Study of Converting waste to energy: Iraq's potential and the role of artificial intelligence in sustainable solutions

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Abstract :
Energy supply and waste management are becoming increasingly important for Iraq and the Middle East. Population growth, rapid urbanization, and economic development have increased waste generation. In addition, when energy demand exceeds supply, it leads to frequent power outages. Waste-to-energy is a new approach that offers environmental, economic, and security benefits by integrating waste treatment with clean energy production. This paper examines several waste-to-energy methods in Iraq today, including gasification, incineration, and others. These technologies have the potential to reduce global greenhouse gas emissions, increase local and sustainable energy sources, and reduce the amount of garbage that ends up in landfills. Strategies for waste-to-energy are also discussed, as are the challenges facing waste-to-energy programs in Iraq. The role of the world and the Middle East in waste-to-energy, especially electricity, is also discussed. In addition, future prospects for Iraq are highlighted, including strengthening government initiatives, the possibility of international cooperation, and utilizing large amounts of waste as a resource for energy generation. Several suggestions have been made to improve the method waste-to-energy projects are implemented in Iraq. These suggestions include developing a strong infrastructure for waste management and energy conversion, using appropriate and advanced waste-to-energy technologies, such as electricity. Also, efficient policies and regulations should be enacted to support waste-to-energy. Iraq can also seize the opportunity to develop strategic partnerships with international companies specialized in environmental technology and waste-to-energy and also focus on marketing and awareness to enhance community awareness of the benefits of waste-to-energy and electricity generation, which would encourage increased investment projects in this field.
Key words: Waste-to-energy, Artificial Intelligence, Renewable Energy. Machine learning ,IoT, Smart cities.

دراسة تحويل النفايات إلى طاقة: إمكانات العراق ودور الذكاء الاصطناعي في الحلول المستدامة

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الخلاصة :
أصبحت إمدادات الطاقة وإدارة النفايات من القضايا المهمة بشكل متزايد بالنسبة للعراق والشرق الأوسط. وقد ساهم النمو السكاني والتوسع الحضري السريع والتنمية الاقتصادية في زيادة توليد النفايات. بالإضافة إلى ذلك، عندما يتجاوز الطلب على الطاقة العرض، يؤدي ذلك إلى انقطاع التيار الكهربائي بشكل متكرر. إن تحويل النفايات إلى طاقة هو نهج جديد يقدم فوائد بيئية واقتصادية وأمنية من خلال دمج معالجة النفايات مع إنتاج الطاقة النظيفة. تدرس هذه الورقة العديد من طرق تحويل النفايات إلى طاقة في العراق اليوم، بما في ذلك التغويز والحرق وغيرها. تتمتع هذه التقنيات بإمكانية تقليل انبعاثات الغازات المسببة للانحباس الحراري العالمي، وزيادة مصادر الطاقة المحلية والمستدامة، وتقليل كمية القمامة التي تنتهي في مكبات النفايات. كما تتم مناقشة استراتيجيات تحويل النفايات إلى طاقة، وكذلك التحديات التي تواجه برامج تحويل النفايات إلى طاقة في العراق. كما تتم مناقشة دور العالم والشرق الأوسط في تحويل النفايات إلى طاقة، وخاصة الكهرباء. كما تم تسليط الضوء على الآفاق المستقبلية للعراق، بما في ذلك تعزيز المبادرات الحكومية، وإمكانية التعاون الدولي، والاستفادة من كميات كبيرة من النفايات كمورد لتوليد الطاقة. وقد تم تقديم العديد من الاقتراحات لتحسين طريقة تنفيذ مشاريع تحويل النفايات إلى طاقة في العراق. وتشمل هذه الاقتراحات تطوير بنية تحتية قوية لإدارة النفايات وتحويل الطاقة. واستخدام تقنيات تحويل النفايات إلى طاقة المناسبة والمتقدمة، مثل الكهرباء. وكذلك سن السياسات واللوائح المناسبة لدعم تحويل النفايات إلى طاقة. ويمكن للعراق

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أيضًا اغتنام الفرصة وتطوير شراكات استراتيجية مع شركات عالمية متخصصة في التكنولوجيا البيئية وتحويل النفايات إلى طاقة، والتركيز أيضًا على التسويق والتوعية لتعزيز وعي المجتمع بفوائد تحويل النفايات إلى طاقة وتوليد الكهرباء، مما من شأنه تشجيع زيادة مشاريع الاستثمار في هذا المجال.

الكلمات المفتاحية: تحويل النفايات إلى طاقة، الذكاء الاصطناعي، الطاقة المتجددة، التعلم الآلي، إنترنت الأشياء، المدن الذكية.

1. Introduction

Waste management and energy production are critical issues in the Middle East region, especially in Iraq. With rapid population growth, urbanization, and accelerated economic development, solid wastes have increased dramatically because of human, commercial, and industrial activities. At the same time, the energy demand has increased significantly, putting significant pressure on the existing energy infrastructure. Traditional waste disposal methods, such as landfilling, are unsustainable and cause critical environmental damage, including soil and groundwater pollution, and greenhouse gas emissions that contribute to climate change [1, 2]. On the other hand, Iraq suffers from recurring electricity shortages, which negatively impact the daily lives of citizens and economic activity and increase development challenges. The country relies heavily on fossil fuels for energy production, which exposes it to fluctuations in oil prices and leads to the depletion of natural resources. The electricity sector in Iraq suffers from outdated infrastructure and poor efficiency, in addition to being severely damaged because of long-standing conflicts, which have led to frequent power outages and a decline in the quality of services provided [3,4]. In this context, waste-to-energy (WtE) technologies (the process of converting waste into electrical or thermal energy, and is considered an important technology that contributes to waste management and reducing dependence on fossil fuels.) offer an innovative and dual solution to these interconnected problems, as municipal solid waste can be converted into electricity. These technologies help reduce the volume of waste destined for landfills, provide a renewable and sustainable energy source, and reduce dependence on fossil fuels, which enhances energy security and improves environmental sustainability. These technologies include incineration, gasification, anaerobic digestion, and pyrolysis, each offers unique advantages in waste treatment and energy generation. Waste-to-energy projects help reduce the negative environmental impacts resulting from waste accumulation in landfills, such as greenhouse gas emissions and the leaching of toxic materials into soil and water. They also provide a reliable and sustainable energy source that can reduce dependence on fossil fuel imports and enhance the country's energy security. These initiatives can also create jobs and boost economic development by investing in waste as an alternative energy resource. Overall, waste-to-energy represents an integrated strategy that can contribute to solving the waste management and energy crisis in Iraq, and enhance sustainable development in the region. To achieve this goal, Iraq must adopt supportive and stimulating policies for waste-to-energy projects, develop the necessary infrastructure, and optimize cooperation with international bodies and technical experts. Research and development in this field should also be encouraged to enhance the efficiency of the technologies used and ensure the best environmental and economic results [5,6].

2. Waste-to-Energy Concept

Waste-to-energy (WtE) is a process that involves converting solid waste into usable energy, typically through various methods such as incineration, pyrolysis, gasification, and anaerobic digestion. The primary goal of these processes is to reduce the amount of waste that ends up in landfills and generate useful energy, whether electricity, heat, or fuel. There are many types of waste, Types of waste can be classified based on their sources and composition. Here is a comprehensive classification of waste types [7,8]:

A. Solid Waste:

- **Municipal Solid Waste:** Household waste includes food scraps, plastic, paper, cardboard, glass, metals, and clothing. Commercial waste is waste from shops, restaurants, and offices (similar to household waste but in larger quantities).

- **Industrial Solid Waste:** Waste resulting from manufacturing includes leftover raw materials, packaging, and damaged products. Hazardous Waste includes toxic chemicals, heavy metals, and flammable or reactive waste.
- **Agricultural Waste:** Vegetable waste includes crop residues, straw, and grasses. Animal Waste includes manure and slaughterhouse waste.
- **Bio-medical Waste:** Waste from hospitals and clinics includes needles, used medical instruments, expired medications, and materials contaminated with blood or body fluids [1,2,7,8].

B. Liquid Waste:

- **Sewage:** Domestic water from household use, including bathrooms, kitchens, and laundry. Industrial water from industrial processes may contain chemicals and pollutants.
- **Agricultural wastewater:** Water resulting from irrigation containing fertilizers and pesticides.
- **Liquid hazardous waste:** Industrial chemicals including used oils, acids, solvents, and toxic materials [6,7,8].

C. Gaseous waste:

- **Industrial emissions:** Gases resulting from industrial processes including carbon dioxide, sulphur dioxide, nitrogen oxides, and particulate matter.
- **Transportation emissions:** Gases resulting fuel combustion in cars and trucks including carbon monoxide, hydrocarbons, and nitrogen oxides.
- **Agricultural emissions:** Gases from raising livestock such as methane and nitrous oxides [7,8].

D. Electronic waste:

- **Consumer electronic devices:** Mobile phones, computers, televisions, and electrical appliances containing heavy metals and chemicals.
- **Batteries:** Rechargeable and non-rechargeable batteries containing heavy metals such as mercury, lead and cadmium [7,8].

E. Radioactive waste:

- Nuclear waste: Waste from nuclear power plants includes spent fuel, radioactive materials, and radioactive medical waste. Medical waste resulting from the use of radioactive materials in medicine and treatment.
- Research waste: Radioactive materials used in scientific research [7,8].

3. Waste to Energy Technologies

There are many technologies to convert waste into valuable sustainable energy, contributing to the long-term environmental and economic goals of communities. These technologies are:

3.1. Incineration: Burning solid waste at high temperatures to convert it into heat used to heat water, producing steam that turns turbines to generate electricity. Furthermore, it helps reduce the volume of waste by up to 90% and generates thermal and electrical energy [9,10]

3.2. Pyrolysis: Heating waste in the absence of oxygen. To produce bio-oil, gas, and charcoal that can be used as energy sources. Helps process different types of organic and inorganic waste [8,9,10].

3.3. Gasification: Converting waste into synthetic gas (syngas) by heating it with a limited amount of oxygen. Synthetic gas can be used to generate electricity or as an industrial fuel. Also, it can generate energy with high efficiency while reducing harmful emissions [7,8].

3.4. Anaerobic Digestion: Decomposition of organic waste by bacteria in an oxygen-free environment. To produce biogas (mainly methane and carbon dioxide) and organic fertilizer. In addition, it can generate renewable energy and reduce greenhouse gas emissions [5,6,7,8].

4. General Strategies for Waste-to-Energy

These strategies include developing advanced infrastructure, developing supportive policies and legislation, encouraging innovation and modern technology, and raising awareness and education to achieve effective community participation. By adopting a comprehensive approach that combines advanced technology and effective management, effective waste-to-energy conversion can be achieved, contributing to achieving environmental and economic goals. Below is the illustration of these strategies [9,10]:

4.1. Infrastructure Development

- Investment in Facilities: Establishing modern facilities equipped with advanced technology to treat waste and convert it into energy.
- Public-Private Partnerships: Collaboration between the public and private sectors to secure financing and develop projects.[1,2,5].

4.2. Legislation and Policies

- Developing Supportive Policies: Implementing government policies that support waste-to-energy projects through financial incentives and legislation.
- Environmental Standards: Setting strict environmental standards to ensure that pollution and harmful emissions are reduced.

4.3. Technology and Innovation

- Research and Development: Investing in research and development to improve the efficiency of existing technologies and innovate new ones.
- Smart Technologies: Using artificial intelligence and big data technologies to improve the efficiency of operations and reduce waste.

4.4. Awareness and Education

- Awareness Campaigns: Implementing awareness campaigns to educate the public about the benefits of converting waste into energy and the importance of participating in recycling programs.
- Education and Training: Providing educational and training programs to qualify workers in this sector and ensure the use of best practices.

4.5. Sustainability and the Circular Economy

- Achieving the Circular Economy: Integrating the principle of the circular economy into waste to-energy strategies, where resources are reused, and waste is reduced.
- Environmental Impact Assessment: Conduct periodic assessments of the environmental impact of waste-to-energy operations to ensure sustainability [1,2,5,7,8].

5. The role of the world in converting waste-to-energy

The world contributes to ensuring efficient and responsible waste-to-energy conversion, Where the world plays several important roles in waste-to-energy Here are some of the key aspects[11,12,13]:

1. Policy development: Governments and international organizations formulate policies and regulations to encourage waste-to-energy initiatives. They also set targets, standards and incentives for waste management and energy production, promote sustainable practices and reduce reliance on non-renewable energy sources.
2. Research and innovation: The world invests in research and development to discover and improve waste-to-energy technologies. This includes supporting scientific studies, pilot projects and technological advances that increase efficiency, reduce costs and minimize environmental impacts associated with waste-to-energy processes.
3. Infrastructure and investment: Governments and private entities invest in developing waste-to-energy infrastructure. This includes building waste treatment facilities such as waste incineration plants, anaerobic digestion plants and gasification units. Adequate investment ensures that the resources needed to convert waste into usable energy are available.
4. Public awareness and education: Creating awareness among the general public about waste management and energy production is crucial.
5. Collaboration and knowledge-sharing: International collaboration and knowledge sharing platforms play a vital role in facilitating the exchange of best practices, expertise and skills in waste-to-energy. This enables countries to learn from successful implementation strategies, share technological knowledge and collectively address global waste management challenges.
6. Environmental Impact Assessment: Implementing waste-to-energy projects requires environmental impact assessments to assess potential environmental, health and social impacts. This ensures that waste-to-energy projects are implemented sustainably and responsibly while minimizing negative

impacts on ecosystems, air quality and communities [1,2,7,8].

7. Waste Reduction and Circular Economy: The world aims to adopt a circular economy approach, prioritizing waste reduction and resource optimization over energy recovery. By reducing waste generation through strategies such as recycling, composting and reuse, the world can reduce the amount of waste that requires energy conversion, thereby promoting a more sustainable waste management model [1,2,5,7,8].

There are many notable experiences in converting waste to energy around the world. Here are some examples:

1. Sweden: Sweden is a pioneer in converting waste to energy. Sweden uses thermal combustion technologies to convert non-biodegradable waste into thermal energy. Also, it pays great attention to cooling systems and applying thermal energy generated in industrial processes and heating [14].
2. Japan: Japan is one of the largest employers of thermal power plants that operate on waste. Japan uses advanced technologies such as biothermal and gas conversion, as well as thermal combustion to convert waste into electrical and thermal energy [15].
3. Denmark: Denmark is a pioneer in the use of biothermal conversion and thermal combustion to produce energy from waste. Danish thermal power plants use these technologies to generate electricity and provide thermal energy for use in heating [16].
4. Germany: Germany is a pioneer in employing advanced methods of converting waste to energy, including thermal conversion and low combustion to produce electrical and thermal energy. It also supports using jet gas extracted from waste as vehicle fuel [17].
5. United States: The United States uses various technologies to convert waste to energy. Some rely on thermal combustion, such as coal-fired power plants, while others use biogasification, bioconversion, and even plasma technologies to dispose of waste and produce energy. These are just a few examples of waste-to-energy experiments worldwide [18].

The field must continually evolve with improvement and innovation to find more effective and sustainable solutions for waste management and energy generation.

6. The Middle East's role in converting waste into energy and the most prominent experiences of Middle Eastern countries in converting waste into energy

Currently, Middle Eastern countries are characterized by their orientation towards sustainable development and reliance on renewable energy sources, within the framework of diversifying energy sources and reducing their dependence on fossil fuels. Although it is too early to talk about specific measures and clear results, there are some efforts and experiences in converting waste into energy in Middle Eastern countries.

1. United Arab Emirates: The UAE is working to make sustainable development part of its national vision. The "Mohammed bin Rashid waste-to-energy plant was built in Dubai and uses advanced technology to convert municipal waste into electrical energy [19].

2. Qatar: Qatar has begun developing projects that recover energy from waste, and it is planned to operate the country's first waste conversion plant in 2021. The plant will use thermal technology to convert solid waste into electrical energy [20].

3. Saudi Arabia: Saudi Arabia has announced an ambitious plan for sustainable development, including a waste management strategy and its conversion into energy. The waste to energy plant was founded in Jeddah in 2019, and the government plans to establish more facilities in the future [21].

It should be emphasized that these countries are still in the early stages of implementing waste-to-energy projects. These projects require advanced technological investments and resources, as well as strict environmental measures to ensure that waste is treated in a safe and efficient manner.

7. Iraq's role in converting waste into energy

In Iraq, waste-to-energy operations are still in their early stages, Iraq, like many other countries, produces a large amount of waste on a monthly and yearly basis. Various factors contribute to different types of waste generation in the country. In Iraq, the commonly generated types of waste include municipal waste, construction and demolition waste, hazardous waste, electronic waste, and medical waste, among others. Municipal waste, which consists of household waste, is one of the primary sources of waste in Iraq. It includes various materials such as paper, plastic, glass, metals, and organic waste. The construction and demolition industry in Iraq also produces a large amount of waste due to ongoing infrastructure development and reconstruction projects. This waste includes concrete, bricks, wood, steel, and other construction debris. Furthermore, industrial activities, agriculture, healthcare facilities, and commercial sectors in Iraq contribute to the generation of hazardous waste, which can be harmful to the environment and human health. This type includes chemicals, oils, contaminated soil, and other materials. E-waste generated in Iraq originates from discarded electronic devices such as computers, televisions, and mobile phones. The amount of waste produced in Iraq varies from month to month and from year to year and is affected by population growth, economic activities, urbanization, and consumption patterns [22,23]. Figure (1) below shows the amount of waste removed by the government in different cities in Iraq daily until 2015.

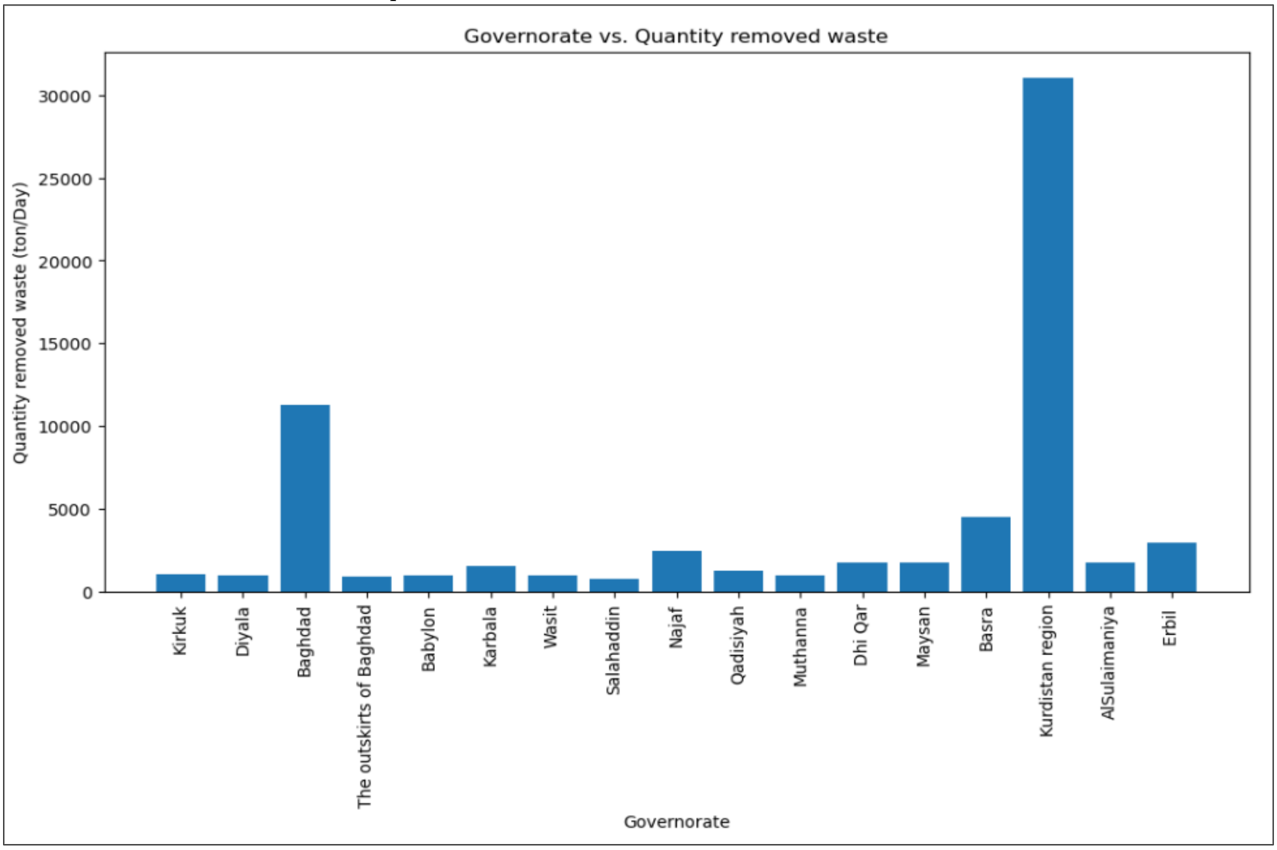

Figure 1: the amount of removed waste daily[24].

while the figure shows the amount of waste removed on an annual basis.

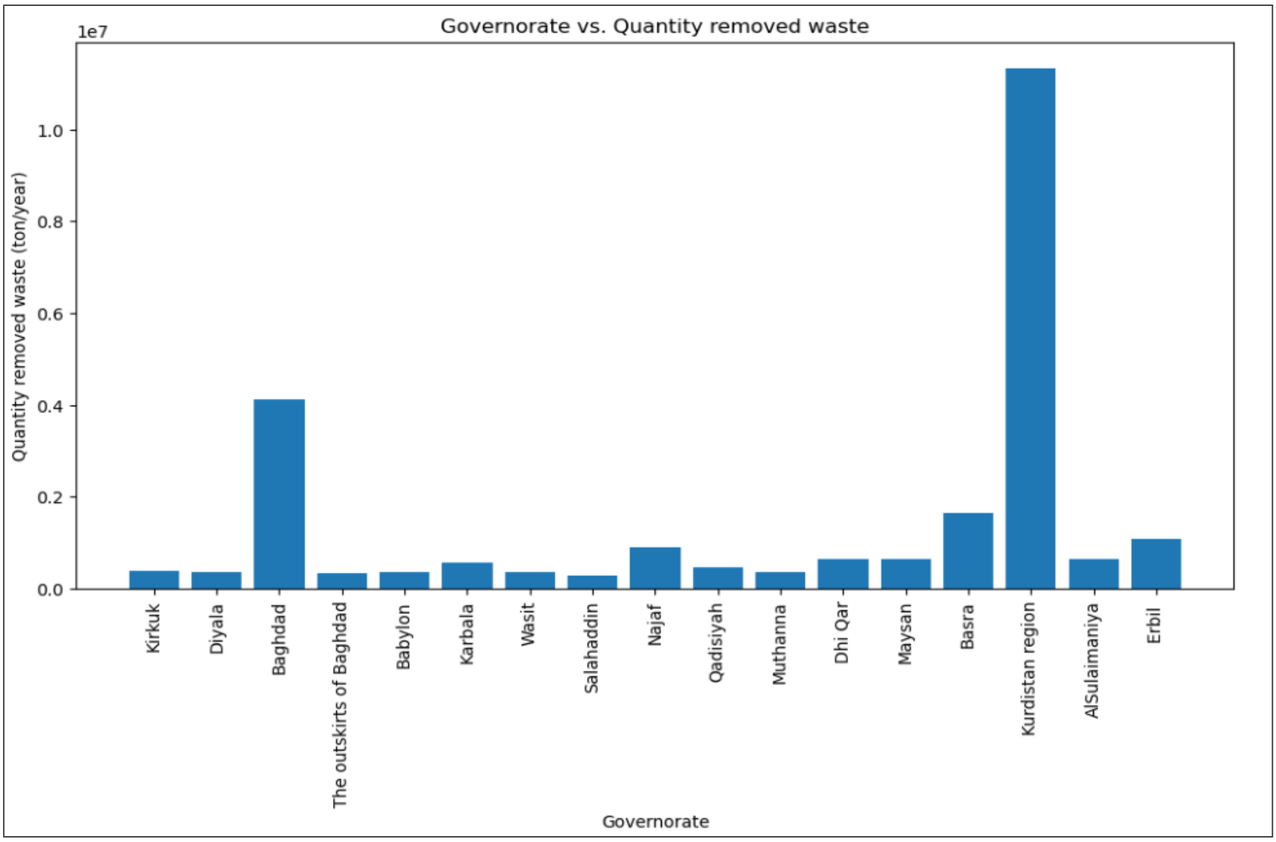

Figure 2: the amount of removed waste yearly[24].

From the above figures, it can be concluded that there is a large amount of waste daily and yearly, this can be considered a motivation to use it in energy production, especially electrical energy.

In Iraq, waste-to-energy operations face many challenges, some of these challenges include:

1. Weak infrastructure: Many areas in Iraq suffer from weak waste management infrastructure, which negatively affects the ability to convert waste to energy. These challenges include a lack of waste collection, classification, and proper treatment facilities.
2. Outdated and undeveloped technology: Utilizing traditional and old technology in waste-to-energy operations can be challenging. It is important to adopt advanced and effective technology to improve the efficiency of energy extraction from waste and reduce the environmental impact.
3. Lack of funding: Obtaining the necessary funding for waste-to-energy projects can be a challenge in Iraq, as these projects require large investments to develop infrastructure and use advanced technology.
4. Lack of environmental awareness: Environmental awareness may be low in some areas, which increases the challenges in understanding the potential benefits of waste-to-energy. Raising environmental awareness in the community and clarifying the economic and environmental benefits associated with waste-to-energy plays an important role in overcoming this challenge.

Although that , there are some available capabilities and potential opportunities for investment in waste-to-energy in Iraq, including electricity generation. Some points to consider are:

1. Infrastructure: Iraq needs to develop a strong infrastructure for waste management and energy conversion. This requires investment in waste collection, classification and treatment facilities.
2. Technology: Appropriate and advanced technology is needed to convert waste to

energy, such as thermal and biogas technologies. Investment in this technology can enhance the ability to generate electricity from waste.

3. Policies and regulations: Appropriate policies and regulations are needed to support waste-to-energy conversion. Strict environmental measures must be in place to ensure that waste is treated safely, and the government must support and encourage investment projects in this field.
4. Strategic partnerships: Iraq can seize the opportunity and develop strategic partnerships with international companies specialized in environmental technology and waste-to-energy conversion. These partnerships can lead to technology transfer and training of local cadres in this sector.
5. Marketing and awareness: The government and relevant institutions should direct marketing efforts and awareness programs to enhance community awareness of the benefits of waste-to-energy and electricity generation. This can encourage increased investment projects in this field [24,25,26].

8. The Role of Artificial Intelligence in Waste-to-Energy

Artificial Intelligence (AI) plays a vital role in waste-to-energy by improving processes, increasing efficiency, and reducing costs. Here are some of the important roles that AI can play in this field:

Improving the sorting and recycling process: Waste identification: Using machine learning and image recognition techniques to improve the waste sorting process and identify materials that can be converted into energy.

- Automation: Developing automated systems that use AI-powered robots to sort waste quickly and accurately.
- Increasing the efficiency of waste-to-energy plants: Optimizing operations: Using AI to analyse data and optimize combustion and conversion processes in plants, which increases production efficiency and reduces harmful emissions [25,26].
- Predictive maintenance: Applying maintenance prediction techniques to identify potential failures before they occur, which reduces downtime and improves plant performance.
- Smart waste management: Data analysis: Collecting and analysing data related to the quantities and types of waste produced in different areas, which helps improve waste management plans and allocate resources more effectively.
- Production forecasting: Using predictive models to estimate future waste quantities and plan the production capacities of waste-to-energy plants [27,28].
- Improving investment and planning decisions: Site planning: Identifying the optimal locations for waste transfer stations based on analysis of environmental, economic and demographic data.
- Improving communication and interaction with the community: Awareness and education: Developing educational applications and platforms that use artificial intelligence to raise awareness in the community about the importance of converting waste to energy and encouraging sustainable environmental behaviours.
- Community engagement: Using artificial intelligence technologies to collect and analyse citizen feedback, which helps improve waste management policies and ensure community acceptance of new projects.
- Integration with smart systems: Smart cities: Integrating waste-to-energy systems with smart city networks to achieve integrated waste and energy management in cities.
- Renewable energy: Improving the integration between waste-to-energy and other renewable energy sources such as solar and wind energy, to achieve a better balance in energy use.

Using artificial intelligence in these areas, the efficiency and effectiveness of waste-to-energy conversion can be improved, contributing to significant environmental and economic benefits.

Economic feasibility analysis: Using artificial intelligence to analyse the economic aspects of waste-to-energy projects, including estimating costs, returns and potential risks [25,26,27,28].

9. The AI techniques that can be used to produce energy from waste

To produce energy from waste, a variety of AI techniques can be used to improve efficiency, reduce costs, and enhance overall process performance. Here are some of the key techniques that can be used [29,30,31,32]:

a. Machine Learning

- Data Analysis: Collecting and analysing the big data generated from waste management and energy conversion processes, which helps improve decisions and increase operational efficiency.
- Predictive Models: Developing predictive models to estimate future waste and energy production quantities, which helps in planning production capacities and better-managing resources [26,28,30,31].

b. Computer Vision

- Waste Sorting: Using image and pattern recognition techniques to improve waste sorting processes and identify materials that can be converted into energy with high accuracy.
- Material Identification: Applying computer vision algorithms to recognize and separate different types of waste based on their physical and chemical properties[30,31,32].

c. Predictive Analytics

- Predictive Maintenance: Using predictive analysis techniques to identify potential failures in waste-to-energy equipment before they occur, which reduces downtime and improves system performance.
- Performance prediction: Analysing historical and current data to predict the performance of waste transfer stations and identifying necessary improvement actions.

d. Optimization

- Process optimization: Using optimization algorithms to optimize waste-to-energy conversion processes, such as optimizing combustion and biogas conversion processes, which increases production efficiency.
- Resource management: Optimizing resource allocation and managing daily operations in waste transfer stations to achieve the highest levels of efficiency and sustainability [26,28,29,30,32].

e. Artificial Neural Networks

- Complex process analysis: Using neural networks to analyse complex processes in waste transfer stations and improve system performance by learning from past data.
- Pattern recognition: Analysing different data patterns to identify differences and changes in processes and improve control and monitoring [26,28,30].

f. Internet of Things (IoT) and Artificial Intelligence

- Real-time data collection: Using smart sensors connected to the Internet to collect real-time data on processes and equipment in waste transfer stations.
- Instant analysis: Analysing data collected in real-time using artificial intelligence techniques to make quick and effective decisions about operations and maintenance [26,28,30].

g. Smart Robotics

- Automation: Developing AI-powered robots to perform waste sorting, transportation, and feeding operations at transfer stations, reducing reliance on human labour and increasing efficiency.
- Adaptive Control: Using AI to improve the performance of robots in handling a variety of waste and different operating conditions [26,28,30].

Using these technologies, waste-to-energy conversion processes can be significantly improved, contributing to sustainable environmental and economic benefits.

AI techniques can effectively assess the feasibility of waste-to-energy conversion, By applying these techniques, decision-makers, governments and companies can accurately and thoughtfully assess the feasibility of waste-to-energy projects, contributing to achieving sustainable development goals and reducing the environmental impact of waste.

a. Big Data Analytics

- Data collection and analysis: Using AI to analyse big data related to waste quantities and types, costs, and expected returns. Historical and future data can be analysed to estimate the economic and technical feasibility of the project.
- Production forecasting: Using prediction models to estimate the amount of energy that can be produced from waste, based on the characteristics of the available waste [33].

b. Predictive Models

- Cost-Benefit Analysis: Developing predictive models to evaluate the total cost of waste-to-energy projects, including construction, operation, and maintenance costs, versus the expected returns from selling energy and by-products.
- Risk Analysis: Assessing the risks associated with the project, such as fluctuations in energy prices and waste availability, and using AI to identify potential scenarios and manage them effectively [34].

c. Process Optimization:

- Selecting the most appropriate technology: Using AI algorithms to evaluate different available waste-to-energy technologies (such as thermal incineration, pyrolysis, and anaerobic digestion) and identify the most appropriate based on waste quality, costs, and returns.
- Efficiency Improvement: Applying AI techniques to improve the efficiency of waste conversion processes, reducing operational costs and increasing return on investment [35].

d. Simulation

- System Modelling and Simulation: Using AI-powered simulation techniques to model waste-to-energy processes, allowing for evaluation of performance under different operating conditions and identifying the best strategies for achieving efficiency and sustainability.
- Scenario Analysis: Developing different simulation models to evaluate the impact of changes in inputs (such as waste volume and energy costs) on the economic feasibility of the project [36].

e. Multi-Criteria Analysis

- Comprehensive Evaluation: Using AI techniques to evaluate feasibility based on a set of multiple criteria, such as economic feasibility, environmental impact, community acceptance, and sustainability.
- Data-Driven Decision Making: Analysing and weighing different criteria to provide data-driven recommendations to decision-makers [37].

f. Machine Learning

- Environmental data analysis: Using machine learning to analyse environmental data related to emissions, and air and water pollution resulting from waste conversion processes, helping to make environmentally sustainable decisions [38].
- Energy demand forecasting: Using machine learning models to forecast energy demand and compare the potential benefits of waste-to-energy with traditional energy sources [39,27].

10. Recommendations to activate Iraq's role in investing waste to generate energy

The following recommendations can be followed to activate Iraq's role in investing waste to generate energy:

1. Developing infrastructure

- Establishing advanced stations: Building modern stations to convert waste to energy using advanced technologies such as thermal incineration, pyrolysis, and anaerobic digestion [40].

- Improving the waste collection system: Developing an effective system for collecting waste at the source and applying waste sorting techniques to ensure the provision of the necessary raw materials [41].

2. Policies and legislation

- Establishing a legal and legislative framework: Enacting laws and legislation that support the conversion of waste to energy and providing financial incentives to companies and investors in this field [42].
- Implementing strict environmental laws: Imposing strict environmental laws to ensure proper waste management and reducing the environmental impact [43].

3. Financing and investment

- Providing funding and government support: Allocating budgets and government support for pioneering projects in converting waste to energy [44,45].
- Stimulating private investments: Providing tax incentives and soft loans to attract local and international investors [46].

4. Technology and innovation

- Using advanced technologies: Adopting the latest technologies in the field of converting waste to energy to ensure efficiency and effectiveness [47,48].
- Supporting research and development: Enhancing research and development in this field through partnerships with universities and research centres [49].

5. Awareness and Education

- Community awareness campaigns: Organize awareness campaigns to educate the community about the importance of converting waste to energy and its environmental and economic benefits [50,51].
- Educational programs: Include educational programs in schools and universities about waste management and sustainability [52].

6. International and local cooperation:

- Partnerships with developed countries: Benefit from the experiences of countries that have successful experiences in converting waste to energy through partnerships and cooperation [53,54].
- Cooperation with international organizations: Work with international organizations to obtain financial and technical support.[55]

7. Integration with national strategies

- Integrating projects into national energy plans: Ensuring that waste-to-energy projects are part of national energy and sustainable development plans [56].
- Connecting with renewable energy networks: Integrating waste-to-energy projects with other renewable energy projects such as solar and wind energy [57].

8. Evaluation and follow-up:

- Performance monitoring: Develop a system to monitor and evaluate the performance of waste conversion plants to ensure that environmental and economic goals are achieved [58].
- Continuous improvement: Use evaluation results to improve operations and technology over time [59].

To make the most of artificial intelligence (AI) in converting waste into energy in Iraq, the following recommendations can be followed:

1. Developing technical infrastructure

- Establishing data platforms: Building platforms to collect and store data related to waste and its conversion into energy processes [60].
- Providing reliable internet connectivity: Ensuring the availability of high-speed and stable internet connectivity in areas where waste conversion plants will be established [61].

2. Training and educating the workforce

- Training technicians and operators: Providing training courses for workers in the field of waste management and conversion on how to use smart technologies [62].
- Cooperation with universities: Strengthening cooperation with universities to develop postgraduate programs focused on artificial intelligence and its applications in waste and energy management [63].

3. Developing supportive policies

- Encouraging legislation: Developing policies and laws that encourage the use of artificial intelligence in converting waste into energy, including tax incentives and financial support for research projects [64].
- Environmental standards: Setting strict environmental standards to ensure that waste conversion processes use clean and sustainable technologies [65].

4. Investing in technology

- Smart sorting technologies: Investing in computer vision and machine learning technologies to sort waste accurately and efficiently [66].
- Predictive Analysis Systems: Developing predictive analysis systems to improve the efficiency of waste transfer stations, predict maintenance, and estimate energy production [67].

5. Intelligent Resource Management

- Environmental Data Analysis: Using AI to analyze environmental data, improve waste management processes, and reduce environmental impact [68].
- Site Planning: Using AI to select optimal sites for waste transfer stations based on analysis of geographic and demographic data [69].

6. Enhancing International and Local Cooperation

- Partnerships with technology companies: Establishing partnerships with global and local companies specialized in AI technology and waste-to-energy conversion [70].
- Cooperation with international organizations: Working with international organizations to benefit from successful experiences and experiments in other countries [71].

7. **Community Awareness and Participation**

- Awareness Campaigns: Organizing awareness campaigns for the community about the importance of using AI in converting waste to energy and its environmental and economic benefits [72].
- Encouraging Local Initiatives: Supporting and encouraging local initiatives and small projects that use AI technologies in waste management [73].

8. Innovation and Research and Development

- Research Support: Funding research and pilot projects aimed at developing innovative solutions to convert waste to energy using AI [74].
- Competitions and Challenges: Organizing competitions and challenges to stimulate innovation in this field and attract young talent [75].

11. Conclusion

In conclusion, waste-to-energy represents a promising and multifaceted approach to waste management while generating valuable energy resources. By leveraging different technologies such as incineration, pyrolysis, gasification, and anaerobic digestion, waste-to-energy processes offer solutions to reduce landfill use and generate electricity, heat, and fuel from waste. The success of waste-to-energy initiatives depends on a combination of technological advances, strong infrastructure, supportive policies, and community engagement.

Globally, several countries have demonstrated effective waste-to-energy practices, each adapting technologies and strategies to their specific needs. The Middle East is making significant progress in this area, with landmark projects in multiple countries. However, many Middle Eastern countries, including Iraq, are still in the early stages of waste-to-energy implementation and face challenges such as outdated infrastructure, limited funding, and low environmental awareness.

Artificial intelligence offers transformative potential to enhance waste-to-energy processes by improving waste sorting, optimizing plant operations, and enabling smart waste management systems. By integrating AI technologies such as machine learning, computer vision and predictive analytics, the efficiency and effectiveness of waste-to-energy projects can be significantly improved. To activate Iraq's role in this field, there are several critical recommendations such as:

- Developing infrastructure.

- Enacting supportive laws, financial incentives and strict environmental regulations.
- Securing government and private sector funding and strengthening strategic partnerships.
- Adopting the latest technologies and supporting research and development initiatives.
- Implementing community awareness campaigns and educational programs in the field of waste-to-energy.
- It is important to cooperate with countries and international organizations with expertise.
- Emphasize national sustainability while continuing to monitor and improve waste-to-energy processes on an ongoing basis.

By addressing these recommendations and leveraging the potential of AI, Iraq and other countries can develop their waste-to-energy capabilities, contributing to environmental sustainability and energy security.

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