management techniques

Definitions of waste management mentioned several techniques of how to manage waste. These techniques are summarized in the so-called "the 5 Rs of Zero waste".

Figure 1: Waste management techniques



Source: (Lenka et al., 2025, p.19)

1. **Refuse:** Refusing waste means avoiding the acquisition of unnecessary items from the start. By not purchasing things we do not truly need, we can effectively minimize waste generation (Kumar & Kanwar, 2026, p.375);
2. **Reduce:** Reducing waste helps minimize environmental impact and conserves resources (Kumar & Kanwar, 2026, p.375);
3. **Reuse:** Single-use plastics cause significant environmental harm, with at least 14 million tons entering the ocean annually. Replacing these items with reusable alternatives—such as metal cutlery—can greatly reduce this damage. Emphasizing reuse, after thorough cleaning, and finding secondary uses for products are important strategies to minimize plastic waste (Kumar & Kanwar, 2026, p.376);
4. **Repurpose:** If an item cannot be reused, it may still serve a new purpose through a process called upcycling. This involves

creatively repurposing materials to extend their lifecycle and reduce waste (Lenka et al., 2025, p.19);

5. **Recycle:** Recycling is the last resort when the first four Rs cannot be applied. If an item cannot be refused, reduced, reused, or upcycled, recycling becomes the best option. This process transforms recyclable waste into fertilizers or other useful products, helping to minimize environmental impact (Kumar & Kanwar, 2026, p.376).

3. Eco-Innovation

In waste management, eco-innovation plays a crucial role by transforming waste into valuable resources like energy, compost, and recyclable materials, thereby promoting environmental protection and sustainable development.

3.1. Definition of eco-innovation

Eco-innovation, environmental innovation, and green innovation are terms used interchangeably to describe the same concept (Pichlak & Szromek, 2021, p.2). Eco-innovation is a relatively new concept of great significance to trade and policymakers, encompassing various innovations that offer environmental benefits.

In common terms, eco-innovation refers to new technologies that enhance both economic and environmental performance. Some definitions also include organizational and social changes aimed at improving competitiveness and sustainability across its social, economic, and environmental pillars (Manasi & Bhat, 2020, p.3).

In addition, “Eco-innovation is any form of innovation aiming at significant and demonstrable progress towards the goal of sustainable development, through reducing impacts on the environment or

achieving a more efficient and responsible use of natural resources, including energy" (Manasi & Bhat, 2020, p.4).

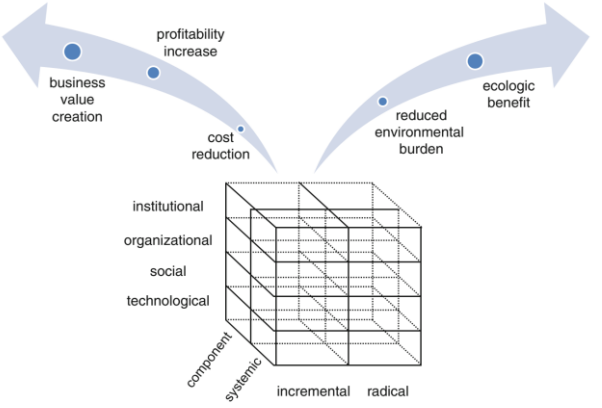
Most of eco-innovation definitions focus on two perspectives: its environmental impact and the innovator's intention. Eco-innovation was developed in the first place to solve pollution and waste problems in order to achieve and maintain sustainable development. So, the utmost purpose of Eco-innovation is saving environment.

The second perspective shows innovator's intention and efforts to create and applicate innovative solutions for the sake of ecology alongside the economic purpose of any firm: creating a competitive advantage and making profits.

3.2. Dimensions and impacts of eco-innovation

Eco-innovation may not always be developed specifically to reduce environmental impact, but it often results in significant environmental benefits (Azevedo et al., 2014, p.4).

Figure 2: Dimensions and impacts of eco-innovation



Source: (Azevedo et al., 2014, p.5)

The figure presents a holistic picture of eco-innovation. Firms can adopt either radical or incremental innovation for the environment good. Eco-innovation can be at technological, organizational, social,

and institutional level. This means that everybody is meant with saving ecology: organizations, individuals, people in communities and governments.

Applying the two types of eco-innovation on the several levels yields two types of benefits. The first is economic for firms who apply innovations in terms of goods, services and processes so firms can cut costs, increase profitability and create a business value and a good image for them. The second benefit is foe the environment by reducing burdens and achieve many ecological benefits.

3.3. Importance of eco-innovation in waste management

Eco-innovation plays a pivotal role in waste management by introducing technologies, policies, and practices that reduce waste generation, improve recycling, and promote circular economies.

Dib & Harnan (2025, p.17) stated that innovative technologies are a good example in this context. Firms (and even governments) can adopt various modern technologies in specific fields and areas of environmental and ecological sciences to deal with waste in more effective and environmentally friendly ways, by working to apply various modern technologies in the processes of collecting, sorting and processing waste. The most important of these technologies are as follows: (Dib & Harnan, 2025, p.17)

- **Mechanical treatment:** Waste is processed through a series of mechanical and biological processes that reduce the size of the waste as well as stabilize it, as it separates the waste material into different parts and is then processed more precisely by stripping, shredding and grinding the material;

- **Biodegradation and bioremediation:** Biological processes usually include the production of fertilizers and anaerobic decomposition of organic matter, the production varies according to the size of the treated material, and the production process can take place in special facilities with optimized and adapted conditions, in addition to the filtering of the emitted gases;
- **Thermal analysis:** This technique is based on the reaction of carbon containing substances at high temperatures up to 1650 degrees Celsius, in an oxygen-free environment. The waste is dried and cut before this process, which produces significant amounts of natural gas and many other usable materials;
- **Landfill:** A site designated for waste disposal by burial. It has been a common method of waste disposal prior to the development of advanced treatment technologies. Today, landfilling continues to be widely practiced, but with more sophisticated techniques to control and minimize environmental risks.

4. Eco-innovation and waste management in Algeria

Eco-innovation and waste management in Algeria are increasingly recognized as essential pillars for achieving sustainable development. The country faces mounting challenges from rising waste volumes, limited recycling infrastructure, and reliance on landfills, yet recent strategies highlight a shift toward circular economy practices and innovative solutions.

4.1. Waste management challenges in Algeria

In general, Algeria faces major waste management challenges including rapid urbanization, rising waste volumes, insufficient

infrastructure, weak recycling systems, and governance issues. These problems are compounded by limited funding, technological gaps, and inconsistent policies. Waste management challenges in Algeria are summarized in:

- **Rising Waste Volumes:** National domestic waste reached 10-12 million tons of domestic waste and similar waste, with forecasts of reaching about 20 million tons in 2035;
- **Infrastructure Deficiencies:** Many municipalities lack adequate collection, treatment, and disposal facilities. In addition, open dumping and poorly managed landfills are still common, leading to environmental and health risks (Hachemi et al., 2025);
- **Recycling and Valorization Gaps:** Waste valorization rate (recycling and utilization) is about only 10%, which is a low rate according to the international standards. This rate is aimed to increase up to 47% by the end of 2035 according to "SNGID 2035" (Stratégie Nationale de la Gestion Intégrée et de la Valorisation des Déchets).

4.2. Algeria's initiatives to manage waste through green entrepreneurship and eco-innovation

In order to manage waste and increase waste valorization rate, Algeria put several initiatives. Some of them are institutional through "SNGID", and the other initiatives are encouraging entrepreneurships and startups to come up with creative ideas and apply eco-innovation for waste management.

4.2.1. SNGID: an institutional solution

Ministry of environment and quality of life put the SNGID: National Strategy for Integrated Waste Management and Recovery. The main aim of SNGID is to reduce domestic waste, increase the valorization rate and turn waste into a value to gain some national revenue. In addition, the SNGID aims achieve the following objectives: (Ministry of environment and quality of life, 2025)

- A 10% reduction in household and similar waste by 2035;
- 47% of household and similar waste will be recycled. Forty-seven percent of special waste and sixty percent of inert waste are expected to be recovered, valued at 88 billion DA;
- Public-private partnerships are expected to generate approximately 54 billion DA;
- 30,000 direct and 70,000 indirect jobs will be created between 2019 and 2035:
- Environmental gains will be achieved by reducing greenhouse gas emissions to a value of 150 billion DA;
- 1,300 landfills will be closed.

4.2.2. Encouraging green entrepreneurship and eco-innovation

Algeria is actively promoting green entrepreneurship and eco-innovation as part of its broader sustainable development agenda. This effort is visible in both government initiatives and the rise of startups that integrate ecological concerns into their business models.

Green entrepreneurship in Algeria has emerged as a response to increasing environmental challenges and the global push for sustainability. Studies highlight that eco-preneurs in Algeria play a crucial role in raising awareness among policymakers and society, while also creating jobs and fostering environmental innovation (Benmessaoud, 2022). By demonstrating the economic benefits of

ecological practices, these entrepreneurs encourage other businesses to adopt green technologies, thereby contributing to a more sustainable economy.

Startups are particularly important in driving eco-innovation. Such startups not only introduce innovative solutions but also highlight the interconnection between entrepreneurship, sustainability, and organizational management. Their success demonstrates that eco-innovation can be a viable path for Algerian businesses to remain competitive while addressing environmental concerns.

The Algerian government has increasingly recognized the importance of supporting green entrepreneurship. Policies that encourage renewable energy, waste management, and sustainable practices provide a fertile ground for eco-innovation. However, challenges remain, including limited financing and the need for stronger institutional support. Despite these obstacles, the growing number of green startups suggests that Algeria is moving toward a more sustainable entrepreneurial ecosystem (Araar et al., 2024).

5. Case study: “Green-Al Energy”

Green-Al Energy is one of Algeria’s most promising eco-innovation startups, specializing in biogas production from organic waste. this startup focuses on providing off-grid energy solutions for households, farmers, and restaurants in isolated regions.

The study is explorative in method. The startup website and statistical reports were used as primary and secondary data collection tools to answer the main question and test hypotheses of the study.

5.1. Overview of Green-Al Energy

Green-Al Energy Biogas is a company in Algeria that provides fully off-grid biogas systems, helping customers lead more sustainable lives (Lioness Weekender, 2024). Green-Al Energy is an Algerian startup founded in 2021 by Kheira Nawel Benaissa, a researcher and professor specializing in waste management. Its core innovation is that the startup designs and sells biodigesters that transform organic waste into biogas and electricity.

Faced with inequalities in access to energy in Algeria, the startup Green Al offers a solution by selling mobile biodigesters to produce biogas from organic waste. This solution, initially conceived for Algeria's desert regions, is also attracting interest from the rest of Africa and Europe, where tests are being conducted in Spain (Vépierre, 2022).

According to the founder, Kheira Nawel Benaissa, Green Al was founded to help communities have access to gas and electricity. She stated: “I lived for 10 years in southern Algeria, and when I went out into the desert, I saw communities in villages that didn't have access to gas and electricity... Otherwise, they used charcoal and wood, but these methods are harmful to the environment and mean that today, we hardly have any palm trees left around these villages. While Algeria is considered an oil and gas country, there is a real problem with energy supply” (Vépierre, 2022).

“I always say that the role of a researcher is to find solutions for society and apply them in the field. That's why I worked on biogas during my PhD, with the idea of creating my own company afterward. I was then able to incubate my project, which allowed me to acquire sufficient business skills. In September 2021, I received the Innovative

Project label from the Algerian Ministry of Startups. From there, I officially created Green Al" said Benaissa (Vépierre, 2022).

5.2. Green-Al Energy eco-innovative product

To overcome difficulties of getting gas and electricity, Green-Al innovated a kit containing a biodigester made of PVC fabric, which has the advantage of being portable and mobile. It also includes a stove for burning the methane gas, an adapter for converting the biogas into electricity by connecting it to a generator, and finally, the startup's inoculum, which is the secret ingredient for boosting biogas production.

Green-Al offers several biodigester sizes depending on the client's needs and the amount of waste to be introduced. The lifespan of the product is 8 to 10 years. Green-Al Energy targets users such as rural households, restaurants, and farmers in isolated desert regions where access to conventional energy is limited (Vépierre, 2022).

The biodigester is installed outdoors on a flat surface and connected to the stove in the kitchen. Waste such as food scraps, peelings, wastewater, animal waste, and our inoculum are placed inside. Once the biodigester is closed, the technology operates through anaerobic digestion, meaning that bacteria do the work, producing biomethane ready to be burned for 12 days (Vépierre, 2022).

Depending on the biodigester's volume, biogas can be produced for 2 to 6 hours of continuous use. After 3 months, the contents of the biodigester are emptied and refilled. The remaining digestate is an excellent biofertilizer and can therefore be reused (Vépierre, 2022). The Green-Al's biodigesters can convert 100–150 kg of organic waste per day into 3–5 m^3 of biogas, which is enough energy for a household or a small restaurant (Techniques de l'Ingénieur, 2022).

Basically, anywhere there's a source of waste, Green-Al Energy serves households, farmers, restaurants, canteens, refugee camps, underserved communities, and individuals seeking a sustainable lifestyle by providing biogas systems. Their pre-engineered, fully off-grid systems offer modular options tailored to each customer's needs, enabling healthier, more efficient, self-reliant, and sustainable living (Lioness Weekender, 2024). Green-Al donated its kits to associations in Algeria for testing, and sold them to agricultural facilities.

Moreover, Benaissa, the founder of Green-Al stated that their biodigester has several advantages: (Lioness Weekender, 2024)

1. The biodigester is portable and user-friendly. It transforms organic waste—such as agricultural residues, food scraps, animal, and human waste—into gas, electricity, and biofertilizer.
2. Currently the biodigester is to be had in sizes to satisfy people and farms desires in terms of waste management, strength manufacturing and natural fertilizers;
3. Green-Al produces electricity unlike our competitors;
4. Green-Al has a creative business model;
5. Green-Al is less than 25% of competitors;
6. Green-Al's kits are 100% recyclable, and they have a lifespan of 10-15 years.

In addition, in the near future it is planned to increase and diversify the product ranges (flexible PVC canvas biodigester with stove and electricity adapter).

5.3. Study results

Green-Al has environmental, economic, and social impacts. Environmentally, Green-Al contributes to reducing methane emissions by diverting organic waste from landfills and open dumping sites. It

also promotes the local production of renewable energy, lowering reliance on propane cylinders and firewood.

Green-Al Energy contributes significantly to environmental sustainability by transforming organic waste into biogas and biofertilizer. As mentioned before, Green-Al's biodigesters can convert 100–150 kg of organic waste per day into 3–5 m^3 of biogas. In addition, Green-Al's biodigesters help valorize the organic fraction (≈60% of total waste), reducing methane emissions from landfills. And each biodigester can cut CO_2 emissions by 2–3 tons per year, depending on usage (Vépierre, 2022).

This process reduces greenhouse gas emissions, lowers reliance on landfills, and minimizes pollution from untreated waste. By promoting renewable energy, the startup helps Algeria transition toward a low-carbon economy and supports climate change mitigation (Techniques de l'Ingénieur, 2022).

Economically, households benefit from reduced energy expenditures, while local manufacturing and maintenance services create employment opportunities. A single Green-Al biodigester produces 3–5 m^3 of biogas daily, equivalent to 2–3 kg of LPG (liquefied petroleum gas). his saves households or restaurants up to 30–40% on monthly energy costs compared to fossil fuels.

For agriculture, the biofertilizer generated can replace up to 25–30 kg of chemical fertilizer per month, lowering agricultural input costs (Lioness Weekender, 2024). On a national level, scaling biodigester adoption to 10,000 units nationwide could create hundreds of green jobs and reduce landfill waste by ≈20% in targeted regions (Wamda, 2022).

Green-Al Energy provides affordable and decentralized energy solutions for households, farmers, and restaurants in isolated regions. The biodigesters reduce dependence on fossil fuels and imported energy, while the production of biofertilizer creates added value for agriculture. The startup also stimulates local entrepreneurship and green job creation, positioning eco-innovation as a driver of economic resilience (Lionesses of Africa, 2024).

Socially, the solution enhances energy autonomy in remote regions and contributes to improved agricultural productivity using organic fertilizer. The company's leadership by a female founder also carries symbolic and practical importance for gender inclusion in Algeria's emerging green economy.

In addition, Green-Al Energy enhances energy access in rural and desert communities, improving living conditions and reducing energy poverty. By empowering women entrepreneurs—through the leadership of founder Kheira Benaissa—the startup also promotes gender inclusion in Algeria's green economy. Furthermore, its educational initiatives, such as publications on biogas and waste valorization, raise public awareness about sustainability and encourage community participation in eco-innovation (Agence Française de Développement [AFD], 2022).

Offering an innovative and environmentally friendly solution, the startup has garnered attention and won awards in several competitions, including the Algeria Climate Change Challenge (A3C) and the Emerging Mediterranean Challenge (Vépierre, 2022).

6. Conclusion

This study shed light on for waste management in Algeria and how eco-innovation can contribute in managing waste as well as reducing it. As Algeria still faces the dilemma of reducing domestic waste to the

international accepted rate, it put a governmental strategy to 2035 for that to manage waste and increase waste valorization rate. This confirms the first sub hypothesis: *H_1: Algeria still faces several challenges regarding waste management*.

In addition, the study found that Algeria encourages startups with innovative solutions in all areas including ecology, so many initiatives took place to apply eco-innovation in Algeria to manage waste with its several types. This in turn confirms the second sub hypothesis: *H_2: There are several initiatives Algeria adopted regarding waste management*.

Eco-innovators like Green Al's biogas systems for 58 families and 65 farms demonstrate scalable solutions, converting organics into energy and fertilizer. Success hinges on enforcement, infrastructure like 150 composting units, public education, and circular economy shifts to turn waste into resources.

Green-Al demonstrates how grassroots technological innovation can address national sustainability challenges while creating inclusive economic opportunities. The case highlights the transformative potential of small-scale eco-innovation in contexts where centralized waste-management systems are insufficient. Scaling such initiatives will require coordinated efforts among policymakers, financial institutions, academia, and entrepreneurs. These findings confirm the third sub hypothesis: *H_3: Green-Al Energy contributes with an eco-innovative solution help manage waste*.

In conclusion, and as an answer to the main question of the study, Algeria like many countries faces several challenges and difficulties to deal with waste in its numerous aspects. Nevertheless, Algeria encourages any initiative regarding waste management, either at the

institutional level, through the ministry of environment and quality of life and the SNGID, or through eco-innovative initiatives adopted by the startups like Green-Al Energy.

Green-Al Energy proved that eco-innovation is vital for waste management and that a country can turn garbage into a sustainable wealth with many other benefits for environment, economy and society. Finally, all the findings of the study confirm the importance and the role of eco-innovation in waste management in Algeria.

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