

# Waste treatment & recovery in Lebanon: Towards a strategy based on the circular economy & innovative technology to convert waste into renewable energy

معالجة النفايات وإعادة تدويرها في لبنان: نحو استراتيجية قائمة على الاقتصاد الدائري والتكنولوجيا المبتكرة لتحويل النفايات إلى طاقة متجددة

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Traitement et valorisation des déchets au Liban : vers une stratégie basée sur l'économie circulaire et les technologies innovantes pour convertir les déchets en énergie renouvelable

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**Abstract:** The valorization of municipal solid waste, MSW, in Lebanon is moving towards a transition to increase the share of renewable energies in the energy mix. A comprehensive strategy aimed at integrating waste treatment with energy production, offering significant potential for waste-to-energy technologies including incineration, Anaerobic digestion, Pyrolysis and Supercritical Water Gasification, SCWG, has been presented. This study will focus primarily on the production of renewable energy through innovative processes, mainly to produce biogas and green hydrogen.

Keywords: MSW, Renewable energy, incineration, Aerobic & Anaerobic digestion, pyrolysis, SCWG, Biogas, Hydrogen, Syngas

Introduction: Waste treatment and recovery in Lebanon are increasingly shifting from a reliance on landfills to an integrated system that optimizes energy recovery, with the goal of increasing the share of renewable energy in the national energy mix. Lebanon produces approximately 6,500 to 7,000 tons of municipal solid waste (MSW) per day. Only 8% is recycled and 15% composted, with the remainder being landfilled. More than 50% of this waste is composed of organic matter, offering significant potential for waste-to-energy (WTE) technologies. The long-term objective is to transform waste from an environmental hazard into a sustainable, energy-generating resource that contributes to the national electricity grid. This study will focus primarily on renewable energy production using innovative processes to produce mainly biogas, biofuels and green hydrogen.

## I - The current situation and solutions for waste management in Lebanon:

Waste management in Lebanon is characterized by overloaded landfills (e.g., Tripoli, Jdeideh, Naameh, Costa Brava), illegal dumping, and a heavy reliance on landfilling (80% of waste). Examining the composition of the waste reveals a high proportion of organic matter (approximately 52.5%), making composting and anaerobic digestion more viable than large-scale incineration.

**Main obstacles:** The sector faces a lack of infrastructure, limited financial resources, insufficient enforcement of environmental regulations, and a lack of centralized sorting and composting facilities.

**Innovative solutions** rely on decentralization to municipalities, the development of composting (of organic waste) and recycling (of plastic waste), as well as the energy recovery of waste for renewable energy production.

## II- Key Strategic Objectives

**1) Reduce Landfilling:** Divert waste to composting and energy recovery facilities.

**2) Increase Renewables:** Implement 13MW of biogas and other bioenergy projects to meet the 30% renewable energy target by 2030.

**3) Localize Treatment:** Strengthen the capacity of municipalities to handle waste, reducing the reliance on central, overloaded landfills.

**4) Strengthen Environmental Protection:** Close and rehabilitate dumpsites to prevent further pollution of water sources like the Litani River and Karaaoun lake

The long-term goal is to transform waste from an environmental hazard into a, sustainable, revenue-generating resource that contributes to the national grid

## III - Energy Recovery Strategy

Waste treatment and recovery increase the share of renewable energy in the energy mix by transforming non-recyclable materials and organic waste into biogas, synthesis gas, and biodiesel, and non-recyclable waste into heat and electricity. Through technologies such as anaerobic digestion, incineration, pyrolysis, and Super Critical Water Gasification, SCWG, these processes provide a consistent and reliable baseload renewable energy source, thus reducing dependence on fossil fuels. The energy produced from this waste (WtE) is considered renewable.

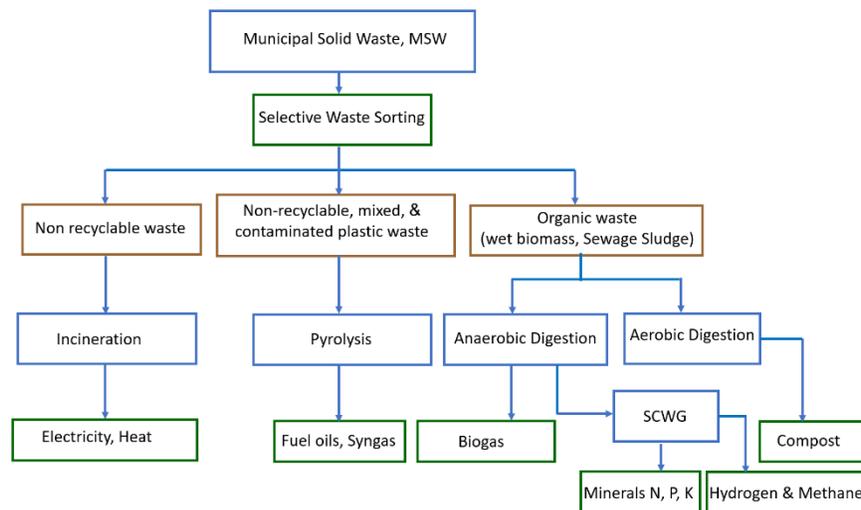


Figure 1 : The Strategy description for renewable energy production using innovation waste (WtE) technology

Here's how waste treatment and recovery contribute to increasing the share of renewable energy in the energy mix:

### 1. Key Technologies and Processes

**a) Incineration (Combustion):** Modern waste-to-energy plants burn non-recyclable household waste to generate high-temperature heat, creating steam that drives turbines for electricity and district heating production. Modern facilities can reduce waste volume by up to 90% while providing a 24/7 programmable energy supply.

**b) Pyrolysis:** These advanced thermal technologies decompose plastic waste at a temperature between 400 - 600 °C in the absence of oxygen to produce syngas or pyrolysis oil, which can be transformed into high-value synthetic fuels.

**Plastic Waste Valorization and Renewable Energy Production:** Faced with the complete lack of facilities adapted for plastic recycling, the complexity of achieving high-quality recycling, and the presence of several challenges in plastic recycling (such as resin complexity and material incompatibility, contamination throughout the supply chain, limited processing infrastructure (as in the case of Lebanon), and a lack of standardization in recycling systems), the ideal low-cost energy recovery process for plastics is pyrolysis. This process transforms mixed or contaminated plastics into oils/fuels and syngas usable as energy or chemical raw materials, thus bypassing the limitations of traditional mechanical and chemical recycling, especially for non-recyclable waste streams.

This method offers an economically viable solution for valorizing complex plastic waste streams, transforming the problem into an energy resource.

**c) Anaerobic Digestion (AD):** AD is considered a priority technology, particularly for organic waste and sewage sludge. Potential sites have been identified in Sour, Aabde, Sarafand, Saida, and Majdal Anjar. Organic waste (food waste, agricultural waste, sewage sludge) is broken down by microorganisms in an anaerobic environment, producing biogas, which is approximately 50% methane. This biogas can be used directly for heating and electricity generation, or converted into biomethane for injection into the gas network.

**d) The Super Critical Water Gasification, SCWG process** represents a new generation of clean technologies with strong industrial potential for organic resources. Indeed, supercritical water gasification (SCWG, operating in a supercritical state (above 374 °C and 221 bar)) is an advanced thermochemical technology that converts wet organic waste—such as sewage sludge, industrial wastewater, food waste, and manure—into high-value renewable gaseous energy (hydrogen, and methane). Furthermore, SCWG constitutes both a solution for treating organic waste and a decentralized, carbon-neutral energy production method, capable of increasing the share of renewable energies in the energy mix.

**e) AD-SCWG, Anaerobic Digestion combined with Supercritical Water Gasification,** is an advanced, hybrid waste-to-energy strategy that combines the biological decomposition of waste with high-temperature thermochemical conversion to maximize biogas/hydrogen production. Indeed, the coupling of AD-SCWG allows for maximum valorization of wet organic waste (sludge, effluents, digestate) and biogas production. SCWG treats non-mechanizable residues, increasing methane yield, destroying pollutants and enabling mineral recovery.

#### Key Advantages for Maximizing Biogas/Energy Production

**Enhanced Energy Yield:** SCWG offers higher energy efficiency (55%–84%) and can convert the remaining lignin-rich solids from AD into renewable gas, which includes high-value hydrogen and methane.

**Direct Processing of Wet Waste:** SCWG operates directly on wet organic sludge (up to 60–70% moisture) without the need for energy-intensive drying.

Comprehensive Waste Conversion: The strategy can treat complex, hard-to-degrade waste streams such as sludge, agri-food waste, olive mill waste, and microalgae.

Higher Efficiency and Faster Rates: Compared to conventional incineration or standalone anaerobic digestion, the hybrid approach improves overall energy conversion, with SCWG-based systems showing higher energy superiority.

Lower Environmental Footprint: This approach reduces the need for landfilling and produces cleaner energy with reduced NO<sub>x</sub> and SO<sub>x</sub> emissions, as the process happens without free oxygen.

This combination allows the system to achieve a "zero discharge" solution, transforming waste into renewable energy carriers.

## 2. Implementation Framework

a) Decentralized Management: The trend is toward waste management solutions at the local, regional, or smaller scale to better manage waste streams and improve energy recovery.

b) Law No. 80/2018 on Waste Management: The new regulatory framework emphasizes the 4Rs (Reduce, Reuse, Recycle, and Recover energy).

c) Public-Private Partnerships (PPPs): The government encourages private sector participation in capital-intensive projects, such as incineration and large-scale sorting facilities.

d) Financial Mechanisms: Tools like the National Program for Energy Efficiency and Renewable Energy (NEEREA) offer long-term, low-interest loans for environmental and green energy projects.

## IV - Conclusion

Waste-to-energy (WTE) is a key global strategy of the circular economy, transforming organic and plastic waste into Renewable energy. Increasing the share of renewable energy (RE) in the energy mix requires a deep transformation of energy systems (from polluting fossil fuels to a sustainable, decarbonized, and more energy-efficient model). The strategy described in this study demonstrated the production of decentralized renewable energy using innovative technologies based on incineration, anaerobic and aerobic digestion, pyrolysis, and super critical water gasification.

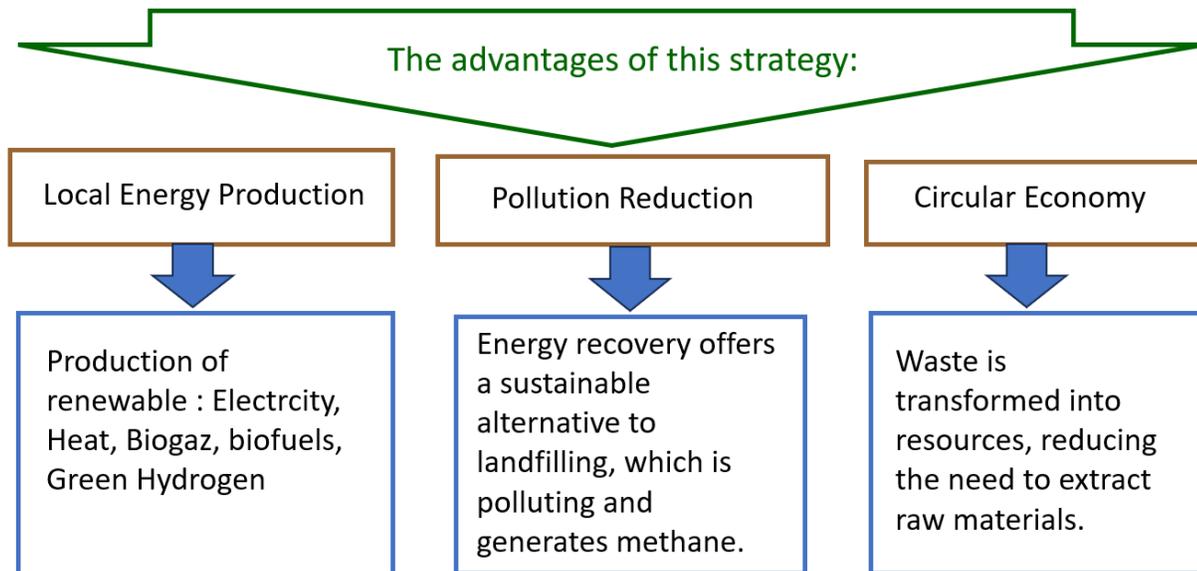


Figure 2 : Advantages of the Adopted strategy

This Strategy aligns with circular economy goals by treating waste as a resource, reducing landfill reliance, and supporting a local, sustainable energy supply.