Converting Solid waste to electrical energy: review the utilization of the techniques and applications in the Region

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Abstract:
The MENA (Middle East & North Africa) face significant challenges in waste management due to rapid urbanization, population growth, and economic development, these challenges require innovative and sustainable solutions to deal with the increasing quantities of solid waste. Converting solid waste to electrical energy represents a promising solution that can reduce the environmental impact and provide an alternative source of energy. This study aims to review the application of different solid waste to electrical energy technologies in the MENA, focusing on incineration, gasification, anaerobic digestion, landfill gas recovery, and hybrid systems. Also, it presents environmental, economic, and social advantages, as well as their Challenges. This study also presents an analysis of the regional waste composition, the suitability of the technologies, and the Regulatory Barriers to Solid Waste to Electrical Energy Technologies with identifying potential opportunities to enhance the application of these technologies. Also, this study provides strategic recommendations to support the adoption of Solid waste to electrical energy technologies in the MENA, including improving regulatory frameworks, providing financial incentives, and enhancing public-private partnerships. The study also calls for increasing public awareness and waste source segregation to maximise these technologies' benefits. Through these recommendations, Solid waste to electrical energy technologies can contribute to achieving sustainable development goals and promoting a circular economy in the region, thus improving quality of life and reducing environmental pollution.
Keywords: Waste-to-energy (WtE), Solid waste to electrical energy, sustainable development, incineration, gasification, anaerobic digestion, landfill Methane gas recovery.

تحويل النفايات الصلبة إلى طاقة كهربائية: مراجعة لاستخدام التقنيات والتطبيقات في المنطقة

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الخلاصة:
تواجه منطقة الشرق الأوسط وشمال أفريقيا تحديات كبيرة في إدارة النفايات بسبب التوسع الحضري السريع، والنمو السكاني، والتنمية الاقتصادية، وتتطلب هذه التحديات حلولاً مبتكرة ومستدامة للتعامل مع الكميات المتزايدة من النفايات الصلبة. يمثل تحويل النفايات الصلبة إلى كهرباء حلاً واعدًا يمكن أن يقلل من التأثير البيئي ويوفر مصدرًا متجددًا للطاقة. تهدف هذه الدراسة إلى مراجعة تطبيق تقنيات تحويل النفايات الصلبة إلى طاقة كهربائية مختلفة في منطقة الشرق الأوسط وشمال أفريقيا، مع التركيز على الحرق، والتغويز، والهضم اللاهوائي، واستعادة غازالميثان من مكبات النفايات، والأنظمة الهجينة، كما تقدم المزايا البيئية والاقتصادية والاجتماعية، فضلاً عن تحدياتها. تقدم هذه الدراسة أيضًا تحليلاً لتكوين النفايات الإقليمية، وملاءمة التقنيات، والحواجز التنظيمية أمام تقنيات تحويل النفايات الصلبة إلى طاقة مع تحديد الفرص المحتملة لتعزيز تطبيق هذه التقنيات. كما تقدم هذه الدراسة توصيات استراتيجية لدعم اعتماد تقنيات تحويل النفايات إلى طاقة في منطقة الشرق الأوسط وشمال أفريقيا، بما في ذلك تحسين الأطر التنظيمية، وتوفير الحوافز المالية، وتعزيز الشراكات بين القطاعين العام والخاص. وتدعو الدراسة أيضًا إلى زيادة الوعي العام وفصل مصادر النفايات لتعظيم فوائد هذه التقنيات. ومن خلال هذه التوصيات، يمكن لتقنيات تحويل النفايات إلى طاقة أن تساهم في تحقيق أهداف التنمية المستدامة وتعزيز الاقتصاد الدوار في المنطقة، وبالتالي تحسين نوعية الحياة والحد من التلوث البيئي.
الكلمات المفتاحية: تحويل النفايات إلى طاقة (WtE)، تحويل النفايات الصلبة إلى طاقة كهربائية، التنمية المستدامة، الحرق، التغويز، الهضم اللاهوائي و استعادة غاز الميثان من مكبات النفايات.

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1. Introduction

The MENA has undergone a significant transformation in recent decades, marked by rapid urbanization, sustained economic development, and notable population growth. These shifts have brought about numerous benefits to the region, such as improved standards of living and increased industrial activity. Still, they have also introduced complex challenges, one of the most pressing being the dramatic rise in solid waste generation. As cities expand and economies flourish, the volume of waste—both industrial and municipal—has escalated to levels that far exceed the capacity of traditional waste management systems. This waste, if not properly managed, poses serious environmental, public health, and economic risks, including the contamination of land and water resources, air pollution from improper disposal methods, and the financial burden of inefficient waste treatment processes. Municipal waste, in particular, has surged due to population growth, which has been unprecedented in scale, as well as evolving consumer habits driven by urban lifestyles and higher levels of disposable income. Additionally, the rapid pace of industrial and commercial activities in the region has led to a significant increase in the generation of industrial waste, much of which is difficult to manage using conventional methods. The MENA's waste management dilemma is further compounded by the region's geographic and climatic conditions, such as limited land availability for landfills and water scarcity, which create additional constraints on traditional waste disposal methods.

In response to this growing crisis, there is a pressing need for the region to adopt innovative and sustainable waste management practices. Conventional methods like landfilling and incineration, which have historically dominated the waste management landscape, are increasingly proving to be insufficient. Landfilling, the most commonly used method in the MENA, is not only unsustainable due to the vast amount of land it requires but also harmful to the environment, as it contributes to groundwater contamination and the release of methane—a potent greenhouse gas. Incineration, on the other hand, while effective at reducing the volume of waste, often leads to the release of harmful pollutants into the atmosphere when not coupled with energy recovery systems.

This is where solid waste to electrical energy technology comes into the picture as a viable alternative that not only addresses the waste management crisis but also contributes to the generation of alternative energy. Solid waste to electrical energy technology can reduce the volume of waste by up to 90% while simultaneously converting it into electrical energy and heat, thus providing a two-fold solution to the region's waste and energy challenges [1-3]. The conversion of waste into energy reduces the reliance on landfills, minimizes greenhouse gas emissions, and offers an alternative energy source that can help Middle Eastern countries diversify their energy portfolios and reduce their dependence on fossil fuels to some extent.

Despite the potential benefits, the implementation of Solid waste to electrical energy technologies in the MENA has been slow and fraught with obstacles. Technical challenges, such as the need for specialized infrastructure and skilled labour, pose significant hurdles to the widespread adoption of Solid waste to electrical energy systems. Economically, the high initial capital costs associated with establishing Solid waste to electrical energy facilities, coupled with fluctuating energy prices, have deterred many countries from fully committing to these technologies. Moreover, regulatory barriers, including inconsistent policies, a lack of clear incentives for alternative energy production, and insufficient coordination between governmental bodies, have further hindered progress in this area [4,5].

Given these challenges, it is essential to conduct a thorough analysis of the waste composition in the MENA, as different types of waste—such as organic waste, plastic, and hazardous materials—require different treatment methods within Solid waste to electrical energy systems. Furthermore, a detailed review of the available technologies and their suitability for the region's specific needs is crucial for the successful implementation of Solid waste to electrical energy projects. Additionally, the regulatory frameworks governing waste management and alternative energy production in the region must be critically examined to identify the policy changes necessary to foster an enabling environment for Solid waste to electrical energy projects [4-6].

The current study aims to comprehensively review the waste composition, and most suitable Solid waste to electrical energy technologies, and assess the regulatory frameworks in place across various Middle Eastern countries. By offering specific and actionable insights, this work seeks to support policymakers, industry stakeholders, and environmental advocates in their efforts to implement Solid waste to electrical energy solutions in the region.

2. Converting Solid Waste to electrical energy :

Solid waste is the term applied to what are also known as primary materials and other related solids discarded upon daily basis (plastic, paper etc) including industrial wastes [7]. This waste has also become a huge problem for thousands of cities and municipalities globally, but especially those regions like the MENA where population booms have outpaced urban expansion. Turning solid waste into electrical energy offers a ground-breaking and environmentally friendly answer to both these problems. Here are the major advantages and processes from this field [8].

- **Environmental Advantages of Waste-to-Energy**

Solid waste to electrical energy offers several significant environmental benefits that address waste management challenges and the urgent need for alternative energy solutions. As the global community seeks to reduce its environmental impact and combat climate change, Solid waste to electrical energy technologies offer a sustainable alternative to traditional waste disposal methods such as landfilling and open burning. The key environmental benefits of Solid waste to electrical energy are:

- **Waste Reduction:** One of the primary environmental benefits of Solid waste to electrical energy technology is its ability to reduce the volume of solid waste that would otherwise end up in landfills. For example, incinerating waste with energy recovery can reduce the mass of waste by up to 90%, significantly reducing the space required for landfills. This is especially important in areas with limited land availability, such as urban areas in the MENA. By reducing the need for large landfills, Solid waste to electrical energy technology helps conserve valuable land and prevent the contamination of soil and water resources [9].
- **Mitigating global warming gas emissions:** Traditional landfills are a major source of methane, a potent greenhouse gas that is more effective at trapping heat in the atmosphere than carbon dioxide. When organic waste decomposes anaerobically in landfills, it produces methane, which contributes significantly to global warming. Solid waste to electrical energy technologies, by diverting waste from landfills and using it as a raw material for energy production, helps prevent the release of methane. Furthermore, Solid waste in electrical energy plants equipped with modern emission control technologies capture and reduce the release of pollutants, making them a cleaner alternative to uncontrolled decomposition in landfills [10].
- **Power Generation and Fossil Fuel Displacement:** Solid waste to electrical energy systems convert waste into electrical energy, heat, or both through processes such as incineration, gasification, and anaerobic digestion. The energy generated can be fed into the grid, reducing reliance on limited fossil fuel resources as a global target with 25 years till (2050) by using (WtE) and other technologies such as nuclear energy, solar and wind energy to produce the electrical energy to cover the global need especially nuclear energy which play important role in replacing the use of fossil fuel in the production of electrical energy [11].
- **Reducing air pollution from open burning:** In many parts of the world, including parts of the MENA, waste is often disposed of through open burning, releasing harmful pollutants such as particulate matter, volatile organic compounds, and dioxins into the atmosphere. These pollutants contribute to poor air quality, respiratory illnesses, and

other health issues. By contrast, Solid waste to electrical energy plants use advanced combustion technologies with strict emission controls to limit the release of harmful substances. This results in cleaner air and a healthier environment for communities [12].

- **Resource recovery and by-product recycling:** Solid waste to electrical energy processes also allow for the recovery of valuable materials that can be recycled or reused. For example, after waste is burned, the remaining ash can be processed to extract metals such as steel and aluminium, which can then be recycled. Furthermore, some Solid waste to electrical energy methods, such as gasification and pyrolysis, produce by-products such as biochar or slag that can be used in construction or agriculture. This resource recovery helps close the loop in waste management, in line with circular economy principles, by turning waste into new resources rather than simply disposing of it [13].
- **Reducing land and water pollution:** Landfills, especially poorly managed ones, can cause significant environmental damage, including soil contamination and groundwater contamination from leachate – a liquid that seeps from waste in landfills and can carry harmful chemicals. By diverting waste away from landfills, Solid waste to electrical energy technology reduces the risk of land and water pollution. Additionally, the controlled and regulated nature of Solid waste to electrical energy facilities ensures that hazardous materials, such as heavy metals and toxic chemicals, are properly handled and neutralized, further protecting the environment [14].
- **Reducing Odor and pest problems:** Landfills and open dumping sites often attract pests such as rodents and insects, which can spread disease. They also emit unpleasant Odors that affect nearby communities. By quickly processing waste and converting it to energy, Solid waste to electrical energy facilities eliminate many of these problems. The waste is burned or treated in controlled environments, preventing the release of odours and reducing the risk of infection [15].
- **Supporting the circular economy and sustainable waste management:** Solid waste to electrical energy technologies play a key role in supporting the development of a circular economy, where waste is not simply disposed of but reused as a valuable resource. By converting waste into electrical energy and recovering useful materials, Solid waste to electrical energy technologies promote more efficient use of resources and reduce the need for raw materials. This approach helps reduce the environmental footprint of both energy production and waste disposal, contributing to a more sustainable and resilient economic system [16].

▪ **Economic Benefits of Waste-to-Energy**

Not only does Solid waste to electrical energy offer significant environmental benefits, it also offers significant economic benefits. By turning waste into a resource, Solid waste to electrical energy technologies create economic opportunities ranging from cost savings in waste management to revenue generation through energy production. As cities and regions, especially in rapidly growing regions such as the MENA, face increasing challenges in waste disposal and rising energy demand, Solid waste to electrical energy offers a sustainable solution with a strong economic case. The main economic benefits of adopting Solid waste to electrical energy are:

- **Reducing waste disposal costs:** One of the most direct economic benefits of Solid waste to electrical energy is reducing waste disposal costs. Traditional waste management systems, especially landfills, require significant financial resources for land acquisition and long-term operation and maintenance costs. Over time, as landfills reach capacity, municipalities are forced to invest in new landfill sites, which becomes increasingly expensive, especially in densely populated areas. Solid waste to electrical energy facilities reduces the need for landfills by reducing waste volume by up to 90%, helping municipalities avoid the high costs associated with expanding and maintaining landfills. In addition, Solid waste to electrical energy systems eliminates the cost of transporting waste long distances to landfills, providing a more local and efficient solution[17].
- **Generating revenue from energy production:** The main economic benefit

of Solid waste to electrical energy is the ability to convert waste into electrical energy, heat, or both, which can then be sold to the power grid or used locally. The revenue generated from selling electrical energy or heat provides a steady stream of income, which can help offset the costs of operating Solid waste to electrical energy facilities. In some cases, the energy produced from Solid waste to electrical energy plants is enough to power thousands of homes, providing an important source of alternative energy for local communities. This is particularly beneficial in regions where energy demand is growing rapidly, such as the MENA, as it provides a diversified source of energy that reduces reliance on imported fossil fuels [12].

- **Diversifying the energy sector:** Solid waste to electrical energy contributes to diversifying the energy sector, especially in countries that rely heavily on fossil fuels. By integrating Solid waste with electrical energy into the energy mix, governments can reduce their reliance on volatile global energy markets and improve energy security. For example, MENA countries, which have traditionally relied on oil and natural gas for energy generation, can benefit from Solid waste to electrical energy by adding stable, locally sourced energy supplies. This diversification not only enhances the resilience of national energy systems but also creates new opportunities for investment in alternative energy infrastructure [18].
- **Job Creation and Economic Growth:** The development and operation of Solid waste to electrical energy facilities stimulate economic growth by creating jobs across sectors. During the construction phase, Solid waste to electrical energy projects require skilled labour for engineering, construction, and equipment installation, creating jobs in local communities. Once operational, Solid waste to electrical energy plants create permanent jobs in plant management, maintenance, and waste collection. In addition, Solid waste to electrical energy facilities generates demand for specialized technical expertise, such as waste sorting, energy conversion, and environmental monitoring, supporting the growth of the green jobs sector. This economic activity goes beyond direct employment, as waste-to-energy facilities also stimulate secondary industries such as recycling, transportation, and energy distribution [19-20].
- **Long-term economic sustainability:** Solid waste to electrical energy facilities provide long-term economic sustainability by providing a reliable waste management solution that also generates alternative energy. Unlike landfills, which incur ongoing maintenance and environmental costs, Solid waste to electrical energy facilities can operate for decades, continually converting waste into energy while generating revenue. The predictable nature of Solid waste to electrical production also provides stability to energy markets, making it easier for governments and businesses to plan for future energy needs. This long-term sustainability reduces the financial burden on municipalities, freeing up resources for other infrastructure projects or public services [19-20].
- **Attracting investment and private sector participation:** Solid waste to electrical energy projects is often attractive to investors and the private sector because of their potential to generate long-term returns. Public-private partnerships are commonly used to develop Solid waste to electrical energy facilities, where governments provide land or financial incentives while private companies build and operate. These partnerships allow governments to leverage private capital and expertise, reducing the initial financial burden of developing Solid waste to electrical energy infrastructure. In return, private companies benefit from revenues generated from energy sales and waste management fees [21].

▪ **Social benefits and Advantages of Waste-to-Energy**

- **Public Health Benefits:** Solid waste to electrical energy technologies provide significant public health benefits by reducing the volume of waste that ends up in landfills. Conventional landfills are known to produce a variety of harmful effects, including the spread of disease, unpleasant odours, and contamination of nearby water sources. By reducing the need for landfills, Solid waste to electrical energy technologies help improve overall public hygiene and protect communities from the risks of improperly managed waste. Removing waste to landfills reduces exposure to toxic substances and harmful emissions, resulting in cleaner air and water quality. Furthermore, advanced Solid waste to electrical energy systems are designed to capture harmful emissions, further contributing to improved environmental health [22].

- **Reducing Environmental Pollution:** Conventional waste disposal methods such as dumping and open burning contribute to environmental degradation by releasing harmful gases, chemicals, and microplastics into the atmosphere and soil. Solid waste to electrical energy technologies mitigate these impacts by diverting waste from landfills and converting it to energy, thereby reducing the environmental pollution traditionally associated with waste disposal. This reduction in greenhouse gas emissions and pollutants such as methane significantly improves the ecological balance and supports cleaner ecosystems. In addition, Solid waste to electrical energy facilities often include mechanisms to capture carbon emissions, thus contributing to global climate change mitigation efforts [12].
- **Contribution to the Sustainable Development Goals**: Solid waste to electrical energy technologies are closely aligned with many of the United Nations' Sustainable Development Goals, particularly those targeting environmental protection, alternative energy and sustainable urban development. Specifically, Solid waste to electrical energy supports SDG 7 GOAL OF UNITED NATION which relates of having (affordable & clean energy) by generating energy from waste that would otherwise end up in landfills. This contributes to the circular economy by ensuring that valuable materials are recovered and reused, reducing overall waste generation. By converting waste into usable energy, these technologies reduce reliance on fossil fuels, thus supporting the transition to cleaner and more alternative energy sources [23].
- **Waste Reduction and Resource Efficiency:** Solid waste to electrical energy technologies play a crucial role in reducing the volume of waste that must be managed through conventional disposal methods. By diverting waste from landfills, they help improve land use, reduce the environmental footprint, and reduce demand for new landfills. In doing so, they support sustainable urban planning and development, ensuring that communities have cleaner, healthier environments. The energy generated from these processes can be reinvested in local grids, enhancing energy security and reducing costs for consumers [7].
- **Promoting economic and social stability**: In addition to environmental benefits, Solid waste to electrical energy facilities provide economic opportunities by creating jobs in the waste management, energy production, and technology sectors. These technologies also encourage innovation and investment in sustainable energy solutions, contributing to economic growth and resilience. In addition, communities benefit from improved waste management services, reduced public health risks, and the availability of alternative energy sources, which enhance overall quality of life [16,17].

3. Solid waste to electrical energy Technologies: Their Advantages and Challenges

Each Solid waste to electrical energy technology has its own advantages and challenges. The choice of the optimal technology depends on local factors such as the type of waste available, economic costs, existing infrastructure, and environmental and regulatory regulations. The best results can be achieved through careful study and application of appropriate technologies in conjunction with government support and coordination between the public and private sectors. See table (1), table (2).

3.1 Incineration: Incineration is the burning of solid waste at a high temperature to transform it into thermal energy where this process can be used for steam and electrical generation [5,24,25].

a.Steps of Incineration
b.Waste collection: Waste is collected in solid form from homes, businesses, and factories.
c.Waste sorting: A process of waste segregation by separating the non-combustible contaminants materials (metals, glass).
d.Preparation: Before packing waste is shredded or crushed into smaller pieces to facilitate better combustion.
e.Combustion: Waste is fed to an incineration furnace and burned at a temperature between 850 °C -1100 ° C, which in turn was converted into heat along with gases.
f.Steam generation: The produced heat is utilized in water heating and gets converted into steam.
g. Electrical generation: Steam is used to turn turbines for generating power.
h.Ash treatment: These are the ashes obtained from the combustion process, it is stored and either treated or sent to specialized landfills.
i.Emissions monitoring: The emissions produced from the process are monitored and treated to comply with environmental standards.

For example, the 30 megawatts energy facility in the Emirate of Sharjah/UAE solid waste to electrical energy was opened in collaboration between Bee'ah and Masdar to convert waste into energy using incineration technology. The project is the first of its kind in the country and is expected to generate significant amounts of electrical energy. The facility has a capacity to process about 300,000 tons of waste annually [26]

3.2 Gasification: is a process that turns waste into syngas by applying heat under pressure in the absence of abundant oxygen. Syngas is suitable to produce electrical energy [27-30].

- **Steps of Gasification**

a.Waste Collector: Collects and stores the solid wastes
b.Waste Sorting and Preparation: Waste is sorted, dried and shredded together to ease the gasification process.
c.Gasification: Waste is fed into a gasification reactor that heats up waste in a low-oxygen environment (700–1500°C) to convert it into syngas.
d.Gas Purification: The syngas gas is cleaned up by removing contaminants such as sulfates and other hazardous gases.
e. Electrical Generation: Lean gas is utilised to produce electrical energy with engines or turbines.
f.Residual Waste Handling: Non-gasifiable solid waste is collected, treated or landfilled.
g.Emission Control: The quality of emissions is checked and handled in such a way that the environment does not deteriorate.

As an example, the 50 megawatts Gasification Project in The Kingdom of Saudi Arabia /Jubail Industrial City. The project aims to treat about 200,000 tons of solid waste annually using gasification technology. Using gasification, about 50 megawatts of electrical energy can be produced. This amount of energy is enough to meet the needs of about 40,000 homes with electricity [31].

3.3 Anaerobic Digestion: Anaerobic digestion is a biological process in which organic waste breaks down into methane gas (biogas), generating electrical energy of non-oxygen [32,33].

- **Anaerobic Digestion Process Steps**

a.Organic waste collection – Organics include food scraps and agricultural waste.
b.Waste sorted by material to separate the organic component,- e.g. Organics that break down or can be reprocessed and other 'waste' such as free clay, and fine sand.
c.Preparation: Waste is shredded or ground for efficient decomposition.
d.Loading to the reactor: Organic waste is loaded into an anaerobic digestion (AD) digester, a sealed container where oxygen cannot enter.
e.Digestion: waste is broken down by the action of specific bacteria in an environment without oxygen, and biogas (methane with carbon dioxide) enzymes are produced.
f.Biogas collection: The biogas that formed in the reactor is gathered.
g.Biogas cleaning: Sulfates and other impurities are removed before the biogas is stored.
h. Electrical generation: Cleaned biogas can be used for power production or as fuel for heat and cooking applications.
i.Composting for producing bio-substances or recycling the solid remains enriched with heavy sentinels to enhance soil properties.

j. Process monitoring– It is responsible for the control of temp, pH, and level of decomposition.

As an example, the 65 megawatts using anaerobic digestion technology to cover about 60% of the electrical energy needed for El Gabal El Asfar Wastewater Treatment Plant, Egypt: In Egypt, El Gabal El Asfar Wastewater Treatment Plant with a capacity of 2.5 million cubic meters per day which is one of the largest wastewater treatment plants in Africa and the Middle East.

The 65-megawatt WtE is produced from the sludge output of the water treatment plant using anaerobic digestion technology [34].

3.4 Landfill Gas Recovery: Landfill gas recovery is a process which captures methane gas from the decomposition of organic waste in landfills and then converts it into energy [35,36].

- **Steps of Landfill Gas Recovery Step-by-Step**

- Waste Collection: Organic waste is collected and sent to landfills, which in turn helps decomposition.
- Installation of Gas Collection System: Install gas collection systems including pipes to collect methane from landfills.
- Gas from Organic Waste Decomposition is Collected in Landfills
- Gas Purification: The impurities are removed from the gas.
- Power Generation: The clean gas produced is then used to generate electrical energy using gas engines or turbines,
- System Monitoring: Check and maintain the gas collection system to be effective.

As an example, the 5 megawatts energy Landfill Gas Recovery Project in Rusaifa /Amman/Jordan was implemented at the Rusaifa landfill. This project is one of the first in the region to use landfill gas recovery technology to generate electrical energy. The Rusaifa landfill handles approximately 1.5 million tons of accumulated solid waste. Biogas, which is mainly composed of methane, is collected from the landfill in an amount of approximately 5 million cubic meters per year. The biogas is used to generate approximately 5 megawatts of electrical energy, which is enough to supply approximately 4,000 homes with electricity annually [37].

3.5 Hybrid systems: Hybrid systems make use of different technologies combined, such as incineration or gasification with e.g. anaerobic digestion to improve efficiency in waste treatment and energy production [29,38].

- **Steps of Hybrid Systems**

a. Waste Collection: Source of solid waste is collected.

b. Waste Sorting: Waste is split into categories and non-convertible materials are extracted.

c. Selection of Technologies: Based on the type of waste, relevant technologies are selected and put together. In theory, it can be a combination of incineration and gasification or anaerobic digestion.

d. Waste Treatment:- This includes treating the waste with the help of these technologies. For instance, a portion of the waste will be combusted in an incineration furnace while other sections are gasified.

e. Energy Production: Every technology generates energy which is integrated for sustainable and efficient high generation.

f. Residual Waste Management: According to the technologies that are deployed, residual waste is either treated or landfilled.

g. Performance Monitoring: Monitors the performance of the hybrid system to ensure its efficiency and control emissions and costs.

Example: Hybrid energy project in the Massa region, Morocco: In Morocco, a hybrid system project combining solar energy and biogas recovery from waste has been developed in the Massa region near the city of Agadir. The project uses a combination of solar panels and waste gas to provide stable and sustainable energy. The project is used to generate about 10 megawatts of electrical energy through solar energy during the day. The hybrid system also relies on biogas recovery technology from local landfills, where methane gas is collected and converted into electrical energy of up to 3 megawatts of electrical energy. Adding the multiple e6nergy sources, the hybrid system generates a total capacity of about 13 megawatts of electricity. This energy is enough to cover the needs of about 12,000 homes annually [40].

Table(1) the advantages of Solid waste to electrical energy Techniques

Technique	Advantages
Incineration	- Waste Volume Reduction: Reduces waste volume by up to 90%, reducing the need for large landfill spaces. - Continuous Energy Production: Incineration plants can provide electrical energy and heat on a continuous basis. - Waste Versatility: Can process a wide range of waste, including non-biodegradable waste [24-26].
Gasification	- High efficiency: Gasification can be more efficient and cleaner than conventional combustion. - Lower emissions: Produces fewer emissions than combustion, making it a more environmentally friendly option. - Fuel flexibility: The resulting syngas can be used in power plants or as a feedstock in the chemical industry [27-31].
Anaerobic Digestion	- Biogas production: Produces methane gas that can be used as a fuel to generate electrical energy or heat. - Compost production: Produces organic fertilizer that can be used in agriculture. - Low emissions: Reduces greenhouse gas emissions by converting organic waste into useful energy [32-34].
Landfill Gas Recovery	- Reducing methane emissions: Collecting and using methane gas reduces harmful greenhouse gas emissions. - Using existing landfills: Can be applied to existing landfills, reducing the need to build new infrastructure. - Energy generation: The collected gas can be used to generate electrical energy or as fuel [35-37].
Hybrid Systems	- Improved efficiency: Combining multiple technologies can improve overall efficiency. - Flexibility: Can handle a variety of wastes. - Sustainability: Provides a more integrated and sustainable solution [29,38,40].

Here is a detailed look at the challenges associated with each of the Solid waste to electrical energy technologies:

Table (2) The Challenges of Solid waste to electrical energy Techniques

Technique	Challenges
Incineration	- Emission Control: Waste incineration produces emissions such as dioxins, furans, and fine particulate matter, which require sophisticated pollution control systems to manage and minimize their impact on air quality. - High Capital Costs: Establishing and operating waste incineration facilities involves significant capital investment and ongoing operational costs. - Waste Pretreatment: Requires extensive pretreatment and sorting of waste to remove non-combustible and hazardous materials, which can be resource intensive. - Ash Management: Waste incineration produces ash, which can be toxic and needs to be disposed of or treated properly, increasing operational complexity and cost. - Public Opposition: There may be resistance from local communities due to concerns about pollution and health impacts [10,21,35].
Gasification	- Feedstock Variability: Gasification processes can be sensitive to variations in the quality and composition of feedstock, requiring constant and controlled inputs to maintain efficiency. - High initial costs: Developing and installing gasification technology and infrastructure is expensive, which can be a barrier to widespread adoption. - Complexity: Gasification systems are complex and require advanced technology and skilled operators to manage the process and ensure optimal performance.

	- By-product management: The process generates by-products such as slag and tar, which require proper handling and disposal. - Energy efficiency: Achieving high energy efficiency and economic viability can be challenging, especially for smaller-scale operations [27-31,38,41].
Anaerobic Digestion	- Feedstock limitations: Only organic waste can be processed, which limits the types of waste that can be utilized and may require additional waste sorting. - Space requirements: Large space is required for digestion facilities and storage of both input materials and digestion products. - Process control: Careful control of environmental conditions such as temperature and pH is required to optimize microbial activity and biogas production. - Low energy density: The amount of energy produced is generally lower than other technologies, which can impact economic viability. - Odor management: The process can produce odors that may need to be managed to minimize nuisance to surrounding communities [32-34,42].
Landfill Gas Recovery	- Gas collection efficiency: Gas collection efficiency can vary depending on the age and type of landfill, and not all landfills are equipped with efficient gas collection systems. - Gas composition: Landfill gas contains a mixture of methane, carbon dioxide, and other trace gases, which can complicate the purification process and impact power generation. - Maintenance: Maintaining and operating landfill gas recovery systems can be challenging due to variability in gas production and the need for regular maintenance. - Slow gas production: Gas production from landfills can be slow and inconsistent, especially in newer landfills where waste has not yet fully decomposed. - Environmental impact: While methane capture helps reduce greenhouse gas emissions, landfills still pose long-term environmental challenges related to leaching and land use [35-37,43].
Hybrid Systems	- Integration complexity: Combining multiple Solid waste to electrical energy technologies into a single system can be complex, requiring sophisticated integration and coordination to ensure efficient operation. - High costs: Hybrid systems can be expensive to develop and operate due to the need for diverse technical components and maintenance. - Operational management: Managing and optimizing different technologies simultaneously requires advanced control systems and skilled personnel. - Waste conversion: Ensuring waste is efficiently converted and sorted to match the capabilities of different technologies can be challenging and may involve additional infrastructure. - Regulatory and permitting issues: Hybrid systems may face regulatory hurdles due to the multiple processes involved, which can complicate the permitting and compliance process. - Each of these technologies has its own set of challenges that must be addressed to ensure efficient and sustainable Solid waste to electrical energy conversion processes [38,40,44].

4. Regional Waste Composition Analysis

It is important to ascertain the sources, types and quantities of waste for a complete analysis of regional waste composition. This investigation can be put in use to control waste and also to determine our status regarding the practice of Waste to Energy Technology. Figure 1 presents immediate steps for analyzing the regional waste composition Full-size image [39,40]

- **Data collection:**

- Waste survey: collect waste samples from various spaces in the region, and analyse them [45].
- Record keeping of types and quantities: Keeping track of different waste like paper,

plastic, metal or organic waste in addition to hazardous wastes.

- **Waste classification:**
- Organic waste: Such as food scraps, vegetable peels
- Inorganic waste: Such as plastic, glass, and metal.
- Recyclable waste – Such as paper, metal and recyclable plastic
- Hazardous waste: Such as batteries, chemicals and pharmaceuticals [46].
- **Data analysis:**

Percentages: Calculate the percentages of each waste type to reflect overall compositions.

- Geographic distribution: determine the most waste-generating land.
- Environmental Impact Assessment
- Environmental impacts: Evaluating the environmental consequential of each kind of waste, in terms of its effects on ground, water and air.
- Solid waste to electrical energy potential: Determine specific waste types of energy sources from their composition [47].
- **Take a more strategic view of management,**
- Reducing and reusing: Develop solutions to decrease the generation of single-use throwaway materials & Reuse more.
- Solid waste to electrical energy: Determine what types of waste will be most suitable to convert into energy and develop the technology for treating it.
- Community engagement:
- Awareness and education: It is necessary to inform the public about how important proper waste separation should be conducted.
- Population data collection: Carry out a population survey and determine how they dispose of their waste, reducing the number of practices that go to the ground [48].

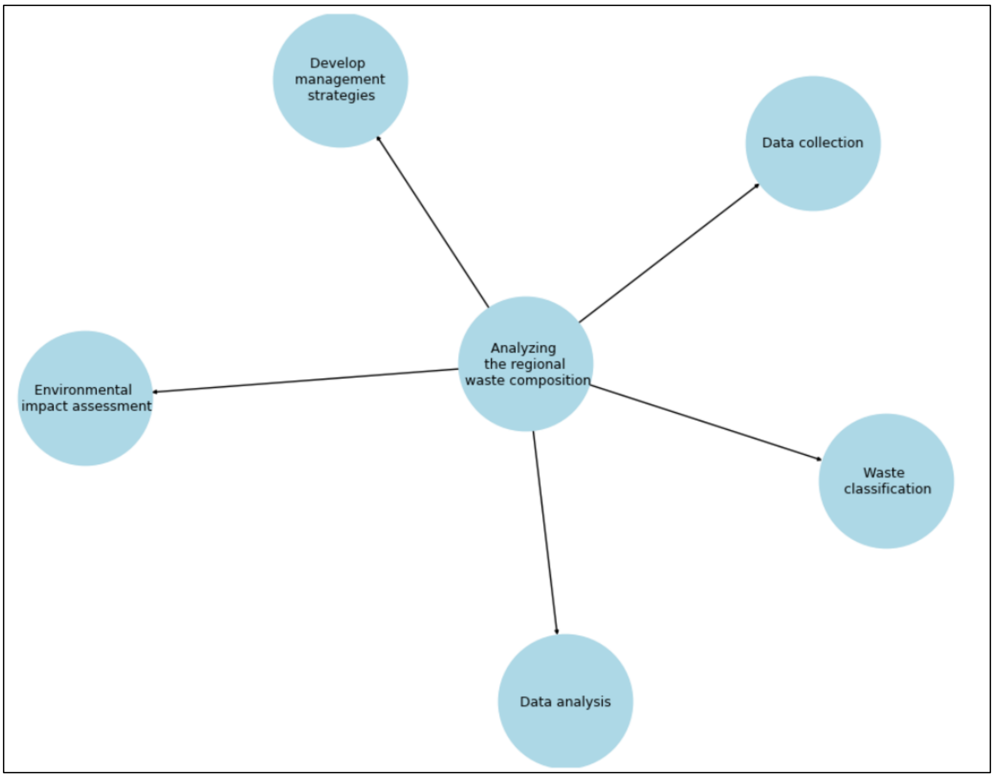

Figure (1): Analyzing the regional waste composition.

5. Regulatory Barriers to Solid waste to electrical energy Technologies

Solid waste to electrical energy technologies face a range of regulatory barriers that can impact their implementation and effectiveness. Here is a detailed look at some of these barriers: See Figure (1).

5.1. Environmental legislation and regulations

- Emission standards: Emission standards vary from country to country, and technologies such as incineration and gasification may require advanced technologies to reduce harmful emissions such as dioxins and nitrogen oxides. These standards can increase operating costs [49].

- Licensing and permits: Obtaining the necessary permits to operate Solid waste to electrical energy facilities can be complex and lengthy. These include environmental permits, building permits, and operating permits [50].

5.2. Health and safety legislation

- Safety standards: Technologies such as incineration and gasification require strict safety measures to protect workers and surrounding communities. These measures can include measures to prevent fires, contamination, and exposure to chemicals [51].
- Toxic waste management: Technologies such as gasification and anaerobic digestion may require special management of the resulting waste, which can be toxic or non-biodegradable [52].

5.3. Economic and financial regulations

- Government support and incentives: Government support or financial incentives may be needed to make Solid waste to electrical energy projects more attractive. The absence of these incentives may make projects unprofitable.
- Cost estimation: Some technologies require significant capital investment, which can be a barrier in the absence of sufficient funding or private sector investment [17-20].

5.4. Storage and transportation regulations

- Waste management: Technologies such as anaerobic digestion and landfill gas purification can require strict regulations for managing and storing the waste generated [53].
- Waste transportation: Transporting waste to Solid waste to electrical energy facilities may require adherence to certain procedures to ensure that the environment is not polluted during transportation [54].

5.5. Property rights and land use legislation

- Land use: Solid waste to electrical energy projects may face restrictions on land use, especially in residential areas or environmentally sensitive areas [55].
- Property rights: Securing property rights to land and facilities can be complex and require coordination with local owners [56].

5.6. Technical Regulations

- Compliance with technical standards: There may be specific technical standards that Solid waste to electrical energy technologies must adhere to ensure efficiency and safety [57].
- Technology and Development: New technologies may face difficulties in obtaining licenses or certifications if they are not sufficiently proven or if they are considered untested [58].

5.7. Community Engagement and Outreach

- Community Acceptance: Lack of community acceptance of projects can impact their ability to obtain necessary permits and licenses. Community outreach and engagement may be essential to gain support [59].
- Environmental Impact: Comprehensive environmental impact studies may be required to demonstrate that technologies do not pose a threat to the environment and human health [60].

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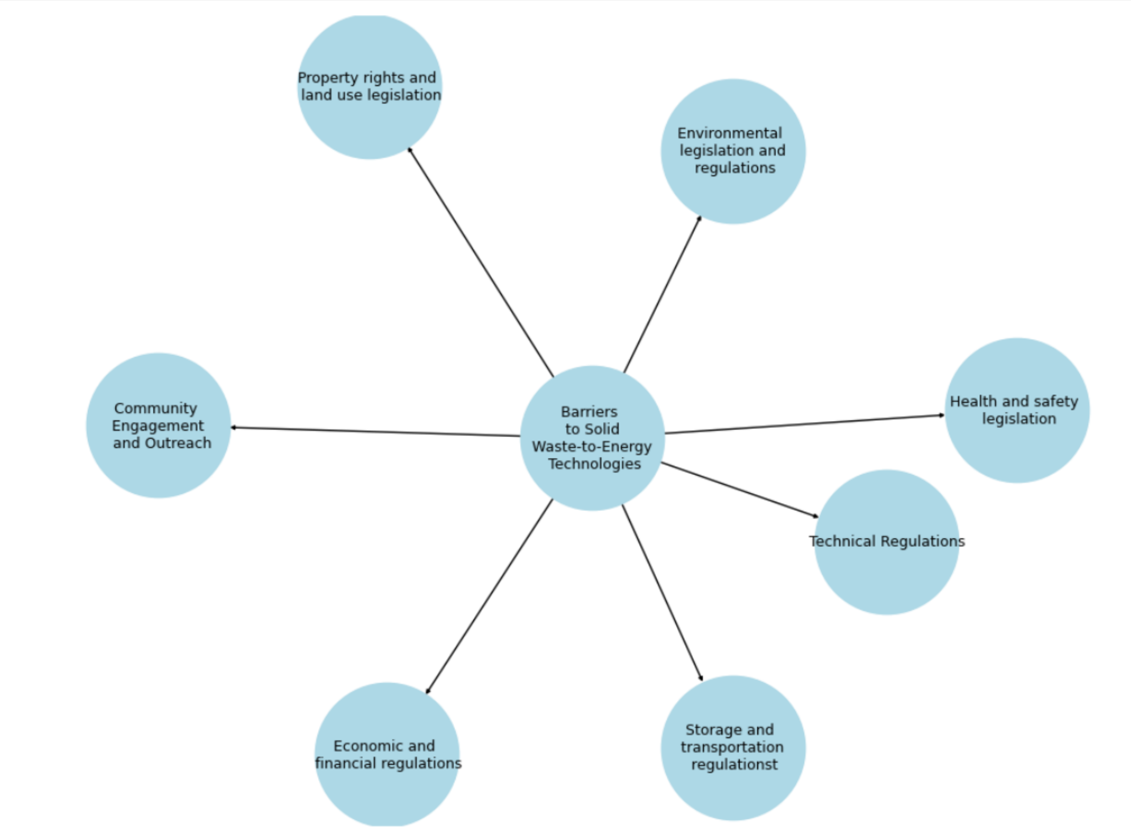

Figure (2): Regulatory Barriers to Solid waste to electrical energy Technologies

Addressing these regulatory barriers is essential to the successful development and implementation of Solid waste to electrical energy projects. Collaboration between governments, companies, and local communities may be required to ensure that projects are sustainable and effective.

6. Potential Opportunities to Promote the Application of Solid waste to electrical energy Technologies

Converting solid waste to electrical energy is a promising field that can have a significant impact on the environment and sustainability. To promote the application of these technologies, the following opportunities can be considered:

6.1. Technology and Innovation:

- Development of conversion technologies: Improving the efficiency of Solid waste to electrical energy technologies such as fermentation, incineration, and gasification.
- Investments in research and development: Supporting research focused on improving the performance of Solid waste to electrical energy systems and reducing their costs.

6.2. Subsidies and financial incentives:

- Government support: Providing financial subsidies or tax incentives for projects that use Solid waste to electrical energy technologies.
- Public-private partnerships: Encouraging cooperation between governments and private companies to finance and develop Solid waste to electrical energy projects.

6.3. Legislation and policies:

- Waste regulation: Establishing laws that encourage waste separation and management in ways that support its conversion to energy.
- Environmental standards: Establishing strict standards to ensure that waste conversion technologies adhere to sound environmental practices.

6.4. Awareness and education:

- Community education: Raising awareness of the benefits of Solid waste to electrical energy among the public and local communities.
- Training of personnel: Providing specialized training for workers in this field to ensure the effective application of technologies.

6.5. Integration with infrastructure:

- Updating infrastructure: Improving the infrastructure for waste collection and treatment to support its conversion into energy.
- Waste management systems: Effectively integrating waste management systems with Solid waste to electrical energy technologies to improve the efficiency of the process.

6.6. International partnerships:

- International cooperation: Sharing knowledge and expertise with other countries that have successful experiences in this field.
- International financing: Benefiting from international grants and loans allocated for sustainable energy projects.

These opportunities can help promote the application of Solid waste to electrical energy technologies and achieve environmental and economic benefits.

7. A comprehensive analysis of the composition of waste in the MENA countries

The study provides a comprehensive analysis of the composition of waste in the MENA countries and important insights into the challenges and opportunities in waste management in this region. Here is what this analysis could look like:

- **Distribution of waste types:**

  -Organic waste: represents a large percentage of waste in many Middle Eastern countries, especially due to dietary habits and eating at home. This waste includes food scraps and plant waste.

  -Plastic waste: the widespread use of plastic in packaging leads to a high percentage of plastic waste.

  -Metal waste: can include metal containers and electrical energy and electronic equipment.

  -Glass waste: occurs less frequently than plastics and metals, but is still part of the waste.

  -Hazardous waste: includes batteries, chemicals, and pharmaceuticals, and requires special management.

- **Quantity and geographical distribution:**

  -Disparity between countries: quantities and proportions vary based on the level of economic development, consumption habits, and environmental policies.

  -Urban vs. rural areas: urban areas tend to produce larger quantities of waste than rural areas.

- **Opportunities and Challenges:**

  -Recycling Opportunities: Improving recycling infrastructure and enhancing waste separation programs to increase recycling rates.

  -Management Challenges: These include weak infrastructure, lack of awareness, and lack of resources to manage waste effectively.

- **Technologies and Possible Solutions:**

  -Waste-to-Energy: Solid waste to electrical energy technologies such as incineration and gasification can be improved, especially for organic waste.

  -Technological Innovation: Adopting new technologies to improve waste management efficiency.

- **Legislation and Policies:**

  -Regulatory Framework: Reviewing and updating environmental policies and laws to encourage sustainable waste management.

  -Economic Incentives: Providing incentives for companies and communities to adopt sustainable solutions.

- **Community Awareness and Participation:**

  -Awareness Campaigns: Raising awareness of the importance of waste separation and recycling through awareness and education campaigns.

  -Community Participation: Encouraging active participation by citizens in waste management efforts.

- **Comparative Experiences:**

  -International Experience Study: Analysing successful experiences in other countries to apply lessons learned in Middle Eastern countries.

These elements provide a comprehensive framework for understanding and analysing the composition of waste in Middle Eastern countries, which can help develop effective strategies for its management and improvement of its sustainability.

8. Strategic Recommendations to Support the Adoption of Solid waste to electrical energy Technologies in the region

The study results in a series of strategic recommendations so as to serve imperative for an increased investment in Solid waste to electrical energy sector amid MENA. Detailed to these recommendations are as follows:

- **Strengthening Regulatory frameworks**

-Stopping supportive policies and laws: Governments must halt effective policies and legislation to encourage waste-to-energy, including good environmental standards guided by clear technical guidelines.

-Enforcing oversight and supervision: Creating a working system for inspection to guarantee environmental law compliances in the projects along with protecting quality.

- Updating regulations: Regularly update and review the regulations to meet technological trends in waste-to-energy

- **Financial Incentives**

- Financial support and subsidies: These can come in the form of financial incentives or tax concessions for projects using waste to energy. These incentives might be in the form of upfront subsidies, soft loans or tax breaks for equipment and technology.

- Sustainable funding: the creation of investment funds to fund green projects and provide capital needed to carry out waste-to-energy.

- **Encouraging public-private partnerships paddling**

-Investment partnerships: Supporting opportunities for links between national governments and private sector companies to create and finance Solid waste to electrical energy projects. Such partnerships could include profit and risk-sharing arrangements between the two parties.

-Knowledge & Technology: Develop Channels research agreements with international specialized companies to transfer advanced technology and expertise required to promote this sector in the MENA.

-Model project: Implement model projects with private industry that demonstrate the economic and environmental benefits of these technologies, encouraging greater market penetration;

- **Awareness and education**

-Awareness campaigns: Conduct awareness drives to spread community education on the merit of waste-to-electrical energy and why they should play an active role in managing their waste.

-Training programs: Holding training programs for technical and administrative employees to train them in operating, and managing Solid waste to electrical energy projects.

- **Infrastructure Development and Tech Support**

- Improving infrastructure: investing in bettering and modernizing the entire waste collection, sorting & processing supply chain to make it easier for conversion of waste into energy.

-Technological innovation support: Support of research and development to improve Solid waste to electrical energy technology, including investment in new or advanced technologies such as gasification and more efficient types of incineration.

- **Promotion of research and development**

-Cooperation and Integration with Universities & Research Centres: Collaboration between the government and academia for sustainable research solutions in this domain.

-Regional cooperation: To improve the practical effect, Middle Eastern countries should work together exchanging knowledge and experiences in utilizing waste for electrical energy.

-Benefitting from international experiences: Gaining knowledge and experience through the best practices abroad, applying them in MENA context considering local characteristics.

-The strategy will implement a framework to create an enabling atmosphere for the uptake of WtE energy technologies in MENA countries, progressing environmental and economic sustenance targets set by policymakers across the region.

9. Conclusion

Waste to Electrical energy technology offers a range of environmental advantages that make it an attractive solution for modern waste management, From reducing waste volume and greenhouse gas emissions to generating alternative energy and supporting resource recovery, also Waste to Electrical energy provides an effective and sustainable way to manage the growing waste challenges faced by cities and regions worldwide. As the MENA and other areas continue to develop and urbanize, Solid waste to electrical energy can play a crucial role in helping these areas transition to more sustainable and environmentally friendly waste management practices. This study reviews the techniques and applications of Converting Solid waste to electrical energy in the region. Also, it presents key strategic recommendations for the uptake of Solid waste to electrical energy technologies in the MENA, such as reforming regulatory frameworks and creating financial incentives as well as public-private partnerships. The paper found that the waste composition in the area consists of different fractions, including organic, plastic and metal being predominant followed by glass and hazardous wastes; hence a detailed analysis of waste composition was mandatory before designing an appropriate Solid waste to electrical energy strategies. The study calls for the development of supportive policies and legislation, financial incentives and subsidies as well as partnerships with investment companies to grow private sector growth. The recommendations also extend to increasing awareness, enhancing infrastructure and promoting technological innovation via R&D. Similarly, the success of these projects depends critically on the breadth and depth of regional and international collaboration in exchanging best practices. Middle Eastern nations will be able to contribute to the regionally accepted sustainable development goals by putting such as these ideas into practice, which will help them achieve long-term environmental and economic advantages.

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