LIFECYCLE ANALYSIS OF BIOMASS ENERGY SYSTEMS IN THE CONTEXT OF CLIMATE CHANGE MITIGATION

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Abstract. This article analyzes the potential of increasing the share of electricity from renewable energy sources and utilizing biomass resources in the decarbonization of the energy sector to mitigate the effects of climate change. It is substantiated that biogas technologies can meet 15–20 percent of the country's energy demand.

Key words: biogas, anaerobic, biomass, waste, environmentally friendly, sustainable source, fermentation, carbon dioxide, biofertilizer.

Relevance of the research topic. Humans have been utilizing biogas since the late 18th century. Biogas is typically a mixture of carbon dioxide (CO_2) and methane (CH_4). It is produced through the decomposition of organic matter by microorganisms in an environment devoid of air and oxygen-a condition known as the "anaerobic state".

Currently, energy is primarily derived from non-renewable sources. At present, the global consumption of natural fuels amounts to approximately 12 billion tons of oil equivalent, which means that each person uses about 2 tons of fuel per year. According to data, more fuel has been consumed in the past 40 years than the total amount of organic fuel extracted throughout the entire history of mankind. This rapid consumption is depleting reserves at an alarming rate. By 2050, the world population is expected to reach 9 to 10 billion, which will lead to a threefold increase in energy demand. Therefore, in order to use existing energy sources more efficiently, it is essential to increase the share of alternative energy sources in the energy system. Energy sources that rely on fuel are classified as non-renewable, while those not based on fuel are considered renewable resources (Fig. 1).

Biomass is the energy obtained by fermenting waste and burning the gas formed from it. In practice, biomass is waste. Biomass energy is the process of converting biomass into waste, obtaining and using biogas, and is considered a promising direction in energy.

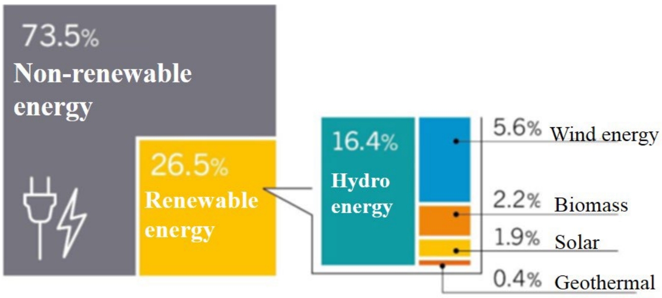

Fig.1. Estimated share of global electricity production by energy type

Percentage indicators by energy production sources in Uzbekistan are shown in Table 1.

Table 1.

Uzbekistan's energy production sources (as of 2025)

Energy source	Share (%)	Note
Natural gas	80–85%	Primary energy source.
Hydropower	8–10%	Makes up the bulk of renewable energy sources.
Solar and wind power	2–3%	A growing area in recent years.
Biogas and biomass	<1%	Not yet widely implemented on an industrial scale.
Other sources	<1%	This includes heat pumps, geothermal energy, and other sources.

According to the above data, biomass energy is not yet widely used at the industrial level in Uzbekistan, and its share in the country's total energy production remains insignificant. However, there is an opportunity to use resources such as agricultural waste, livestock waste, food, plant residues, and household waste, and there is great potential for development in this area.

Literature review. The main areas of research and development of renewable energies are: creation, production and commissioning of new types of steam turbine solar power plants; design and production of autonomous (photovoltaic for consumers) devices; design and construction of hot water supply, heating and cooling systems using sunlight; construction and commissioning of solar thermal power plants; design and construction of geothermal heat supply; design and introduction into production of wind power units and wind power plants; development of the use of biogas energy.

Foreign and domestic scientists have conducted various studies on the use of biomass energy. These researchers have studied in depth the conversion technologies of various forms of biomass energy - solid biomass, liquid biofuels and biogas [1]. They have studied the environmental and economic advantages of biogas production technology and emphasized the importance of preliminary substrate preparation in increasing the efficiency of the anaerobic fermentation process [2]. They have provided a fundamental analysis of the role of biogas technology in reducing greenhouse gases, showing that it is possible to reduce the level of CH_4 in the atmosphere by converting methane emissions into energy [3].

Studies conducted by Uzbek scientists have concluded that increasing the efficiency of gas production by 30-40% through substrate mixing and temperature control in biogas production from waste brings not only energy but also environmental benefits [4-5].

Problem-solving approaches. Climate change is a global problem, and the use of renewable energy sources is becoming increasingly important to reduce its negative impact. Biomass energy is an environmentally friendly and sustainable source, and in the conditions of Uzbekistan, it has great potential, especially based on agricultural waste, livestock biowaste and household organic waste. The following are proposed approaches to solving the problem in the implementation of energy systems (Fig.2).

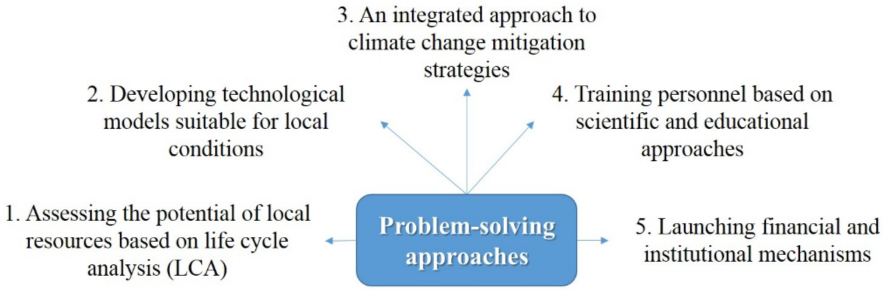

Fig.1. Problem-solving approaches

In this article, we have selected approaches that are integrated into the development of technological models suitable for local conditions and climate change mitigation strategies.

Biogas and other biomass energy technologies are often imported based on foreign models. However, in the conditions of Uzbekistan, it is necessary to develop simplified, low-cost, and flexible technologies for small and medium-sized farms.

Biomass energy systems need to be aligned with Uzbekistan's climate policy and carbon emission reduction strategy. Reducing greenhouse gases through methane gas capture and conversion to energy, and increasing the share of renewable energy are key priorities.

Biomass sources include solid household and industrial waste, wetlands, urban sewage and wastewater, livestock waste, crop residues, forest products, in particular, wood processing and shipping waste, wood pulp, paper pulp, and other waste. Biomass can be used directly in landfills to produce biogas. During the decomposition of waste, methane gas (CH_4) is released. It is collected in pipes and sent to a thermal power plant, where the mixture is combined with natural gas and used to generate electricity (Fig.3).

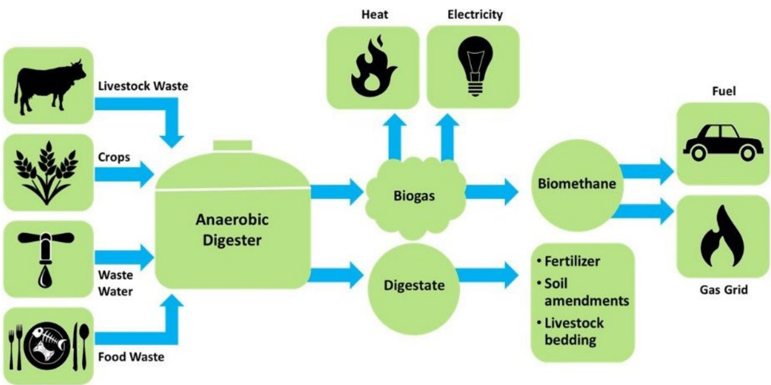

Fig.3. Anaerobic digestion process [6].

Biogas is similar in properties to natural gas. Biogas can be used in the same way as natural gas in the following processes: cooking, electricity, and heat energy (hot water and home heating); and as a vehicle fuel.

Biogas is produced both in industrial enterprises and manually using biogas plants (BGP). In February 2024, during the advanced training course titled “Energy Systems, Security, and Net Zero Emission” at the Indian Institute of Technology Delhi, we had the opportunity to learn about biogas production technology and explore the institute's existing laboratory facilities (Fig. 4).

Fig.4. Biogas energy generation technology [7].

Biogas production is based on anaerobic fermentation of waste, which is stored in a special, tightly sealed container - a methane tank. The waste microbes, which are the source of fermentation, develop in the methane tank, which gradually decomposes organic substances to the point of producing acids, which are then converted into gaseous products by methane-producing bacteria, namely methane and carbon dioxide.

The technology of this process is as follows: The waste from which biogas is produced is collected in a special container, then, using a fecal pump, it is placed in a methane tank, where the fermentation process begins (Fig.5).

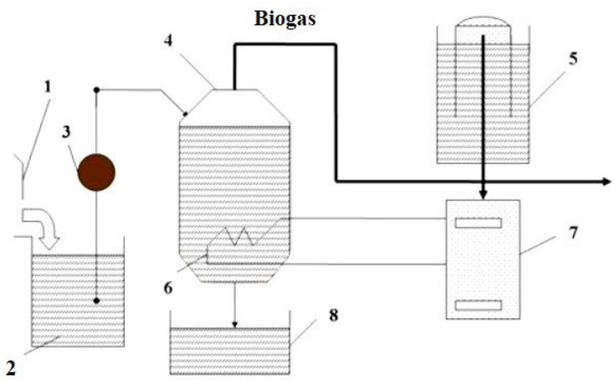

Fig.5. Technological scheme of biogas utilization:

1-waste generation areas; 2-waste receiver; 3-pump; 4-methane tank; 5-gas holder; 6-heat exchanger; 7-boiler; 8-waste storage.

The biogas produced during the fermentation process is transferred to the gas holder and then to the consumer. To heat the waste to the fermentation temperature (45-55 °C) and maintain the temperature in the methane tank, hot water is passed through the heat exchanger in the boiler. The fermented waste is collected in a collection point and then sent to the field.

The amount of biogas produced and the quality of the manure from the well depend not only on the temperature, but also on the duration of the fermentation of the product. For example, in a methane tank, when fermenting the waste for 5 days, biogas is obtained by 50%, in 10 days by 90%, and in 20 days by 98% of the maximum capacity. Depending on the duration of the fermentation of the product, the required volume of the methane tank is determined, and the amount of waste added using pumps is also taken into account. In some cases, in order to speed up the fermentation process, part of the biogas is pumped from the gas holder to the bottom of the methane tank using a compressor, and mixing of the entire mass in the methane tank is achieved. For this purpose, the necessary mixing devices are also used.

Biogas is successfully used as a fuel and can be utilized in low-pressure heating device burners, water heating boilers, gas generators, absorption refrigerators, infrared heaters, and tractor engines. Experimental results show that the by-products from biogas production in anaerobic digestion plants produce high-quality fertilizers that are richer in nitrogen and phosphorus compared to those obtained from traditional sources. Furthermore, it has been determined that these fertilizers are non-toxic and environmentally safe.

Table 2.

Physical properties of biogas

Indicators	**Components**				**Mixture 60%**
	CH_4	CO_2	H_2	H_2S	40% CO_2
Volume fraction	55-70	27-44	1	3	100

Specific heat of combustion, *J/m³*	35,8	-	20,8	22,8	21,5
Ignition temperature, °C	650-750	-	585	-	650-750
Nominal density, *g/l*	0,72	1,48	0,09	1,54	1,2
Hard armor, *g/l*	102	408	31	349	320

Biogas production is being developed on a large scale. In China, the number of biogas plants exceeds 7 million, meeting the energy needs of approximately 30 million rural residents. India has several hundred biogas plants in operation. In countries such as Switzerland, Germany, France, Italy, the Netherlands, the United States, and India, individual biogas plant capacities typically range from 100 to 300 m^3.

Science-based suggestions and recommendations. It is advisable to use local waste materials for the construction of a biogas plant. However, the outputs from such a plant are considered waste-free. Building a biogas plant is economically beneficial for both farm managers and homeowners. In addition to producing biogas, the plant also generates heat energy and high-quality biofertilizer through a biogas generator. This demonstrates that, beyond meeting gas demands, it can also satisfy the need for thermal energy. A small-scale biogas plant is capable of fully supporting a household heating system and can completely offset the cost of natural gas.

In addition, when the biofertilizer produced as a residue from the biogas plant is applied to the soil, it can increase crop productivity by 25–30% and reduce the use of mineral fertilizers by 15–20%. The larger the volume of the biogas plant, the greater the amount of biogas, electricity, and biofertilizer that can be produced. As a result, the payback period of the biogas plant shortens, and it begins to generate profit more quickly.

The main and operating costs of biogas production are inextricably linked to the sum of the main design and operating indicators of biogas plants.

Expected economic impact. The technology is considered effective only when the amount of energy obtained from biogas significantly exceeds the amount of energy consumed for its production. In other words, biogas production is efficient only when the following condition is met:

$$V_T = V_r - \frac{Q_{CH}}{\lambda}, m^3$$

Where: V_T – amount of biogas, m^3; V_r – total amount of biogas obtained, m^3; Q_{CH} – energy consumed by the device for its own needs, kJ/m^3; λ – heat transfer coefficient of biogas, kJ/m^3.

An average-sized biogas plant typically pays for itself within 4–5 years. Foreign countries have significantly more experience in biogas production, and their plants achieve faster payback periods due to the efficient and rational use of biogas and its byproducts.

According to experts, energy generated from biomass has the potential to meet 15–20% of Uzbekistan's energy needs. This method of energy production also contributes to environmental protection and supplies the country's agricultural sector with high-quality fertilizers.

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