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KƏRİMOV ELGÜN ƏLİKRAM oğlu

SALMANOV CEYHUN NAZİM oğlu

ANALYSİS OF WASTE-ENERGY POLICY IN DIFFERENT COUNTRIES; PRACTICES AND IMPLICATION FOR SUSTAINABLE DEVELOPMENT

mövzusunda

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CONTENT

INTRODUCTION

As we know, the increase in the number of people in today's world and the excessive consumption of energy, whether by humans or by man-made devices, become a global problem for us. Therefore, in order to prevent this consumption, countries have to invest in alternative energy sources. It is possible to show wind energy, solar energy, wave energy, nuclear energy and waste energy as examples. So, which of these alternative energies are the most promising and which are the sources that scientists plan to generate the most energy from, especially in developed countries?

Concurrently, qualitative dimensions emerge from our comparative case studies, involving interviews with policymakers, industry experts, and stakeholders. Early findings suggest that the success or challenges faced by each country extend beyond technological choices, encompassing socio-economic factors, political will, and community engagement.

Environmental scrutiny adds another layer, revealing divergent approaches to air and water quality, greenhouse gas emissions, and overall environmental sustainability. These initial insights emphasize the necessity for a nuanced approach that considers both positive and negative environmental impacts in waste-to-energy initiatives.

The preliminary analysis underscores that waste-to-energy policies are intrinsically linked with socio-economic dynamics and regulatory frameworks. This foundational exploration lays the groundwork for a comprehensive understanding of global waste-to-energy policies, preparing us for a more intricate examination of each country's distinct approach in subsequent phases of our study.

The actuality of the subject. Urbanization and spending on consumer good sincreases, more solid waste is generated. Therefore the amount of solid waste has increased in the last century. At present, 3 million tons of production waste are produced in the world every day. By 2025, its number is expected to double. A lot of money is spent on solid waste management. In greenhouse gas (GHG) emissions, air and odor with increasing solid waste in landfills pollution, soil and water pollution occur**.** There are almost 20 developed countries in our world. Some of them have made energy sources, which we call alternative energy, their priorities. As many as 134 countries (65%) generate most of their electricity from fossil fuels, 66 countries (31%) from renewable energy sources.

Statistically China leads the way by generating 90% of their electricity (13.3 exajoules) by renewable energy in 2022. When it comes to getting energy from waste, things are a little different. Statistically, the countries that get the most energy from waste are Japan, South Korea and Northern European countries. Waste-to-energy technology has attracted the attention of almost all Asian countries and they continue to develop further.

But there are some countries that have the technology to convert almost 52% of their waste into energy. It is possible to show Sweden as an example. This country continues to hold the 1st place in the world in energy production from waste.

Purpose of the study. World studies and every analysis, summarizing research and experience, based on optimal methods and technologies and applying them to the realities of Azerbaijan.

The research explores the various approaches countries take in turning waste into energy, looking at different technologies like burning, digestion, and new ways of converting trash into power.

Subject and object of research. To analyze the waste management methods, technologies and policies of the developed countries, as a result of the analysis, to put forward major projects in our country and advance in the field of energy procurement from waste. To achieve world-scale and important goals by further developing the waste energy policy in Azerbaijan**.**Applying and evaluate and compare waste-to-energy policies globally, identifying strengths, weaknesses, and best practices to inform the development of more effective and sustainable approaches. Improvement of waste-to-energy policies, fostering global collaboration and influencing practical advancements in waste management practices.

Scientific innovation. Recognizing the significance of practical experiences, the study engages in structured conversations with world experience and statistical data, experts, policymakers, and individuals actively involved in waste-to-energy practices in various countries. These qualitative insights contribute a human element to the research, providing a deeper understanding of the complexities and challenges associated with policy implementation.

In order for the waste energy policy in Azerbaijan to reach the desired limits, it is planned to eliminate the differences and ensure the use of more modern and effective technology by comparing it with the countries of the world. Environmental impact assessment is a critical component of the study, involving the scrutiny of air and water quality, evaluation of greenhouse gas emissions, and an overall assessment of sustainability resulting from waste-to-energy technologies. Data sourced from environmental agencies and research institutions play a pivotal role in this evaluative process.

Based on the implementation of this project, one of the main plans is to minimize the damage to the environment and immediately eliminate the damage. For this purpose, it is desirable to develop and apply special constructions, to improve the replacement devices.

Practical significance. In this research methodology, undertakes a comprehensive exploration of waste-to-energy policies across a spectrum of countries, employing a methodology that integrates rigorous data analysis with real-world insights.

Commencing with an extensive review of diverse sources—ranging from academic papers to government reports and expert writings—the study aims to unearth existing knowledge and identify gaps in understanding waste-to-energy policies. This foundational step provides a robust theoretical framework, ensuring a nuanced perspective on the subject.

Transitioning to the quantitative phase, the study focuses on a meticulous analysis of data related to energy extraction from waste and success rates in diverting trash from landfills. This involves a thorough examination of databases from environmental and energy agencies, applying statistical methods to discern patterns and correlations across different policy frameworks.

Structure and scope of work. Dissertation work is **52** pages, consists of introduction, **2** chapters, conclusion, summary and list of used literature.

Research methods. In this work, it is planned to compare the waste-energy policy of developed countries with the waste-energy policy of our country. This research is to strengthen our country's sustainable waste to energy policy, explore more efficient technologies, and help protect the environment from harmful waste and create possible waste-to-energy plants, mostly in our liberated territories. Shifting focus to the economic dimensions, the study explores how waste-to-energy policies influence jobs, economic growth, and community well-being. This multifaceted analysis involves dialogue with stakeholders, examination of surveys, and a detailed analysis of economic data to provide a comprehensive understanding of the economic implications. This analysis allows us to closely observe the renewable energy policies of the countries of the world, as well as the policies of purchasing energy from waste, and to understand what is the important role in mutual energy economies. It is the main task of Azerbaijan to take its place in the world economy by increasing the efficiency of renewable energy sources through these observations.

The regulatory landscape governing waste-to-energy initiatives is thoroughly examined through a detailed analysis of policy documents, legal frameworks, and regulations. This exploration aims to unravel the role of policy in shaping and guiding sustainable waste management practices, providing crucial insights into the regulatory environments of different countries.

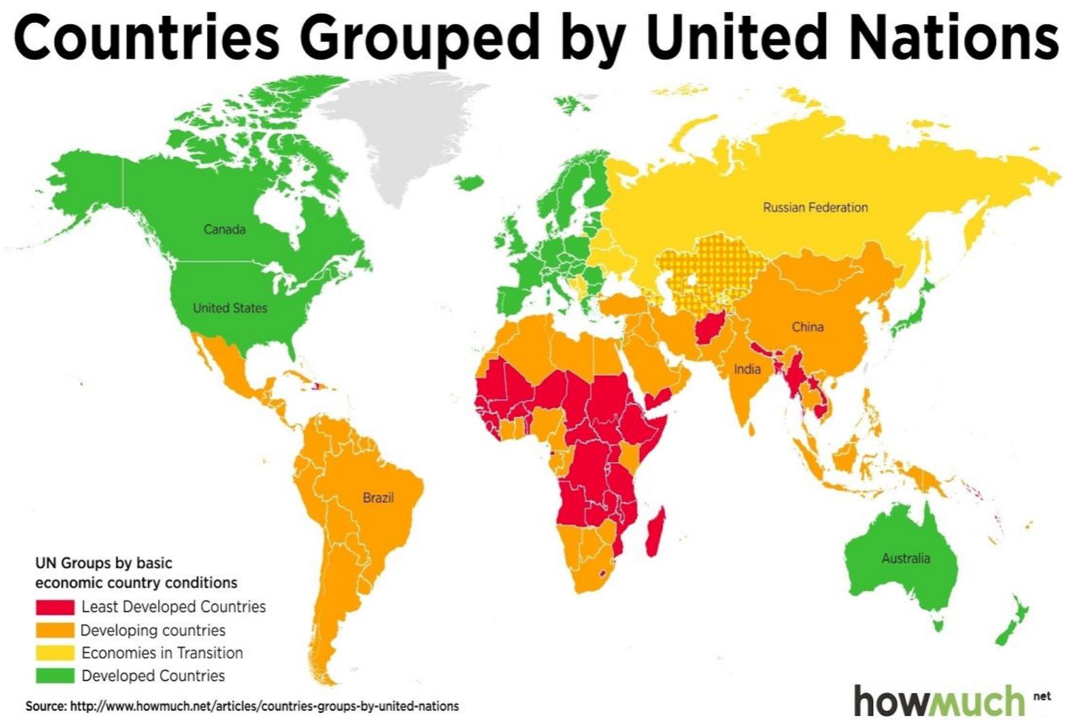
I CHAPTERWASTE TO ENERGY POLICY OF DEVELOPED COUNTRIES

1.1. Developed countries

Figuring out how best to measure the difference between developed and developing countries is difficult. Although gross domestic product (GDP) is one of the most popular values for assessing economic health, a number of other indicators can also be used to see a country's progress.

Perhaps some measurements have the potential to be more accurate than others. The use of neither is inherently wrong. To make things even more complicated, some countries are large, complex entities that cannot be neatly categorized. As a result, many countries exhibit characteristics of more than one category.

According to the UN, 36 countries will be considered developed in 2023. Almost all of the developed countries were located in North America, Europe, and "Developed Asia and the Pacific".



Picture 1.1.Most developed countires to least developed countries shown by colour.

Developed countries often share other advantages:

- Birth and death rates are generally stable. Thanks to quality medical care and high living standards, newborn mortality rates are low, so birth rates are not higher than in underdeveloped countries.
- They use a disproportionate share of the world's resources. More people in developed countries drive cars and can power their homes with electricity and gas. Developing countries often do not have access to the technologies that require the use of these resources.
- They have higher levels of debt. Countries with developing economies cannot afford the kind of crappy financing options that more developed countries can afford.

Azerbaijan is an upper-middle-income country with high levels of economic development and literacy. Like many former Soviet republics, Azerbaijan had difficulty transitioning to a market economy.

1.2. Economy of Azerbaijan. Statistic information

Azerbaijan has rich oil and natural gas reserves. According to BP's June 2021 World Energy Statistical Review, oil reserves of 7 billion barrels (1 Mt) at the end of 2020 represented 0.4% of global reserves. Oil is produced onshore and offshore in the Caspian Sea, with offshore production accounting for about a quarter of the total.

Discovered in the early 1970s, when Azerbaijan was part of the Soviet Union, this reservoir consists of numerous separate reservoirs located in the Caspian Sea at a depth of 2000-3500 meters. The Azerbaijani government and a consortium of 11 foreign oil companies signed the PSA Agreement in Baku in September 1994.

According to BP's 2021 World Energy Statistics Review, Azerbaijan has approximately 2.5 trillion cubic meters of proven natural gas reserves. Although Azerbaijan is not as prominent in global gas as it is in oil, it is expected that gas production will continue to make a significant contribution to gas production. economy in the coming decades(Hulgaard T. & Vehlow J. (2011)).

The country's energy mix is largely concentrated in fossil fuels, with oil and gas accounting for more than 98% of the total supply. Although security of supply is not a concern, over-reliance on fossil fuels increases GHG emissions and exposes the country to the risks of fuel price fluctuations. In addition, while aging natural gas networks have been significantly modernized with new compressor stations and supporting infrastructure, distribution system losses and the quality of gas supply is a concern. Natural gas dominates electricity production (90%), and large hydropower plants produce 4%. In the decade 2007-2017, the security of electricity supply was improved by modernizing the generation system and strengthening the west-east transmission network; additional gas-fired generation capacity has reduced the frequency of power outages, and hydropower projects have also reduced shortages. As resource-related incomes accelerate the growth of the middle class, demand for electricity has increased, necessitating additional capacity additions.

Azerbaijan's renewable energy potential promises many advantages for the country. Greater dependence on renewable energy allows Azerbaijan to save natural gas for export and use in the petrochemical industry. Reduce the country's GHG emissions to meet its commitment under the 2030 Paris Agreement; and improving electricity security through diversification of production. As part of planned energy market reforms, the government has drafted a renewable electricity bill and aims to provide 30% of electricity generation capacity from renewable energy by 2030, up from 16% in 2018.

In addition, in May 2021, the Law "On the use of renewable energy sources in the production of electricity" was adopted, which provides a legal basis for the development of renewable energy projects in the country. The law envisages the introduction of auctions and tenders as support mechanisms and includes drafts of other legislative instruments such as PPAs and connection agreements.

Oil pipelines connect Azerbaijan not only with its neighbors, but also with European and world markets. Three main pipelines belonging to SOCAR pass through the country. Oil is transported safely through these pipelines (Huseynov[1], A., Abbasov[1], E., Salamov, O., & Salmanova, F. (2015)).

1.3. Types and management of waste

Different sources of waste are identified by recognizing the types of waste.

Solid waste: These are excess substances thrown away by human society. These include municipal waste, industrial waste, agricultural waste, biomedical waste and radioactive waste.

Liquid waste: Refers to the waste generated during the washing of industrial enterprises or during the production process.

Gaseous wastes: These wastes include gaseous wastes from cars, factories or burning fossil fuels such as oil. By mixing with other gases in the atmosphere, they can sometimes cause phenomena such as fog and acid rain and cause serious damage to the environment.

Medical or clinical waste: These wastes produced from healthcare facilities such as hospitals, clinics, surgical theatres, veterinary hospitals and laboratories are called medical or clinical wastes. This includes surgical instruments, medicines, blood, body parts, dressing materials, needles and syringes.

Agricultural waste: These wastes are generated as a result of agricultural activities and horticulture, animal husbandry, market gardens. Waste from this source includes empty pesticide containers, old silage husks, expired drugs and worms, used tires, excess milk and etc.

Industrial Waste: These include waste from manufacturing and processing industries such as chemical plants, cement factories, power plants, textile industry, food processing industry, oil industry. These industries produce various types of waste products that are hazardous to the environment.

A waste management system is a system created to simplify what organizations use to eliminate, reduce, reuse and prevent waste. Also known as waste disposal, it is an approach in which companies implement comprehensive strategies to effectively manage waste from its origin to its final disposal. Possible waste disposal methods include recycling, incineration, landfills, bioremediation, waste-to-energy and waste minimization.

Picture 1.2. Waste Management Service

Almost all waste management strategies and methods exist. Modern waste management strategies focus on sustainability. Other alternative methods for waste disposal are waste reduction, reuse and recycling.

Recycling also known as physical recycling, recycling is a method used to dispose of inorganic waste such as plastics, glass and metals. Although organic waste such as paper and food can also be recycled, composting would be a better waste disposal method as it turns organic waste into nutrient-rich fertilizer.

Waste to Energy or WtE, on the other hand, is where non-recyclable waste can be converted into heat, electricity or fuel using renewable energy sources such as anaerobic digestion and plasma gasification.

Anaerobic digestion is the process of biological recycling of animal manure and human waste into methane-rich biogas. Plasma gasification uses a plasma-filled vessel operating at high temperatures and low oxygen levels to convert hazardous waste into syngases.

Thermal treatment is used in the application of heat for cleaning and decomposition of waste materials in different approaches. Open burning is one of the main methods of treatment of waste heat, but it is not considered to be a very environmentally friendly process. No pollution control device deals with open burning, which can cause pollutants to cause critical damage to the environment. This method is used in most countries as it provides a cheaper solution for solid waste treatment.

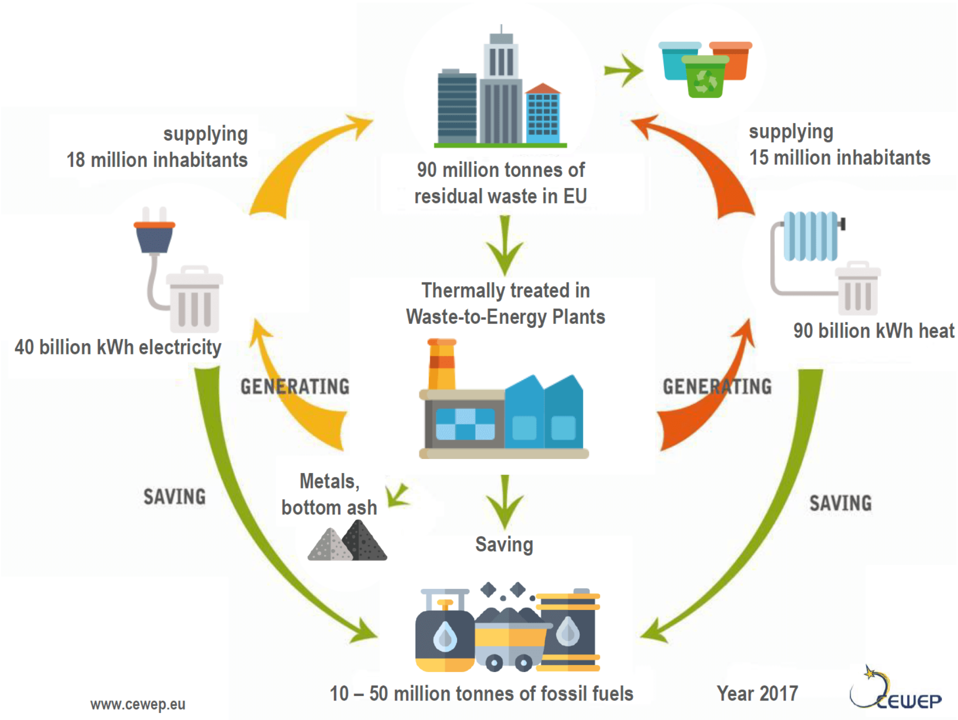
1.4. Plants and countries

For decades, Japan, South Korea, Sweden, Finland, Great Britain and other wealthy countries have turned to incineration and other methods to deal with growing consumer and industrial waste. More than 1,000 incinerators in Japan and more than 500 in European countries such as Germany, Sweden, and Denmark burn thousands of tons of household waste every year, generating 6.3 gigawatts of energy in Japan and 11.2 GW in Europe. .

Although there have been problems with dioxin and other heavy metal pollution from incinerators in the past, advances in pollution control technology have somewhat reduced these concerns.

Proponents of waste-to-energy, an industry group based mainly in European countries, Waste-to-Energy Technology Suppliers, say the technology has improved in recent decades, making it cleaner and more renewable. For Southeast Asian countries, it could be a useful tool in combating rising consumer waste, advocates say.

However, opponents say the Southeast Asian landscape of waste incineration, where the waste sector remains largely an informal industry, pollution controls are lax, and there are almost no systems in place to monitor the combustion products of dioxins and other highly toxic chemicals.



Picture 1.3. European WtE Plant

Globally, it is estimated that 2.24 billion tons of waste were generated in 2020, a figure expected to rise to 2.88 billion tons by 2050[29]. This leads to pollution of our environment and serious risks to the health of some of the world's most vulnerable people. Disposing of this abundant waste responsibly while striving for environmental sustainability is a growing challenge. These innovative devices are key to turning waste into valuable resources and generating electricity and heat while minimizing environmental impact. As demand for safe waste management and sustainable energy solutions grows, Waste-to-Energy plants provide an efficient and environmentally conscious means of progress.

This refers to non-recyclable, household solid waste. This is waste generated from households, offices and other small businesses that is not sorted for recycling, composting or other specific waste streams and is collected separately as residual waste. The composition may vary according to local regulations and procedures, as well as individual habits, but in general, a mixed household waste bin may contain the following items:

Non-recyclable or difficult-to-recycle plastics such as composite materials, laminates and certain types of plastic films; multi-layer packaging materials that cannot be easily separated for recycling; soft plastics such as plastic bags, wrappers and packaging materials that are not accepted in conventional plastic recycling or are lightweight and non-biodegradable, such as foam cores and airbags and styrofoam commonly used in packaging and disposable containers; rubber gloves, disposable knives made of non-recyclable plastic; metal or plastic-coated paper, non-recyclable wrapping paper, etc.

1.5. Waste to energy policy

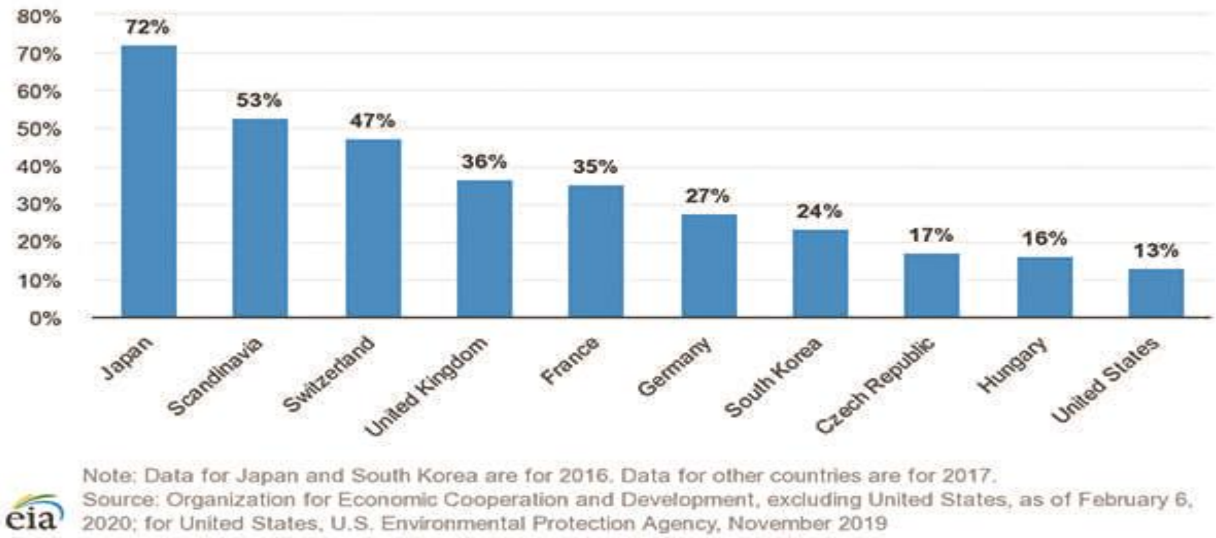
Addressing global imperatives for enhanced waste management and sustainable energy, this examination meticulously explores how countries worldwide approach the conversion of waste into energy. The primary goal is to closely assess the effectiveness of these policies across diverse social, economic, and environmental contexts. With population growth and increased industrial activity worldwide, innovative approaches are essential to manage rising waste levels while meeting growing energy needs.

Commencing the analysis of waste-to-energy policies across diverse countries reveals a mosaic of methodologies and challenges. Our preliminary investigation involves an in-depth review of scholarly works, governmental reports, and expert perspectives. This foundational step provides a theoretical framework, elucidating historical contexts and nuanced trends that shape global waste-to-energy policies.

Supplementing this academic review is a quantitative analysis, wherein we scrutinize data concerning energy output, waste diversion rates, and other pertinent metrics. Early observations underscore variations in energy generation and disposal methods, contributing to initial comparative insights.

Concurrently, qualitative dimensions emerge from our comparative case studies, involving interviews with policymakers, industry experts, and stakeholders. Early findings suggest that the success or challenges faced by each country extend beyond technological choices, encompassing socio-economic factors, political will, and community engagement.

Table 1.1. Most energy producing countries in 2016-2020



Daily waste production per capita is expected to increase by 40% and 19% in developing countries and developed countries, respectively, by 2050. At the World Bank, total waste generation is predicted to triple in Sub-Saharan Africa and double in South Asia by 2050. These statistics show the rates of waste for energy production in developing countries and the world, focusing on Sub-Saharan Africa and South Asia. Sub-Saharan Africa is the one of the promising land that locates in Africa Region.

Greenhouse gas emissions from various sectors, including electricity generation, are one of the vital barriers to sustainable development. Even renewable energy such as hydropower is an example of this. Electricity generation from fossil fuels is known to be a significant contributor to global greenhouse gas emissions, higher than some renewable sources. In Bangladesh, gas and oil-fired power plants with efficiencies of about 24% and 15% were found to have carbon intensities of 930 and 1750 gCO2-e/kWh. A carbon intensity of only about 179 gCO2-e/kWh was found for the New Zealand electricity generation system; because the electricity system is dominated by renewable energy, including hydro (56%), geothermal (18%) and wind (9%).

Average waste generation for various small island developing states in the Caribbean, Pacific, Atlantic, Indian Ocean, Mediterranean and South China is about 1.35 kg per day, compared to 1.45 for OECD countries. In developing countries, organic materials (45%) and recyclables (42%) predominated in the waste composition, respectively. A recent study found mass incineration to be the best option in Pacific Island Developing States (PSIDS), followed by "hybrid mechano-biologically treated anaerobic digestion and combustion of waste-derived fuels." Although their findings indicated that incineration was the most appropriate option in these countries, the waste was dominated by organic components that are more suitable for anaerobic digestion. This is the opposite situation in India, where biodegradable waste constitutes about 51% of other total waste and AD has been found to be most suitable with incineration, gasification and gas recovery compared to landfill.

Table 1.2. Waste to energy statistics for small island countries.

	Redang	Tioman	Pangkor	Langkawi
Size (km^2)	10.7	131	8	478.5
Population	1,400	3,400	26,000	79,000
Waste generated (metric ton/day)	2.7	6.95	13	85
Waste generation rate (kg per person per day)	0.86	0.87	0.48	1.08

Source: Agamuthu, Nagendran (2010)

1.6. Discussion and Policy Implications

In most developing countries, food and green waste ranges between 51% and 61%. The increase in organic waste is inversely related to the country's economic development. Only 21% of the waste generated in the developing world can be recycled. In contrast, around 55% of waste in the developed world can be recycled. Collection of waste for production and processing opens the way for developed and developing countries to differ from each other. Waste collection rates for upper-middle-income countries in high-income countries range from 82% to 96%.

In developing countries, it ranges from 39% to 51%. The process of waste collection and disposal or recycling also depends on the country's GDP per capita. That is, there is a general relationship between GDP per capita and waste collection and disposal standards[33].

In South Asia, about three-quarters of waste is dumped openly; About 44% of this is collected through the door-to-door system and about 57% of the waste is separated as organic waste, which is food and other waste. Similarly, in sub-Saharan Africa, approximately 66% of waste is dumped openly. About 40% of the waste generated is organic, while total waste collection is about 44%.

Regarding the waste composition for the selected countries in Sub-Saharan Africa, with the exception of Burkina Faso, Mali and Senegal, their total waste contains 35-87.50% organic waste. On average, the organic component is about 48.70%. On the other hand, the organic component of total waste in South Asian countries ranges from 24% to 80.58% with an average of about 51.16%. The Maldives alone has 26% organic waste.

In many countries, waste-to-energy recovery is an important element of the waste management system. Thus, according to the Confederation of European Waste-to-Energy Plants, the share of waste incinerated for energy production in 2018 was 28% on average in European countries[34]. Among the leaders in the field of energy from waste, countries known for their high environmental responsibility are Finland (57%), Sweden (53%), Denmark (51%).

Landfilling is one of the main methods of waste management in Russia: 94% of solid household waste is landfilled today. However, in the coming years, serious reforms will be carried out in the waste management system.

Currently, wood processing and pulp-paper agro-industrial enterprises operate their own waste-based energy sources, producing electricity, steam and hot water from wood waste: plywood, wood chips, bark, sawdust, etc. Another area with important prospects in the field of energy recycling of industrial waste is agro-industrial production. Sunflower husks, rice husks, corn husks, straw - all these wastes generated during the collection and processing of agricultural products can be fuel for your own thermal power plant or waste boiler, providing up to 98.5% of the energy demand.

It has been observed in the public consciousness that the burning of waste releases toxic substances into the atmosphere, their accumulation and creates a danger to human health.

In fact, thermal power plants using RDF fuel do not burn landfill waste, but are part of the entire waste management system, whose first and foremost link is waste sorting. At this stage, all waste that can release toxic substances during combustion is separated.

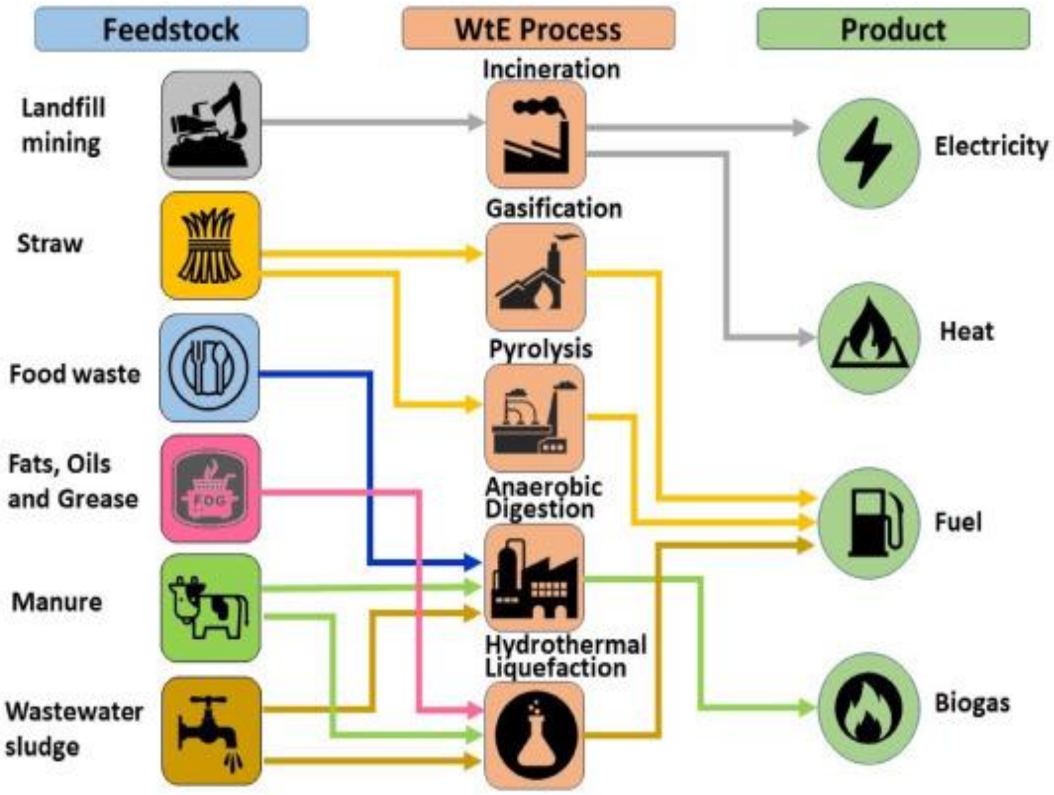
Ideally, RDF fuel contains metals, glass, and modern automation and control systems that ensure equipment operation and constant monitoring of the composition of combustion products.

According to CEWEP, between 1990 and 2000, dioxin emissions from waste treatment plants in Germany fell from 500 g to less than 0.5 g per year, while the amount of thermally treated waste more than doubled over the same period.

1.7. Waste-energy technologies

Waste-to-Energy Technologies provides a brief overview of available technologies. Each mentioned technology has its own advantages, disadvantages and areas of application. These technologies are used to significantly reduce the discharge of waste to open areas, such as thermal treatment of domestic or industrial waste and sludge, medical or industrial hazardous waste. This generated energy output is seen as a new source of income with economic benefits for the local community and environmental benefits in cleaner air, water and soil.

Waste-to-energy projects are extremely complex and expensive to build. Most investors are driven by economic interestsfinancial incentives, renewable identification numbers, tax credits, etc. with. In addition to other economic streams, waste-to-energy projects typically require high fees. It is the money that the garbage hauler has to pay to dispose of the garbagein the facility.



Picture 1.4. Types and sources of waste

- **Liquefied Bed Technology.**

  Liquefied bed is one of the main technologies for converting waste to energy. There are static or circulating types of bed. The technology is mainly used for sludge or solid waste treatment. It has high processing efficiency and low residual values. Fluidized bed technology always involves energy recovery and flue gas cleaning. The pollution level of flue gases is much lower than the legal requirements.

- **Rotary Kiln.**

  It is used in the processing of hazardous, medical, biological and industrial waste. Higher temperatures allow the complete destruction of viruses and microbes to be controlled, while low oxygen uptake ensures low emission values.

  Rotary kilns are also used in the cement industry. The scarcity and depletion of fossil fuels as well as the management of gaseous emissions and fine particles in the atmosphere is one of the main real problems facing rotary kilns, especially those involved in cement production.

- **Gasification.**

  It is also a popular technology with a long history in the market. However, it is not as widely used as the grilling process due to various problems such as oxidation of hydrocarbons, high $CO2$ production, formation of pollutants during gasification, and low calorific value of the produced synthesis gas.

  Gasification is a thermal WtE method that is considered a better alternative to incineration because its product is purified before use. In other words, gasification waste-to-energy plants produce less pollution than other incineration plants.

  In gasification, household waste is used as raw material, not as fuel. This process produces syngas, which is used as an alternative to natural gas and as a fertilizer fuel. It should be noted that most gasification plants require careful sorting and pretreatment of household waste, as not all materials may be suitable for gasification.

The advantage of this process is that non-recyclable plastics can be used here without releasing harmful air pollutants. The newest development in gasification is the plasma gasification or plasma arc gasification process.

- **Plasma Arc Gasification**

Technologists use plasma arc gasification to process and dispose of a special group of waste: a very dangerous and radioactive process. It is very expensive, consumes a lot of energy for the process and presents several problems. The low level of net energy is much higher than energy efficiency. A high temperature of 9600°C is good for hazardous waste processing, but poses management problems.

Plasma gasification uses a plasma torch at an extremely high temperature of approximately 5000°C to 7000°C in a reactor to transform the feedstock into a reactor[5-6]. As a result of the plasma burning of syngas, the breakdown of molecules and the change in chemical composition is also called plasma pyrolysis.

The resulting syngas is not only used as fuel and is cleaned before use, and plasma gasification produces valuable by-products. The glass-like byproduct of the process, the slag left over from the molten waste of plasma forging, is safe to use as a building material. Plasma torches have been used in the past to destroy toxic waste and chemical weapons.

The downside here is that dioxins are still released as the syngas cools. However, compared to dioxins produced in traditional incineration plants, they are much less. Needless to say, future sustainable waste management technologies are headed in this direction because it is both efficient and less polluting.

- **Pyrolysis**

The application of the pyrolysis process to waste has started relatively recently. The technology has many advantages, such as minimal oxidation of waste, no production of pollutants, high level of synthetic gas production, and clean gas production. It seems to be the most ecologically clean, simple and modular modern technology of waste disposal. The only problem is that since it is a new technology, it is not well known in the market.

WTEI pays special attention to this technology and tries to apply it in every new project. WTEI has an agreement with the owner to market and sell this patented pyrolysis technology in various regions of the world, including Europe.

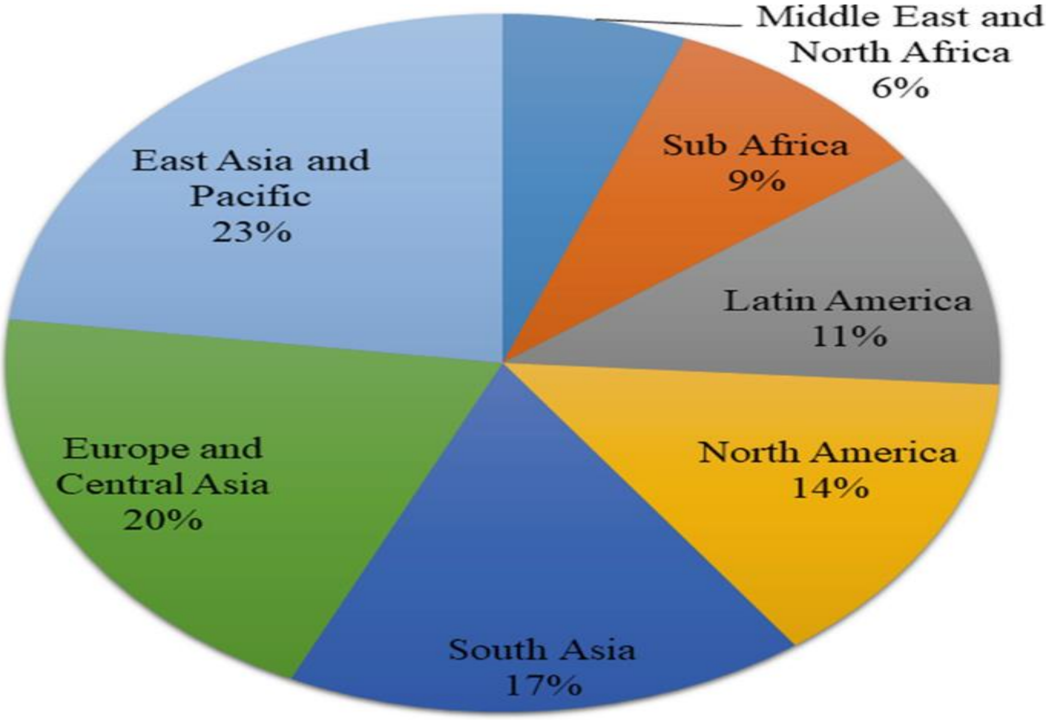
Dendroliquid energy (DLE) is probably the most promising and almost zero-emission waste-to-energy technology that biologically treats waste. DLE units operate at an average temperature of 150°C to 250°C, making them approximately four times more efficient at producing electricity than anaerobic digestion and other WtE solutions.

`Dendro liquid power plants work with both wet and dry waste to create clean fuels for electricity, such as hydrogen and carbon monoxide. Moreover, DLE is more economical than other technologies because there is no combustion in the process, which means that there is no need for expensive anti-emission technology to be environmentally safe.

Some of the main advantages of DLE are that it has high energy conversion with efficiency close to 80% and near zero emissions. Low operating costs make it perfect for a variety of municipalities, usable and efficient. Waste-to-energy engineering will enable increased access to DLE by 2030.

The potential of waste-to-energy technology is clear, although there are some issues that we cannot ignore if we look closely[17]. Some major criticisms have been leveled at WtE efforts by the global zero-waste movement.

These are mainly the harmful by-products of WtE projects, the fact that waste is a non-renewable energy source, the questionable efficiency of WtE facilities, and the fear that waste-to-energy technologies will decrease.



Picture 1.5. Most WtE technology using regions

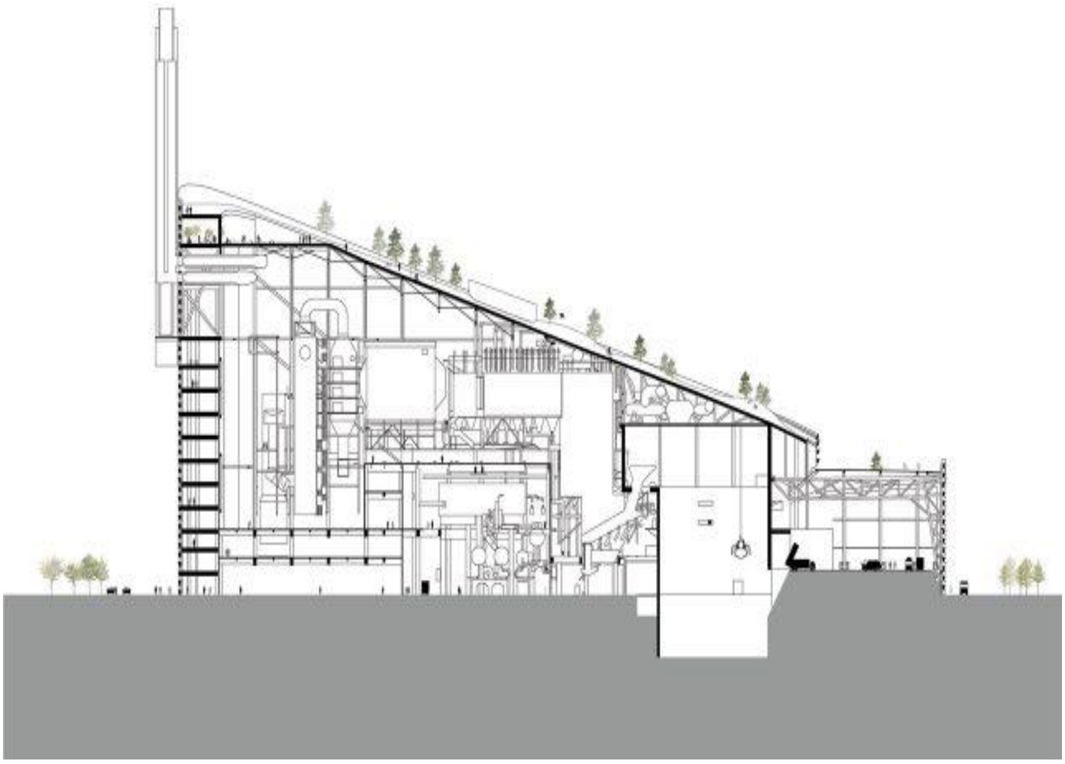
Currently, 1.3 billion tons of Solid Household Waste are generated in the world every year. By 2025, the world may produce 2.2 billion tons of Solid Household Waste per year. Such a prediction forces us to consider and develop alternatives to solve future waste management problems.

The solution to this problem is to divert waste from landfills to energy production, improving waste-to-energy technologies that will help facilitate waste management programs. Unfortunately, waste-to-energy practices are underutilized and therefore most of the world still uses landfills as the primary disposal method.

Perhaps the two most prominent countries that have played a major role in sustainable waste management infrastructure by incorporating waste-to-energy technologies are Sweden and Denmark. Sweden recycles more than 99% of MSW, 50.3% of all household waste is incinerated for energy recovery and 16% is used in. Similarly, Denmark has adopted the idea of "hedonistic sustainability"[18]. Here, infrastructure that contributes to building an ecologically and socially responsible society becomes a dynamic and usable public space. As an example, Copenhagen's recent projects include a ski slope and an incinerator that functions as a WTE education center for citizens. Only 3% of Copenhagen's garbage is thrown away. 54% is sent to incineration plants and used there to generate heat and electricity.97% of all urban residents receive their energy as excess heat produced by waste incineration plants.

In South Asia, about three-quarters of waste is dumped openly; About 44% of this is collected through the door-to-door system and about 57% of the waste is separated as organic waste, which is food and other waste. Similarly, in sub-Saharan Africa, approximately 66% of waste is dumped openly. About 40% of the waste generated is organic, while total waste collection is about 44%.

Baku's waste-to-energy policy is not just a project; it is a paradigm shift towards a greener, more sustainable future. It exemplifies how a commitment to sustainability and public good can turn strategic challenges into opportunities for environmental improvement and social progress. As cities around the world grapple with similar challenges, Baku's journey from "City of Smoke" to beacon of green innovation offers hope and inspiration.



Picture 1.6. WtE plant in Denmark.

Supplementing this academic review is a quantitative analysis, wherein we scrutinize data concerning energy output, waste diversion rates, and other pertinent metrics. Early observations underscore variations in energy generation and disposal methods, contributing to initial comparative insights.

Concurrently, qualitative dimensions emerge from our comparative case studies, involving interviews with policymakers, industry experts, and stakeholders. Early findings suggest that the success or challenges faced by each country extend beyond technological choices, encompassing socio-economic factors, political will, and community engagement.

II CHAPTER. WASTE TO ENERGY POLICY IN AZERBAIJAN

2.1. Renewable energy policy in Azerbaijan

Azerbaijan is one of the candidate countries to be among the leading countries in terms of renewable energy sources. Thus, the technical potential of our country's land-based renewable energy sources is approximately 135 GW, and 155 GW in the sea. The economic potential of renewable energy sources is 27 GW, including 3000 MW of wind energy, 23000 MW of solar energy, 380 MW of bioenergy potential, 520 MW of mountain rivers.

Despite being rich in energy resources and known as an energy exporter in the world, the use of renewable energy sources in the Republic of Azerbaijan is constantly developing. One of the main goals of the energy policy under the leadership of President of the Republic of Azerbaijan Mr. Ilham Aliyev is the strengthening and continuous development of the use of renewable energy sources in the country.

By the Decree No. 1159 of the President of the Republic of Azerbaijan dated September 22, 2020, the Agency for Renewable Energy Sources of Azerbaijan was established under the Ministry of Energy of the Republic of Azerbaijan[1].

Appropriate laws and normative legal acts have been adopted in our country for the purpose of development of the renewable energy sector, legislation in this area, as well as improvement of the environment. In recent years, the work carried out in this field has been continued and the development of renewable energy, which has a special contribution to the implementation of the Law No. 339-VIQ dated May 31, 2021 of the Republic of Azerbaijan "On the use of renewable energy sources in the production of electricity", has been approved.

The total electricity production capacity of Azerbaijan is estimated as 8320.8 MW. The capacity of renewable energy power plants, including large HPPs, is 1687.8 MW, which is 20.3% of the total capacity.

Water power 1301.8 MW (35 stations, 24 of which are HEPS), wind power 66.4 MW (8 stations, 3 hybrid), bioenergy power 37.7 MW (2 stations, 1 hybrid), solar power capacity 281.9 MW (13 stations, 3 of them hybrid)[20]. Two hybrid power plants (Gobustan) operate on the basis of 2.85 MW wind, 3.8 MW solar and 0.7 MW bioenergy. TPPs with a total capacity of 39 MW have been put into operation in Nakhchivan MR. Excluding large hydropower plants, the installed capacity of renewable energy sources was 529.3 MW in 2023, accounting for 6.4% of the total electricity generation capacity.

Bioenergy in Azerbaijan involves utilizing organic materials like biomass, biogas, and biofuels for renewable energy production. The country's abundant biomass resources, including agricultural and forestry residues, along with organic waste from various sectors, present ample opportunities for bioenergy generation. Processes such as combustion, gasification, and anaerobic digestion can convert these biomass feedstocks into usable energy forms.

Biogas production through anaerobic digestion offers a sustainable energy source primarily composed of methane and carbon dioxide. This biogas can be used for electricity generation, heating, and cooking, providing an environmentally friendly alternative to traditional fossil fuels.

Waste-to-energy technologies enable the conversion of organic waste into heat, electricity, or biogas, thereby managing waste while simultaneously generating renewable energy. This approach contributes to environmental protection and enhances energy security by reducing reliance on non-renewable energy sources.

Azerbaijan also has potential for biofuel production, including biodiesel and bioethanol, derived from agricultural crops, algae, and waste oils. These biofuels can be blended with conventional fuels or used independently, reducing greenhouse gas emissions and promoting energy independence.

Supportive policies, such as feed-in tariffs and tax incentives, can encourage investment in bioenergy projects and infrastructure. Research institutions and universities play a vital role in advancing bioenergy technologies, improving efficiency, and exploring new feedstock sources through collaborative efforts with international partners.

Environmental benefits of bioenergy include reducing greenhouse gas emissions, mitigating air pollution, and promoting sustainable land use practices. By harnessing renewable organic resources, Azerbaijan can contribute to climate change mitigation and environmental sustainability goals.

In 2023, electricity production in the republic amounted to 29.3 billion kilowatt hours. During the reporting period, the production of electric power in SPPs was 1757.2 million kilowatt hours, compared to other sources, it was close to 359 million kilowatt hours. 56.6 million kilowatt-hours of electricity were produced in CHPs, 79.4 million kilowatt-hours in thermal power plants, and 220 million kilowatt-hours in the solid household waste incineration plant. Electricity produced from renewable energy sources made up 7% of the total production.

Since 2020, cooperation on renewable energy projects has started with Masdar, ACWA Power, bp, Fortescue Future Industries, China Gezhouba Group Overseas Investment and other companies.

On October 26, 2023, the foundation of the 230 MW Garadagh Solar Power Plant was established in cooperation with Masdar (UAE), the largest solar power plant in the Caspian region and the CIS. The plant, which was built with foreign investment worth 262 million US dollars, is the first solar power plant in our country realized with the involvement of foreign investment. The station is expected to save 110 million cubic meters of natural gas by producing 500 million kilowatt-hours of electricity per year. At the same time, carbon emissions into the atmosphere will decrease by 200,000 tons. About 570,000 solar panels have been installed in the power plant covering an area of 550 hectares. In order to connect this station to the grid, a 330-kilovolt substation has also started operating.

Picture 2.1 Foundation of Garadagh SPS

Within the framework of the opening of the Garadagh Solar Power Station, three investment agreements on green energy projects with a total capacity of 1000 MW were signed between the government of Azerbaijan and the UAE company "Masdar"[21]. It is planned to implement YES and 240 MW HPP in Absheron-Garadagh region.

Construction of the 240 MW Khizi-Absheron Wind Power Plant is also planned in cooperation with ACWA Power of Saudi Arabia. On January 13, 2022, the ground-breaking ceremony of the station was held with the participation of the President of the Republic of Azerbaijan Ilham Aliyev. In 2022, drafts of the "Environmental Impact Assessment" and "Interaction Plan with Stakeholders" documents of the Khizi-Absheron Wind Power Plant project were prepared and presented. According to the project, it is planned to be implemented in Absheron-Khizi near Pirakashkul and Sitalchay. Within 2 years from March 2020, 7 measurement-observation stations were built at an altitude of 100 m, and topographic and preliminary geodetic works were carried out.

Waste-to-energy initiatives in Azerbaijan encompass various strategies aimed at extracting energy from waste materials while simultaneously addressing waste management challenges. These methods primarily include landfill gas capture, biogas production through anaerobic digestion, and potentially waste incineration for energy generation.

Landfill gas capture involves the collection and utilization of methane gas emitted during the decomposition of organic waste in landfills. This methane, a potent greenhouse gas, can be harnessed as a renewable energy source for electricity generation or heat production. By capturing methane, not only is a significant greenhouse gas mitigated, but valuable energy is also recovered from what would otherwise be a waste byproduct.

Biogas production via anaerobic digestion is another prominent approach. This process involves the breakdown of organic waste in the absence of oxygen, resulting in the release of biogas composed primarily of methane and carbon dioxide. Biogas can be utilized in various applications, including electricity and heat generation, as well as fuel for transportation. Anaerobic digestion not only provides an energy source but also contributes to waste reduction and odor control in waste management facilities (Abbasov, E. (2015)).

Waste incineration, while less common and often contentious due to environmental concerns, remains a potential method for energy recovery from waste in Azerbaijan. The heat generated can be used to produce steam, which in turn drives turbines to generate electricity. However, this method requires stringent pollution control measures to minimize air emissions and ensure environmental safety.

The successful implementation of waste-to-energy projects in Azerbaijan hinges on several factors, including supportive government policies, regulatory frameworks, and investment in infrastructure. It is crucial to develop comprehensive waste management strategies that prioritize sustainability and environmental stewardship. This involves minimizing the environmental footprint of waste-to-energy processes, including controlling air and water pollution, managing ash disposal, and mitigating greenhouse gas emissions.

In conclusion, waste-to-energy initiatives in Azerbaijan present opportunities to address both waste management and energy needs. By employing a combination of landfill gas capture, biogas production, and potentially waste incineration, Azerbaijan can harness the energy potential of waste while promoting environmental sustainability and resource efficiency.

According to preliminary observations, the total technical potential of wind energy in the Azerbaijani part of the Caspian Sea is estimated as 157 GW. At the same time, the project supports attracting investors to relevant marine projects, establishing partnerships with the private sector, and making necessary investments. Effective use of this phased potential is expected to create opportunities that add value to the country's economy, along with new jobs.

Within the Baku Energy Week held in Shusha on June 4, 2022, between the Ministry of Energy and the UAE company Masdar regarding the assessment, development and implementation of 1 GW utility-scale projects for onshore solar and wind energy in the Republic of Azerbaijan and 2 GW integrated offshore agreement on wind and green hydrogen evaluation, development and implementation.

On December 15, 2022, the Ministry of Energy and Australia's Fortescue Future Industries (FFI) signed a Framework Agreement on joint cooperation on the study and development of renewable energy projects and "green hydrogen" potential in Azerbaijan.

In summary, Azerbaijan's bioenergy sector holds significant potential for sustainable energy production, waste management, and economic development. Strategic policy measures, investments in research and infrastructure, and collaborative partnerships will be crucial in unlocking the full potential of bioenergy to meet the country's energy needs while advancing environmental and socioeconomic objectives.

2.2. WtEplants in Azerbaijan

The construction of the waste-to-energy plant was decided within the framework of the "Comprehensive Action Plan for 2006-2010 Improvement of the Environmental Situation in the Republic of Azerbaijan" approved on December 20, 2006. The French company "CNIM" started to work on the construction of the plant based on the design and "turnkey" principle. The President of the Republic of Azerbaijan Ilham Aliyev laid the foundation of the "Waste to Energy" plant on November 3, 2009 and participated in the opening ceremony of the plant on December 19, 2012.

The plant, built on an area of 20 hectares in Balakhani settlement and with an annual production capacity of 500,000 tons of household waste and approximately 10,000 tons of medical waste, is currently managed by the PAPREC Energy Azerbaijan company. As a result of the waste incineration process, the plant can produce up to 200 million kilowatt hours of electricity per year, and the energy obtained during the year has the capacity to fully supply 100 thousand homes with electricity. It is considered the largest waste-to-energy plant in Eastern Europe and CIS countries. The plant fully complies with local and European standards for environmental protection. The fly ash generated during the burning process is captured by specially designed filters and does not pollute the environment. Bottom ash, which is heavier and less harmful, can be used as construction material for road construction. And finally, the industrial water used for cooling during waste incineration is discharged through sewer pipes only after treatment. Emission level monitoring at the plant is done daily and is under full control.

2.3. The Integrated solid waste management project

The ongoing initiative known as the "Integrated Solid Waste Management" Project is a significant collaborative effort between the World Bank and the Republic of Azerbaijan under the broader umbrella of the "Absheron Ecological Rehabilitation Program.

The genesis of this project traces back to May 20, 2009, marked by the signing of a pivotal loan agreement between Azerbaijan's Minister of Economic Development and the World Bank's representative in Azerbaijan. Since then, concerted efforts have been channeled into five distinct components, each strategically tailored to tackle various facets of the solid waste management landscape.

Beginning with institutional reform and project management, the project endeavors to bolster administrative capacities, foster strategic planning initiatives, and establish and bolster the operational efficiency of "Tamiz Shahar" JSC, the designated waste management entity (Delucchi, M., and Jacobson, M, (2013)).

The rehabilitation and management of the Balakhany landfill constitute another crucial facet of this endeavor. Here, a multifaceted approach is adopted, encompassing environmental impact control, landfill efficiency enhancement, and the infusion of state-of-the-art equipment and technologies such as weigh bridges and bulldozers. Furthermore, preparatory groundwork is underway for the eventual cessation of Balakhany landfill operations, with simultaneous preparations for the establishment of modern, environmentally sustainable alternatives.

Beyond Balakhany, efforts extend to the closure and effective management of other landfills scattered across Baku. This necessitates the meticulous closure and decontamination of unofficial landfills, coupled with upgrades to existing landfill management practices to align with modern standards of environmental stewardship.

A cornerstone of this initiative lies in the provision of cutting-edge equipment for waste collection, with a particular focus on expanding service coverage and enhancing operational efficiency in underserved areas. This entails the procurement of a fleet of lorries and waste trucks to bolster service quality and extend the reach of waste collection services.

Lastly, a critical aspect of the project entails technical groundwork for future investments. This encompasses the execution of comprehensive feasibility studies and rigorous environmental impact assessments, laying the groundwork for the design and establishment of novel landfill facilities and transfer stations. Such preparatory measures are envisioned to optimize waste collection systems and ensure the long-term sustainability and efficacy of waste management endeavors.

In aggregate, these concerted measures are poised to herald a transformative paradigm shift in Azerbaijan's solid waste management landscape, heralding a future marked by enhanced environmental sustainability, improved public health outcomes, and heightened resilience against the perils of indiscriminate waste disposal. With a projected budget totaling $41.5 million over a span of five years, this ambitious undertaking stands as a testament to the unwavering commitment of both the World Bank and the Azerbaijan Government towards fostering a greener, more sustainable future for generations to come.

2.4. The Balakhany project

The Balakhani landfill, founded in 1963, has created a threat to human health and the environment. Waste was simply thrown away a landfill that causes methane emissions from anaerobic waste processing. One of the first work of the Clean City.

Since October 2009, it has been done to improve the management of the site, which has approximately 3 million m³ solid household waste is collected every year. This includes waste covering and leveling works as well as defining operational zones. The current tailings depth of the waste disposal site is approximately 20 m. It could beif necessary, it is increased to 40 m. Energy is mainly produced by fossil fuel power station. It produces CO2emissions from burning fossil fuels. This is expected to continue in the absence of project activity,thus, the initial scenario is the same as the scenario before the implementation of the project.

The project involves the incineration of waste that would otherwise be collected. Production of electricity from waste heat is in Balakhani waste area.

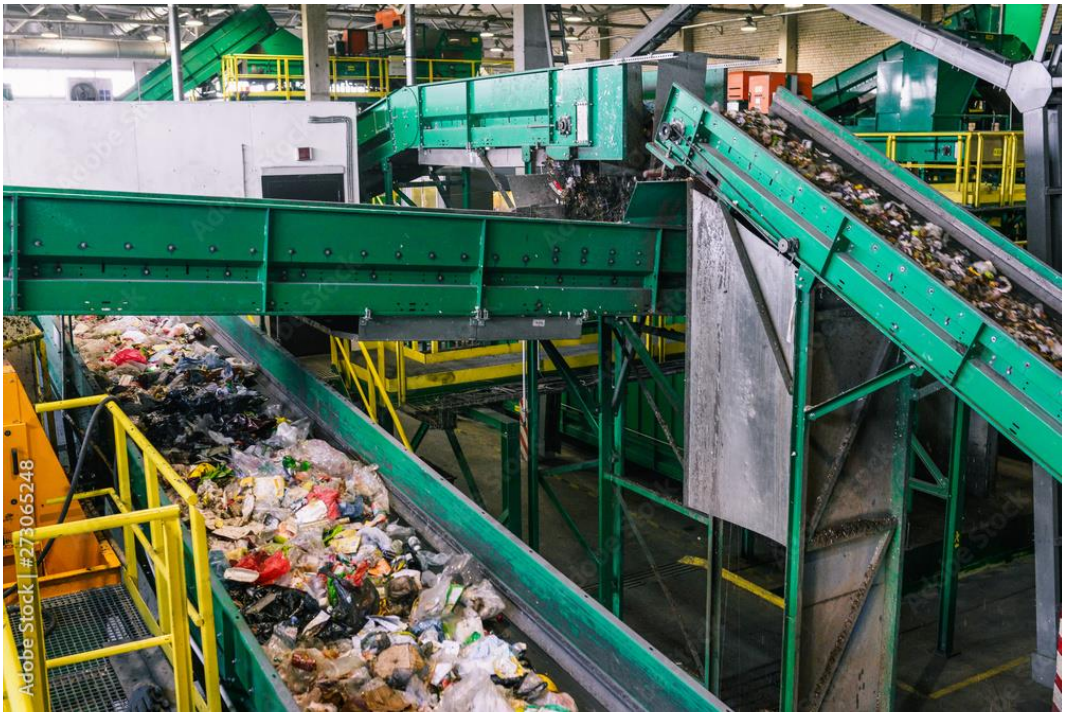
As an additional service, electricity will be exported to the national grid.

An alternative solution to waste reduction was requested by the Cabinet of Ministers dependence on the Balakhani landfill health and environmental hazard risks that the incineration plant will produce approximately 500,000 tons of waste

it makes up more than half of the expected waste in the Baku region every year. It is an incineration plant highly efficient. The plant strictly adheres to environmental protection and safety standards. Factory key the equipment includes grid-type combustors, each with heat recovery boilers, and a 39.5 MW condenser turbogenerator to be driven by steam from all boilers. More equipment includes feeders, flue gas filtration and treatment, electrical substation and control equipment. The plant is conceptualized as two separate waste lines with the addition of a third consisting of a furnace, a boiler and a suitable turbogenerator are required. Each waste line is capable burns about 250,000 tons of waste per year (Hulgaard T. & Vehlow J. (2011)).

The Baku Waste-to-Energy Plant is proof of what can be achieved through joint effort and visionary leadership. With state-of-the-art emission control systems, the facility represents a leap forward in environmental control and sets the benchmark for waste-to-energy operations globally. Its ISO 14001 certification reflects a commitment to environmental management and sustainability, principles that are currently central to Azerbaijan's development agenda.

The project has had a ripple effect, sparking a broader conversation about sustainability and waste management in Azerbaijan and beyond. The introduction of semi-automatic sorting facilities and plans for future waste transfer stations highlight a proactive approach to increasing plant efficiency and effectiveness. Additionally, engagement with international partners such as the World Bank has opened avenues for expanded collaboration and innovation.



Picture 2.2. The Balakhani project

This enterprise with an annual production capacity of 200,000 tons, built for the purpose of developing the domestic waste separation and recycling business in the country, has been operating in trial mode since August. It became fully operational on December 19, 2012.

The material recovery facility was designed by "Aztech Project Construction" LLC. The contractor is "M-Naf" company, and the supplier is "Adelmann" company.

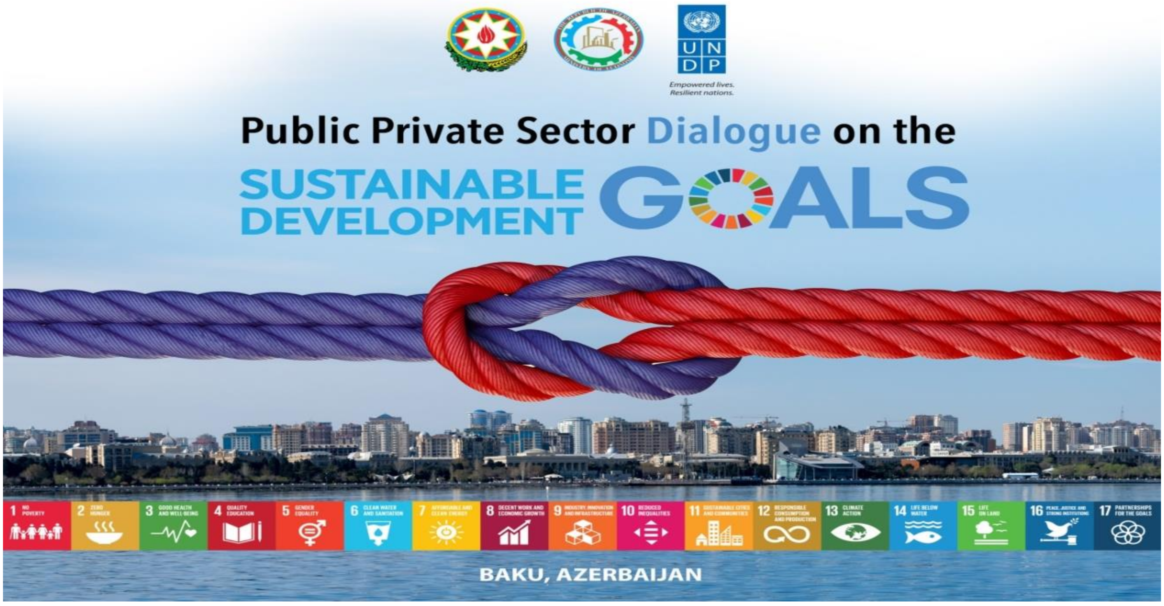
As a result of sorting, paper, glass, plastic, non-ferrous metal, iron and other recyclable materials are separated, and as a result, the total volume of waste is reduced, a cheap raw material market is formed, and the basis for the creation of a recycling industry is created. is created in the country, energy is saved, the negative impact on the environment is reduced. In addition, hazardous waste such as batteries, accumulators and e-waste are separated from general waste and sent to appropriate locations.

2.5. The sustainable development of waste energy in Azerbaijan

The Decree of the President of Azerbaijan dated November 29 on the preparation of the Concept "Azerbaijan 2020: a vision of the future" by 2020 plays a major role in the implementation of the principles of sustainable development. Currently, more than 60 state programs related to social and environmental issues are implemented in the country, where Azerbaijan develops comprehensive strategies for development, sustainable development and environmental protection both in the economy as a whole and in its individual sectors.

The main links between the green economy and the implementation of sustainable consumption and production policy are confirmed in the "Azerbaijan-2020: vision of the future" Development Concept. The long-term goals of the concept include the development of an economic model based on effective state regulation and market relations, ensuring sustainable socio-economic development, improving the structure of the economy, especially transit and logistics, balanced regional development and environmental protection (Safaroff Agency, (2024)).

Management of natural resources in Azerbaijan is carried out on the basis of permits, including permits for discharge of pollutants into the atmosphere, permits for special use of water resources. Careful work based on the timely application of international standards encourages the country's participation in the global market, as well as reducing the burden on the environment and more efficient use of natural resources. Azerbaijan uses the operating permit system approved by the State Ecological Expertise Department of the Ministry of Ecology and Natural Resources. Permits for major projects are also issued based on internationally recognized methodologies and procedures for environmental impact assessment. Currently, environmental criteria are being prepared for products and services produced and sold in the Azerbaijani market. The basis for the development of these criteria is to support the development of environmental criteria for goods and services within the framework of the European Union directives, as well as the United Nations Development Program.



Picture 2.3 Future goals in Azerbaijan for WtE

Possibilities of introducing stimulating measures for the introduction of new technologies aimed at supporting and improving the quality of the environment in Azerbaijan and attracting national and foreign investments are being considered. The state tries to attract attention for international technical assistance to increase the technological capabilities of the national economy and ecological principles. Based on sustainable regional development for 2014-2018, technical maintenance has been prepared taking into account the requirements related to the production and operation of environmentally friendly products in Azerbaijan. At the same time, financial support mechanisms are being developed for organizations producing organic products.

Industrial base created in Azerbaijan to process Caspian oil for the needs of the Soviets The union became completely incompatible with industrial supply during the Soviet era and arrangements collapsed (Robbani, A. (2024)). As a result, the reduction of industrial waste. The improvement of atmospheric air quality in the Baku-Sumgait area, however, left the massive old pollution problem unresolved. The problem of abandoned industrial facilities, their old waste is found in many other parts of Azerbaijan, but not the same scale. Repairs have been carried out on a pilot scale so far the situation did not fundamentally change. Rather, the environment the indicators of the oil production sector have improved direct investments from the Economic Cooperation Organization and developing countries.

Like other energy sources Azerbaijan, which exports to countries of the former Soviet Union, uses its own energy and is relatively inefficient. Using heavy oil for electricity by burning natural gas between generation and general energy-using equipment inefficiencies are the main factors. Air pollution in Azerbaijan has decreased significantly Industrial contraction since 1991 is largely responsible.

What is needed is the promotion of clean manufacturing practices and new regulations is approaching.

In 2022, Azerbaijan experienced a notable increase in waste generation, with 3,984.1 thousand tons produced, marking a 5.4% rise compared to the previous year. A significant portion of this waste, accounting for 66.7%, stemmed from solid domestic sources, while 33.3% originated from the production activities of various enterprises across the country.

Of the 2,658.3 thousand tons of solid domestic waste generated, a substantial 78.3% was transported to landfills for disposal, reflecting the prevailing waste management practices. However, a commendable 21.2% of this waste was utilized for energy production, indicating a growing inclination towards sustainable waste management approaches. Additionally, a marginal 0.5% of the domestic waste was sold within the country, possibly for recycling or other purposes, demonstrating efforts towards resource recovery and circular economy principles (Burns, T. R. (2016)).

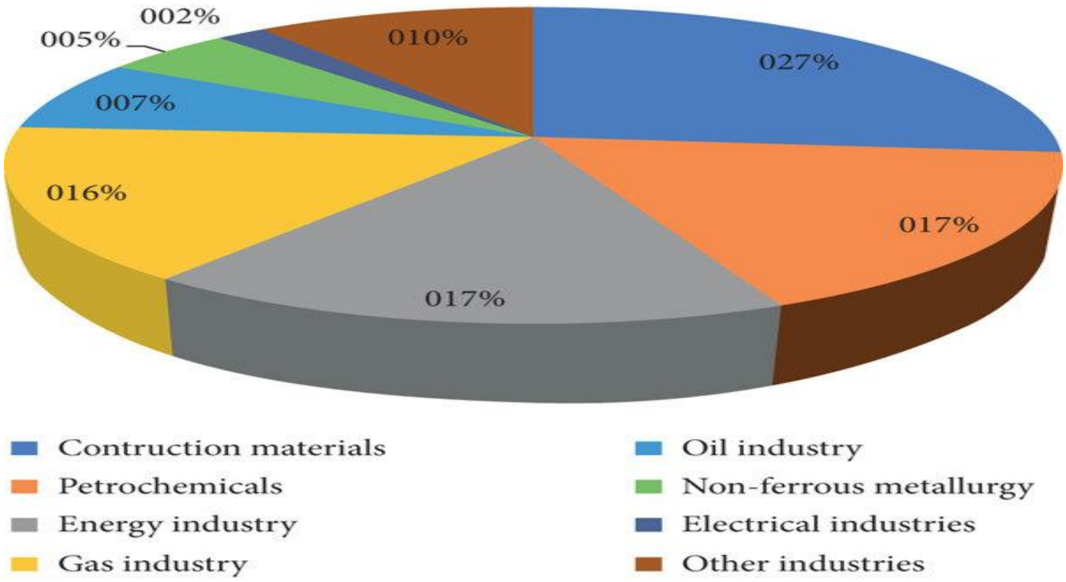
The utilization of solid domestic waste for energy production yielded positive outcomes, contributing to the generation of 205.3 million kWh of electricity, representing a 6.3% increase compared to 2021. This uptick underscores the potential of waste-to-energy technologies in meeting energy demands while concurrently addressing waste management challenges.

Moreover, in industries and other sectors, 28.5% of waste resources were repurposed as raw materials within enterprises, fostering a closed-loop approach to resource utilization. Additionally, 42.7% of waste resources were sold domestically, underscoring the economic value associated with waste materials and the potential for fostering a vibrant secondary materials market. A further 3.8% of waste resources were exported, showcasing Azerbaijan's engagement in international waste trade. However, 13.8% of waste was still directed to landfills for disposal, highlighting the need for continued efforts to optimize waste management practices and minimize landfill reliance.

The production activities of enterprises also generated hazardous waste, amounting to 337.1 thousand tons, constituting 8.5% of the total waste generated. Notably, a substantial portion of this hazardous waste, around 63.1%, originated from mining enterprises, with significant contributions from entities located in the capital city, Baku. Efforts to manage hazardous waste were evident, with 55.0 thousand tons being completely neutralized, including remnants from previous years, emphasizing the importance of effective hazardous waste management measures to mitigate environmental and public health risks.

In summary, the waste landscape in Azerbaijan in 2022 reflects a mix of challenges and opportunities, with efforts underway to enhance waste management practices, promote resource recovery, and address environmental concerns associated with waste generation and disposal. Continued focus on sustainable waste management strategies, innovation in waste-to-energy technologies, and regulatory measures to minimize hazardous waste generation will be critical for advancing Azerbaijan's waste management agenda in the coming years.

Azerbaijan is disproportionately depends on polluted transboundary rivers for his inner needs. The eastern part of Kura-Aras plain is wide irrigated water shortage area. Violation of operation of irrigation systems worsened salinity build-up, which now affects more than a third of all irrigated lands. Reduction of industrial wastewater discharges accompanied by a decrease in industrial output were compensated by reducing municipal waste. Only 16 at most Country Environmental Analysis-Azerbaijan An important 75 cities have sewage treatment plants and most of 16 work only partially. 50-95% of the urban population is provided with drinking water. Depending on city center. After considering water quality, effective provision of safe drinking water falls below 50%. There is an imbalance in water use (and wastewater discharges) between the main there are losses in cities (especially Baku) and the rest of the country and systems high across the board. In weak form with surface waters, it is used more often the country's underground water resources are seen as a necessity (Konstadinos Abeliotis (2011)).



Picture 2.4. Distribution of air pollution by industries

Agricultural productivity in Azerbaijan is very low. The loss of Nagorno-Karabakh increases the feeling of land scarcity in Azerbaijan. The destruction of collective farms caused widespread repercussions for cropping patterns such as pasture use and patterning maintenance of previously common infrastructure. Overall, these changes protected livelihoods deterioration of land use, in particular in mountainous areas where perennials are replaced by annuals. At the same time, the land reform carried out in Azerbaijan is more advanced than all others other FSU country. Former pasture and forest areas were not touched. However, due to reform and some environmental problems found there for land use. Changes in the approach to managing them to assets are needed in new circumstances. He remained under the forests increased pressure due to power supply disruption, coal and gas to smaller settlements and poorly managed pastures.

This ambitious three-year initiative, collaboration between the Government of Azerbaijan and the Islamic Development Bank (IDB), aimed to revolutionize waste management in Baku and usher in a new era of environmental awareness and improved public health. With the construction of the first waste-to-energy plant in the country, Azerbaijan has set a strong precedent by demonstrating its commitment to sustainable development.

The scale and impact of the project was remarkable. As a result of more than 4.8 million man-hours of work, a state-of-the-art facility capable of turning more than 500,000 tons of household waste into 230 GW/h of electricity per year has been created. This not only solved a pressing waste management problem, but also provided a clean energy source that powered more than 50,000 Baku households.

Beyond the statistics, the impact of the project was transformative. Since its establishment, the plant has processed more than 3.2 million tons of household waste (2012-2020), which significantly reduces dependence on landfills. The remarkable achievement of processing and sorting 80% of Baku's household waste exceeds initial goals and complies with strict EU environmental directives.

The success of the project was achieved through a strong partnership that combines local initiatives with international expertise. The collaboration between the Government of Azerbaijan and the IDB is an example of the synergy required for such a ground-breaking endeavor. IDB's participation provided not only financial resources, but also rich knowledge and experience in the implementation of large-scale sustainable projects. This partnership has played an important role in implementing advanced technology and solving problems that meet the highest environmental and health standards.

The Baku Waste-to-Energy Plant is proof of what can be achieved through joint effort and visionary leadership. With state-of-the-art emission control systems, the facility represents a leap forward in environmental control and sets the benchmark for waste-to-energy operations globally. These principles currently occupy a key place in Azerbaijan's development agenda.

The project has had a ripple effect, sparking a broader conversation about sustainability and waste management in Azerbaijan and beyond. The introduction of semi-automatic sorting facilities and the principle of future waste-to-energy production, the plans of these plants play a decisive role in increasing the efficiency and effectiveness of the plant. Additionally, engagement with international partners such as the World Bank has opened avenues for expanded collaboration and innovation.

Baku's waste-to-energy policy is not just a project; this is one important step towards a greener, more sustainable future (Mavropoulos, Alexandros (2012)). It exemplifies how strategic partnerships guided by a commitment to sustainability and public good can turn challenges into opportunities for environmental rejuvenation and social progress. As cities around the world grapple with similar challenges, Baku's journey from "City of Smoke" to beacon of green innovation offers hope and inspiration.

2.6. Renewable energy in Azerbaijan’s Liberated Zones

One of the main directions in the course of the economic development of the territories liberated from occupation by the President of the Republic of Azerbaijan Ilham Aliyev was defined as projects for renewable energy sources in the territories liberated from occupation. The President of the Republic of Azerbaijan, Ilham Aliyev, put forward a strategic view on the creation of a Green Energy Zone in the liberated territories and stated that the liberated territories have sufficient renewable energy potential.

According to the Decree of the President of the Republic of Azerbaijan dated May 3, 2021 on the measures related to the creation of renewable energy zones in the liberated territories of the Republic of Azerbaijan, cooperation with an international consulting company has begun. A relevant concept document was prepared in cooperation with the Japanese company TEPSCO.

The purpose of the concept document is to provide the area with environmentally friendly green energy by using the existing high renewable energy potential in the liberated territories and formulate proposals by studying the prospects of applying environmentally friendly and energy-saving green technologies.

For this purpose, energy demand models were developed using different scenarios in the liberated areas.

Production of electricity from renewable energy sources within the Green Energy Zone, energy efficiency measures, use of electric vehicles, installation of renewable energy objects (especially solar panels) on the roofs of buildings, use of solar energy-based LED lamps in lighting. measures such as the use of renewable energy technologies in the heating, cooling and hot water supply of streets and roads, the application of smart energy management, targeted management of waste energy are envisaged.

At the same time, at the UN Climate Change Conference held in Glasgow on November 26, the Azerbaijani goverment declared its intention to reduce greenhouse gas emissions by 40% compared to the base year by 2050 and create a "net zero emission" zone. in liberated areas. This, in turn, will contribute to the transformation of freed areas into renewable energy (Miliūtė J., & Staniškis, J. K. 2010).

According to the preliminary observations, the favorable potential for solar energy projects in Gubadli, Zangilan, Jabrayil and Fuzuli regions is expected to be more than 7200 MW. At the same time, according to preliminary studies, the technical potential of wind energy in the amount of 2150 MW was determined in the mountainous areas of Lachin and Kalbajar. In addition, the tributaries of Tartarchay, Hekari River and these rivers have great hydropower potential.

Picture 2.5. Renewable enrgy project in Zangilan/Jabrayil zone

As an important component of the process of rehabilitation of the liberated territories, special importance is attached to the construction of energy infrastructure and ensuring energy security. In accordance with this goal, 4 restored hydropower plants in Lachin, Kalbajar and Sugovushan have already been put into operation as part of the restoration of 20.5 MW power generation capacity:

At the same time, the construction of two hydroelectric power plants with a total capacity of 140 MW (100 MW “Khudafarin”, 40 MW “Giz Galasi”) is being continued for the Azerbaijani side on the Araz River in Jabrayil region.

Also, the introduction of a wind power plant with an estimated capacity of 100 MW in Lachin/Kalbajar will make an additional contribution to the establishment of this zone in the liberated territories (Frost & Sullivan (2011)).

In addition, on June 3, 2021, an agreement was signed between the Ministry of Energy of the Republic of Azerbaijan and bp company on the start of the construction project of a solar power plant with a capacity of 240MW in the Zangilan/Jabrayil zone.

2.7. Combustion Processes and Environmental Protection

Incineration of waste is one of the many public applications of combustion. Combustion is known as an active, exothermic reaction between fuel and oxygen. Combustion applications use waste (although fossil fuels can be co-fired) and oxygen as fuel. Whether the material being burned is natural gas, coal, wood, gasoline, solid waste, or hazardous waste, combustion produces most of the same end products. In the combustor of a quality incinerator, temperatures are high enough to break down all organic and many inorganic molecules, allowing reactions between the most volatile components of the waste and the oxygen atoms and nitrogen. The main reactions are those between carbon and oxygen. Hydrogen also reacts with organically bound chlorine to produce hydrogen chloride. In addition, many other reactions occur that form sulfur compounds from sulfur compounds, nitrogen oxides from nitrogen compounds, metal oxides from some metal compounds, and metals (National Library of Medicine (2024)).

The furnace is designed to ensure good mixing of combustion air and gases and vapors from burning waste. However, in the incomplete combustion parts of the furnace, the combustible components of the organic compounds are burned off, leaving behind noncombustible particles known as fly ash that enter the flue gas. The non-burnable part of the waste is left behind.

Optimal furnace design and operation requires consideration of combustion temperature, combustion gas mixture turbulence, and gas residence time at combustion temperature. In order to achieve effective combustion of mixtures, each part of the gas stream must reach an adequate temperature in the appropriate time and have an adequate mixture of fuel and oxygen.

Several new design features and operating techniques have been adopted to increase temperature, extend residence time, and increase turbulence in waste incinerators to provide other benefits such as improved combustion efficiency and improved ash quality. These include high-efficiency burner systems, waste pretreatment practices such as shredding and mixing, and oxygen enrichment, in addition to the features and methods discussed below. Great attention has also been paid to measuring and controlling the operating conditions of the main process in order to better control the entire combustion process.

In recent years, spray dryers have been used for acid-gas control at municipal solid waste and several larger hazardous waste and medical waste incinerators. The water in the atomized slurry droplets evaporates, the gas cools, and the alkaline particles react with the acid-gas contents to form dry salts. Salts and unreacted alkali should be captured downstream in a fabric filter or electrostatic precipitator. Dry injection scrubbers using an anhydrous alkaline reagent have also been used in recent years, although they are rarely used in municipal waste, hazardous waste, and medical waste incineration plants in Europe and mainly in many areas of the United States. They are usually not as efficient at removing emissions as spray dryer absorbers. Important design and operating criteria for spray desiccant absorbers and dry alkali scrubbers include gas temperature in the reagent contact zone, reagent to acid gas stoichiometry, reagent gas distribution, and reagent type (National Library of Medicine (2024)).

Heavy metals in waste cannot be destroyed by burning. Compounds with high vapor pressure are converted to the vapor phase in the combustion chambers and condense as the flue gas cools. They can adsorb to fine particles. It is likely that mercury remains in the vapor phase in the air pollution control section of the incineration process depending on the temperature, and the same is true for some of the other compounds.

CONCLUSION

Based on an analysis of world experience, the practice of countries around the world, including Azerbaijan, and having statistical data, we can talk about the prospects for the development of this energy sector. Waste disposal is vital for humanity, primarily from an environmental point of view. There are various waste disposal methods depending on their type. The work describes in detail methods for processing waste and using it as energy and fertilizers. These methods are widely used in countries with developed economies, and in those countries that are not indifferent to the fate of the planet and humanity. In our work, we carefully analyzed global experience in the waste-to-energy sector and came to the following conclusions:

The term "Waste to Energy" is used to describe various technologies that convert non-recyclable waste (plastic film, tissues and kitchen paper, foil, and soiled food packaging) into usable forms of energy including heat, fuels and electricity.WTE technologies convert non-recyclable waste into usable forms of energy. The heat from the combustion of waste generates produce electricity.

The most significant challenge to WTE technology adoption is the clean technologies for sustainable waste management and awareness that waste can be used as a source of clean and reliable energy.

1. Using the method of energy analysis to determine the performance of the system.
2. Long-Term Planning: Contribute to formulating sustainable, long-term waste management plans globally, targeting a 20% improvement in overall waste management efficiency by 2035.
3. Policy Enhancement: Identify strengths and weaknesses to refine waste-to-energy strategies and improve policies, aiming for a 20% increase in waste diversion rates by 2030.
4. Environmental and Economic Insight: Provide a comprehensive understanding of environmental and economic implications for informed decision-making, with a

focus on achieving a 15% improvement in cost-effectiveness of waste-to-energy projects over the next five years.

5. Ensuring the use of resources with high efficiency and in harmony with the environment.

REFERENCES

Aghapouramin, K. (2020). Technical, economical, and environmental feasibility of hybrid renewable electrification systems for off-grid remote rural electrification areas for East Azerbaijan Province, Iran. Technology and Economics of Smart Grids and Sustainable Energy.

A., Abbasov[1], E., Salamov, O., & Salmanova, F. (2015). Hybrid Solar-Wind Installation Prospects for Hot Water and Heating Supply of Private Homes on the Absheron Peninsula of the Republic of Azerbaijan. Environmental Research, Engineering & Management, 71(3), 36-48.

Abbasov, E. (2015). Sustainable Solution for Increasing the Share of Solar Photovoltaic Usages on Residential Houses in Azerbaijan. Environmental Research, Engineering & Management, 71(4).

A.V. Meier, Electric Power Systems: A Conceptual Introduction (Hoboken, NJ: Wiley–IEEE Press, 2006)

BP: BP Statistical Review of World Energy 2006. London: 2006.

Burns, T. R. (2016). Sustainable development: Agents, systems, and the environment. Current Sociology, 64(6), 875–906.

Cəlilov M.F. Alternativregenerativenerjilər. «Enerjimenecmenti (binalarda)» magistr ixtisaslaşması üçün dərs vəsaiti, Bakı: AzMIU, 2008.-141s

Delucchi, M., and Jacobson, M. 2013. Providing all global energy with wind, water, and solar power.Energy Policy, 39(3): 1170-1190.

De Feo, G., & Malvano, C. (2009) The use of LCA in selecting the best management system. Waste Management, 29, 1901-1915

Dalwadi, P., Shrinet, V., Mehta, C. R., & Shah, P. (2011, December). Optimization of solar-wind hybrid system for distributed generation.

Environment and Planning C: Politics and Space, 35(7), 1285–1303.Huseynov[1],

IRENA – International Renewable Energy Agency. (2023, December 11). https://www.irena.org/

Hong, R.J., Wang, G.F., Guo, R.Z., Cheng X., Liu Q., Zhang P.J. & Qian G.R. (2006). Life cycle assessment of BMTbased integrated municipal solid waste management: Case study in Pudong, China. Resources, Conservation and Recycling, 49, 129-146

IEEE (2020) - The world's largest technical professional organization dedicated to advancing technology for the benefit of humanity. (n.d.). https://www.ieee.org/

Sims R.E.H. Renewable energy: a response to climate change // Solar Energy. 2004. Vol. 76. P. 9-17.

Vidadili, N., Suleymanov, E., Bulut, C., & Mahmudlu, C. (2017). Transition to renewable energy and sustainable energy development in Azerbaijan. Renewable and Sustainable Energy Reviews, 80, 1153-1161.

Moriana, I., San Martin, I., & Sanchis, P. (2010, June). Wind-photovoltaic hybrid systems design. In SPEEDAM 2010 (pp. 610-615). IEEE.

Gupta, S. C., Kumar, Y., & Agnihotri, G. (2007). Optimal sizing of solar-wind hybrid system.

Pogson, M., Hastings, and A., Smith, P., 2013. GCB Bioenergy, 5 (5): 513-524.

Liu, J., Zuo, J., Zillante, G. and Chen, X., 2013. Renewable & Sustainable Energy Reviews, 9: 230-237.

Liu, H., Leng, S., He, C., Peng, J., Piao, S., Wang, X. (2019). China's road towards sustainable development: Geography bridges science and solution. Progress in Physical Geography: Earth and Environment, 43(5), 694-706.

Malekpour, S., Brown, R. R., de Haan, F. J. (2017). Disruptions in strategic infrastructure planning – What do they mean for sustainable development?

Law of the Republic of Azerbaijan No. 678-IQ "On Environmental Protection". (1999,June)

Hasanov, R. I. (2023). Promoting sustainability in Azerbaijan's energy sector: A green policy evaluation and future outlook. *Green Economics*, *1*(1), 62-69.

Frost & Sullivan (2011). Key opportunities in waste to energy plant market (technical insights).

Hong, R.J., Wang, G.F., Guo, R.Z., Cheng X., Liu Q., Zhang P.J. & Qian G.R. (2006).

Life cycle assessment of BMTbased integrated municipal solid waste management: Case study in Pudong, China. Resources, Conservation and Recycling, 49, 129-146

Safaroff Agency, (2024) https://area.gov.az Green Energy Zone in Liberated Zones

Robbani, A. (2024). Effectiveness of The Islamic Development Bank (IDB) in Promoting Development in Muslim Countries. *Afkar Journal: Islamic & Civilisation Studies*, *1*(1), 12-26.

Eurostat(2013):http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/introduction/

Frost & Sullivan (2011). Key opportunities in waste to energy plant market (technical insights).

Iriarte, A., Gabarell, X., & Rieradevall, J. (2009) LCA of selective waste collection systems in dense urban areas. Waste Management, 29, 903-914

Hulgaard T. & Vehlow J. (2011). “Incineration: process and technology,” in Solid waste technology & management

Karakashev D. & Angelidaki I. (2011) “Emerging biological technologies: biofuels and biochemicals” in Solid waste technology & management

Konstadinos Abeliotis (2011). Life Cycle Assessment in Municipal Solid Waste Management, Integrated Waste Management - Volume I, Mr. Sunil Kumar (Ed.), ISBN: 978-953-307-469-6

Mavropoulos, Alexandros (2012). International Scenario in Waste and e-Waste Management,D-waste.

Mendes, M.R., Aramaki, T., & Hanaki, K. (2004) Comparison of the environmental impact of incineration and landfilling in Sao Paulo city as determined by LCA. Resources, Conservation and Recycling, 41, 47-63

Miliūtė J., & Staniškis, J. K. 2010. Application of life-cycle assessment in optimisation of municipal waste management systems: the case of Lithuania. Waste Management & Research, 28, 298-308 Min B., Cheng S. & Logan B.E. (2005). "Electricity generation using membrane and salt bridge microbial fuel cells" Münster M. (2009). "Energy Systems Analysis of Waste-to-Energy technologies"

Nic, M.; Jirat, J.; Kosata, B., eds. (2006–). "esters". IUPAC Compendium of Chemical Terminology (Online ed.). doi:10.1351/goldbook.E02219. ISBN 0-9678550-9-8.

National Library of Medicine (2024) 8600 Rockville Pike Bethesda, MD 20894