sciendo

DOI: http://dx.doi.org/10.12775/EEC.2021.004

Eastern European Countryside
27' 2021

Natalia Pryshliak[*]
Andrii Shynkovych[**]
Dina Tokarchuk[**]
Tatiana Korpaniuk[****]

Efficiency of using individual biogas digesters for processing biowaste of rural households in Ukraine

Abstract

Biogas production is a promising area for the development of alternative energy sources in Ukraine and in the world. The aim of this study is to investigate the possibilities of implementing individual biogas digesters in rural households in Ukraine and to determine the energy, economic and environmental benefits of biogas production from organic waste. As part of the study, an analysis of the main characteristics of households in Ukraine was carried out and the

[*] Candidate of Economic Sciences, Associate Professor, Department of Administrative Management and Alternative Energy Sources, Vinnytsia National Agrarian University, Vinnytsia, Ukraine. ORCID: 0000-0002-0544-1441.

[**] Candidate of Economic Sciences, Vice-rector for scientific and pedagogical work, prospective development and humanitarian policy, Senior Lecturer, Department of Administrative Management and Alternative Energy Sources, Vinnytsia National Agrarian University, Vinnitsia, Ukraine. ORCID: 0000-0001-5740-0492.

[***] Candidate of Economic Sciences, Associate Professor, Department of Administrative Management and Alternative Energy Sources, Vinnytsia National Agrarian University, Vinnitsia, Ukraine. ORCID: 0000-0001-6341-4452.

[****] Candidate of Economic Sciences, Associate Professor, Department of Accounting and Taxation in the Sectors of the Economy, Vinnytsia National Agrarian University, Vinnitsia, Ukraine. ORCID: 0000-0002-2345-6380.

prerequisites for organising biogas production by households were determined. Household incomes were analysed, and it was determined that the costs of housing and communal services tend to grow. It was determined that the price of natural gas for the population over the past years has increased by almost 10 times, and thus replacing natural gas with biogas becomes especially relevant. The positive economic and environmental factors of using individual biogas plants in rural areas were characterised, and the theoretically possible potential of biogas production from household waste in Ukraine was calculated. Following this, a number of government measures to promote the proliferation of individual biogas plants were proposed. The economic benefits from the use of biogas were determined, including energy autonomy, the possibility of using organic fertilisers, and additional profit from the sale of surplus products. The ecological effect of using individual biogas plants will include the possibility of recycling organic waste and waste water, thus improving the hygiene situation for individual users.

Individual biogas digesters constitute a promising direction in Ukraine in terms of energy (production of biogas) and ecological areas (household waste management and production of organic fertilisers). At present, the sector of individual biogas production from biowaste is not widely spread in Ukraine, due to the lack of state support and insufficient awareness among rural residents about the benefits of biogas technology. In this research we determined the economic efficiency of the construction and operation of an individual biogas plant. Considering the average price of natural gas in Ukraine (229.9 USD per 1000 m^3), the use of a biogas plant would save 144.1 USD annually on the purchase of natural gas. Given that the cost of building an individual biogas digester is 825.6 USD, its payback period would be 4.7 years.

Keywords: renewable energy, biogas, individual biogas plants, anaerobic digestion, efficiency, households, biowaste, rural areas, efficiency

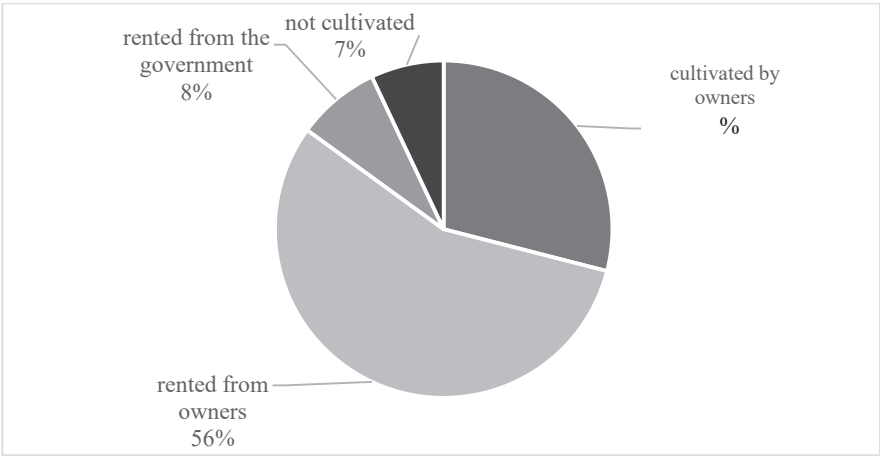
Introduction

Each production has its own waste, including agricultural. Active development of agriculture, and increasing the production of crop and livestock products to meet the needs of the population and industry lead to an increase of both

household waste and the burden on the environment (Berezyuk et al. 2019). At the same time, crop waste, animal and poultry waste, and human waste have a negative impact on land, air and water resources.

Ukraine is an agricultural country. The area of Ukraine is 60.3 million hectares (6% of the territory of Europe). The area of agricultural land is 41.4 million hectares, while that of arable land is 32.7 million hectares (19% and 27%, respectively, of agricultural land in Europe). In the ownership structure, 31 million gazelles are privately owned, while 10.4 million hectares are in state and communal ownership. The structure of agricultural land in Ukraine is shown in Fig. 1.

Figure 1. The structure of agricultural land use in Ukraine



Source: formed according to the data from State Service of Ukraine for Geodesy, Cartography and Cadastre.

At present in Ukraine, there is still a moratorium (ban) on the sale and purchase of agricultural land. More than 41 million hectares are under the moratorium – with the exception of those allocated for the maintenance of subsidiary and personal peasant farming, gardening and truck farming. In terms of the amount of land which is under the moratorium, more than 31 million hectares are privately owned land (their owners are 7 million Ukrainians). Moreover, the owners themselves cultivate less than a third of the land. Those who cultivate leased land receive it mainly from private owners – 56%. Land leased from the state provides another 8% of cultivation,

while approximately the same amount – 7% of the land – is not cultivated at all.

In 2019, according to the data from State Service of Ukraine for Geodesy, Cartography and Cadastre, 27.842 million hectares were cultivated in Ukraine. The structure of land cultivated by big agroholdings, farmers and personal farms in 2017–2019 is shown in Table 1.

Table 1. The total cultivated area in terms of types, 2017–2019

****	**2017**		**2018**		**2019**		**2019 to 2017**	
Size	**Number**	**Total area, ha**	**Number**	**Total area, ha**	**Number**	**Total area, ha**	**Number**	**Total area, ha**
Up to 500 hectares	32553	2589010	32100	2665770	31097	3047501	–1456	458491
500–1000 hectares	2689	1927193	2738	1957439	2688	1930809	–1	3616
1000–5000 hectares	4240	8866567	4198	8708938	4130	8546973	–110	–319594
5000–10000 hectares	383	2564414	365	2435467	353	2351952	–30	–212462
10000–20000 hectares	92	1220513	93	1221125	92	1213451	0	–7062
20000–50000 hectares	50	1433220	60	1773843	59	1748738	9	315518
Over 50000 hectares	4	309688	7	478157	9	609267	5	299579
Total number of enterprises	40011	–	39561	–	38451	–	–1560	

Source: formed according to the data from State Service of Ukraine for Geodesy, Cartography and Cadastre.

Despite the fact that over the past three years there has been a decrease in the number of operating units and the consolidation of farms, after the end of the moratorium on the sale of agricultural land, scheduled for July 1, 2021, an increase in the number of small and medium farms is expected. This is due to the fact that, in accordance with the Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine on the Conditions of Circulation of Agricultural Land", from July 1, 2021 to January 1, 2024, there will be

restrictions on land purchase – no more than 100 hectares for one owner. Moreover, from July 1, 2021 to January 1, 2024, the right to buy agricultural land will apply only to individuals. Legal entities will be prohibited from buying agricultural land.

In Ukraine, medium- and large-scale farms are actively developing the installation of biogas production capacities. According to the State Agency for Energy Efficiency, today 49 plants in Ukraine produce energy from biogas and operate under a "green" tariff. The total installed capacity of such plants is 86 MW. Unfortunately, biogas technology is not being spread among small farms and rural households.

Rural households are promising for the organisation of biogas production, as they have a potential feedstock base: in addition to the actual household waste, there is also waste from subsidiary farms.

High prices for traditional energy resources encourage Ukrainian households to constantly search for opportunities both to save energy resources and to use new types of those resources, including renewable ones. The most widely used renewable energy in rural areas is the thermal energy of woody biomass, which is obtained via direct combustion in solid fuel boilers and stoves for the purpose of heating premises, cooking and heating water. However, the analysis of world experience allows us to confirm the rapid development of biogas technology, which is widely used not only on an industrial scale, but also at the household level (International Energy Agency 2020).

Literature review

The current irrational use of fossil fuels and the impact of greenhouse gases on the environment are driving research into renewable energy production from organic resources and waste (Achinas et al. 2017). Anaerobic digestion of energy, crops, residues, and wastes is of increasing interest with a view to reducing the greenhouse gas emissions and to facilitating a sustainable development of energy supply (Weiland 2010). Moreover, the use of biogas is one of the ways to supplement and partially replace traditional fuels in rural areas (Pryshliak 2019).

Biogas technology is becoming more popular each year. The number of biomethane plants in Europe has increased by 51% in 2 years, from 483 in 2018 to 729 in 2020. There are currently 18 countries producing biomethane in

Europe. Germany has the highest share of biomethane plants (232), followed by France (131) and the UK (80) (European Biogas Association 2021).

The advantages of using individual biogas digesters in rural areas are undeniable, as evidenced by the experience of countries that have introduced biogas technology. Among these countries are China, India, Denmark, Austria, Sweden, Germany, the Czech Republic and many others (Kaletnik et al. 2020). In China, approximately 28 million individual biogas digesters have been installed to produce biogas. Every year such digesters produce 18 billion cubic metres of biogas (Pryshliak and Tokarchuk 2020).

Ukraine is not self-sufficient in energy supply and is dependent on the imports of energy carriers, which leads to political tensions and has socio-economic implications. Production of agricultural biogas is a way to both slow down climatic changes and increase energy self-sufficiency by replacing or complementing conventional sources of energy (Wąs et al. 2020).

Ukraine has enough biomass resources for biogas production. However, this energy potential is not used sufficiently (Havrysh et al. 2020). The feasibility of farms' energy supply from their own energy source and the need to reduce harmful emissions into the environment make the biogas plant an indispensable element of modern livestock complexes (Tokarchuk et al. 2020).

Today in Ukraine there are approximately 200 individual biogas plants which have been installed by private households. Individual biogas plants are a modern and affordable solution for households with livestock and those that are engaged in the cultivation of agricultural products, as well as a relevant solution for non-gasified rural areas of Ukraine and in conditions of power outages (AgroBiogas 2021).

Taking into account natural and climatic conditions, and based on the needs of biogas production, Ukrainian households should use biogas plants which have a thermophilic mode of operation. Kaletnik et al. (2018) suggest that households should use a mini biogas plant with the possibility of continuous manual loading of biological raw materials and manual mixing, the biogas output of which is 12 cubic metres at a temperature of 55 °C.

Fabiyanska and Zdirko (2018) emphasise that the use of biogas plants by households creates great prospects for the energy independence of rural areas, as well as conditions for self-employment of rural residents, while it also leads to an improvement in their material well-being, the development of crop production through the production of biofertilisers, and an increase

in the environmental situation in rural areas, since waste disposal reduces emissions of methane (greenhouse gas) and carbon dioxide in the atmosphere.

Previous research (Pryshliak and Tokarchuk 2020; Kaletnik, Pryshliak and Pryshliak 2019) has found that the production of biofuels from agricultural waste will have social, economic and environmental effects. Using the SWOT method of analysis, factors that will affect the development of biofuel production from agricultural waste were determined. However, Ukraine still lacks effective state support for the development of individual kinds of biogas technology. Moreover, the previous research (Pryshliak 2011; Pryshliak 2019) describes the peculiarities of biogas production in individual biogas digesters in India, as well as China's experience in building individual biogas plants for Ukraine which have the above-described prospects.

However, the production of biogas in individual biogas digesters has not received significant development in Ukraine due to the population's low awareness of this kind of energy, the economic and environmental benefits of its use, the peculiarities of the technical aspects of building individual biogas reactors, and the use of household waste as a feedstock for biogas production.

The aim of the present work is to study the prospects for the introduction of biogas technology by individual households in Ukraine and to determine the energy, economic and environmental benefits of its use.

Materials and methods

The data source used in this analysis comprises regulatory documents, and statistical and analytical data of Ukrainian governmental institutions, organisations and associations. The method of system analysis is employed to study and substantiate the advantages of implementing biogas technology in rural households in Ukraine. Data analyses were conducted with the means of descriptive statistics and graphic methods. The strengths, weaknesses, opportunities and threats of biogas production in individual biogas digesters in Ukraine were identified with the means of SWOT analysis. The abstract-logical method was used to summarise the results of the study and formulate conclusions.

Results and discussion

In 2020, there were 14.78 million households in Ukraine, of which 32.3% (4.8 million) were in rural areas. The average household size by number of persons was 2.58 persons (2.67 persons in rural areas) (State Statistics Service of Ukraine 2019). Over the past 5 years, the share of farms that raise livestock and poultry has slightly decreased, and in 2020 it was 28.2%. In 2020, the average land area used by one household that owns a land plot was 1.734 hectares (Table 2).

Table 2. Characteristics of household farms

	2015	2016	2017	2018	2019	2020
Number of households (thousands)	15073.7	15033.4	14985.6	14934.9	14881.7	14784.3
Of the total number, the share of households (%) that keep livestock and poultry	31.1	31.5	31.4	30.3	30.8	28.2
Number of households with land plots (thousands)	8324.0	8362.5	8234.4	8175.8	8451.2	8315.3
Average land area used by one household that owns land (ha)	1.652	1.933	1.895	1.909	1.804	1.734

Source: developed by the authors according to the State Statistics Service of Ukraine 2019.

Thus, 4.169 million households which have land plots and also keep livestock and poultry are promising farms in terms of building individual biogas digesters, since these farms have the greatest potential for organic waste.

At the same time, in Ukraine, more than 20% of households still do not have connections to a centralised gas supply, instead using bottled gas, electricity or firewood for daily needs (cooking, heating water, heating a room) (Table 3). At the same time, the share of households with hot water supply is quite low (only 40% as of 2018).

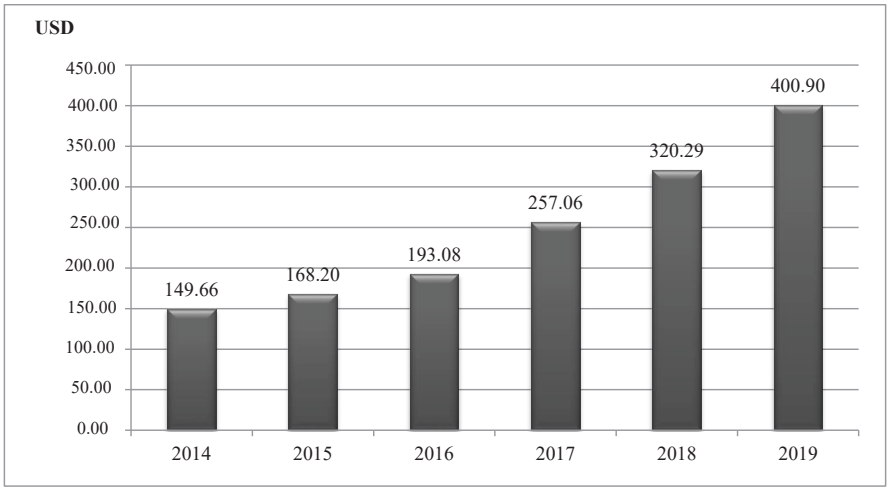
Table 3. Main characteristics of households in Ukraine

	2011	2012	2013	2014	2015	2016	2017	2018
Number of households (million)	17.023	16.984	16.959	16.076	15.074	15.033	14.986	14.935
Distribution of households (%) by availability in their housing:								
Centralised gas supply;	75.2	75.9	75.8	78.7	79.3	78.1	77.8	77.8
Bottled gas;	15.2	13.8	14.0	12.1	11.0	11.4	11.7	11.7
Electric stove;	4.9	4.8	5.4	4.4	5.4	5.8	6.8	6.2
Hot water supply.	32.5	31.6	32.1	35.3	38.1	39.2	39.9	40.0

Source: developed by the authors according to the State Statistics Service of Ukraine 2019.

The general analysis of the dynamics of household income has a positive trend. Thus, since 2014, there has been an increase in the total cash income of households (Fig. 2). However, taking into account the average household size (2.58 persons in 2019), per capita cash income in 2019 was 155.4 USD, which is only 23.7 USD higher than the actual subsistence minimum (131.7 USD) in Ukraine.

Figure 2. Dynamics of household cash income, USD



Source: developed by the authors according to the State Statistics Service of Ukraine 2019.

In general, household incomes do not provide a decent standard of living for most Ukrainians. Analysing the number of households that in 2019 received income below the subsistence level (official and actual), it should be noted that 23.3% of households (3.471 million) had income below the actual subsistence level (Table 4).

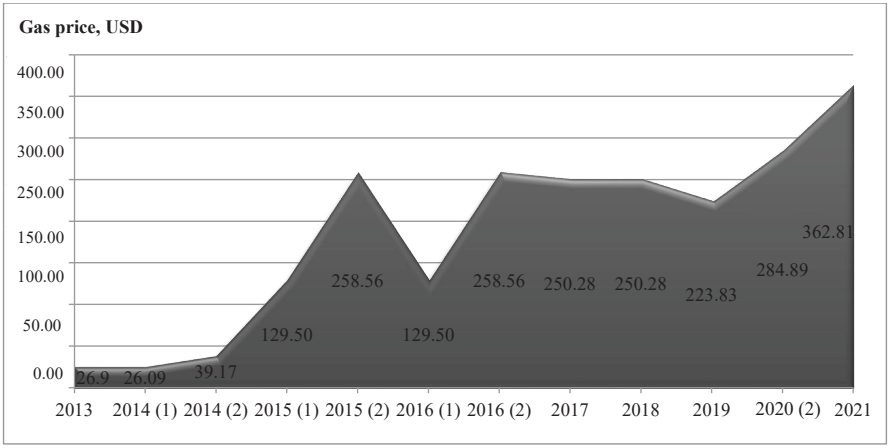
Table 4. Cash income of households in 2019

	The amount of cash income, USD	**Number of households (thousands)**	**Average household size (persons)**
Cash income in households with total cash income below the legislatively established subsistence minimum (68.4 USD)	2970.70	163.3	2.11
Cash income in households with total cash income below the actual subsistence minimum (131.7 USD)	5538.19	3471.0	2.09
Cash income in households with total cash income below the average level of total income (202.1 USD)	7771.84	8883.4	2.14

Source: developed by the authors according to the State Statistics Service of Ukraine 2019.

Tariffs for housing and communal services are growing in Ukraine every year, especially for natural gas. Tariffs for natural gas for the population in Ukraine are quite differentiated, and depend on the volume of consumption, the availability of a meter, the season (heating or no heating), and the intended use of natural gas (for cooking, for individual or integrated heating). In certain years (for example, 2015, 2020), gas tariffs for the population changed almost every month. In general, the prices for gas in Ukraine for the population, although slightly decreasing in the summer months, have a positive upward trend from year to year (Fig. 3). As of January 2021, the gas price for the population was 0.39 USD per 1 m^3 (gas and transportation price).

Figure 3. Tariffs for natural gas for the population on average per year, depending on the availability of a meter, the volume of consumption and the period



2013 – up to 2500 m³ per year with a meter
2014 (1) – up to 2500 m³ per year with a meter during the non-heating period
2014 (2) – up to 2500 m³ per year with a meter during the heating period
2015 (1) – during the non-heating period, volume up to 200 m³ per month
2015 (2) – during the heating period or more than 200 m³ per month in the heating period
2016 (1) – during the non-heating period, volume up to 200 m³ per month
2016 (2) – during the heating period or more than 200 m³ per month during the heating period
2017 – all the needs of household consumers in natural gas
2018 – all the needs of household consumers in natural gas
2019 – all the needs of household consumers in natural gas
2020 (2) – all needs of household consumers in natural gas during the heating period

Source: compiled by the authors based on data from the official website of the National Joint Stock Company "Naftogaz of Ukraine" 2021.

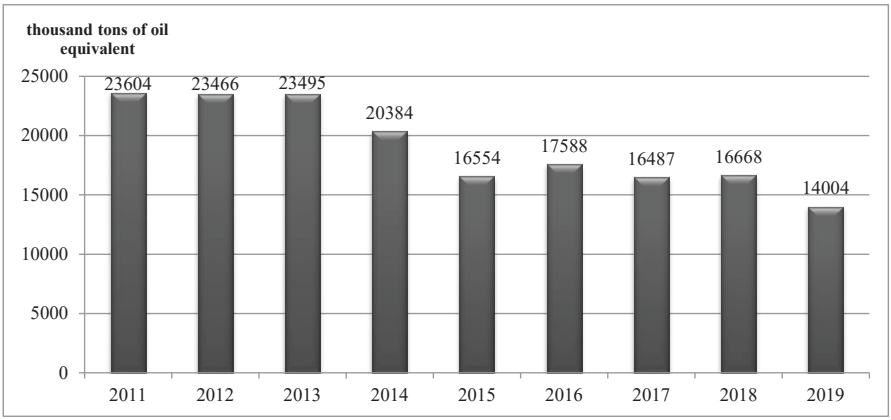
The growth in the cost of natural gas for the population in Ukraine has a direct negative impact on the growth of household expenditures for housing and communal services and, accordingly, leads to a decrease in expenses for other items, particularly food and household items. A significant part of the population has reduced its consumption of natural gas and, if possible, switched to the use of other energy resources (electricity, firewood), especially during the heating period.

In 2019, the average annual consumption of natural gas by one household in Ukraine amounted to 1,443 m³. Of this, 291 m³ was used for heating water and cooking, and 1152 m³ for space heating (official website for natural gas consumers "CENTRGAS" 2019). Thus, in 2019, Ukrainian households consumed 21.33 billion m³ of natural gas.

According to household self-assessment of the availability of certain goods and services in 2019, the number of people living in households affected by the inability to maintain a sufficiently warm temperature in their homes during the heating season in Ukraine was 8.353 million people (in cities – 4.411 million people, in rural areas – 3.942 million people) (State Statistics Service of Ukraine 2020).

In 2019, the total energy consumption of Ukrainian households amounted to 14,004 tons of oil equivalent. The dynamics of final energy consumption by households has a gradual downward trend (Fig. 4). This is due to a decrease in the total number of households in Ukraine (from 17.023 million households in 2011 to 14.935 in 2019) and an increase in the price of fuel and energy resources.

Figure 4. Final energy consumption by Ukrainian households



Source: developed by the authors according to the State Statistics Service of Ukraine 2019.

In terms of the structure of final energy consumption by households, in 2019, electricity was used to a greater extent for lighting and powering household devices, thermal energy – for heating residential premises, natural gas – for space heating and cooking, solid fuel – for heating, oil products – for cooking, biofuel and waste – for heating living quarters (Table 5).

Table 5. Structure of final energy consumption by households by purpose in 2019

Energy sources	Destination						
	Total	**Residential heating**	**Air conditioning (cooling) of residential premises**	**Water heating**	**Cooking**	**Lighting and power supply of household appliances**	**Other**
Electricity	100.0	5.3	2.3	10.4	8.5	73.3	0.2
Thermal energy	100.0	71.1	–	28.9	–	–	–
Natural gas	100.0	58.5	–	12.7	28.8	–	–
Solid fuel	100.0	94.0	–	5.6	0.4	–	–
Petroleum products	100.0	10.0	–	11.1	78.9	–	–
Biofuels and waste	100.0	97.1	–	2.9	–	–	–
Total	100.0	54.8	0.4	13.3	17.5	14.0	0.0

Source: developed by the authors according to the State Statistics Service of Ukraine 2019.

The production of biogas by households will reduce consumption from natural gas, which makes up a significant part of the cost of housing and communal services. The savings can be used to meet other household needs. Thus, the economic advantages lie in the fact that the production of biogas technology will enable households to reduce costs through energy autonomy.

At the same time, the need for household biogas production has both economic and environmental justification. Household waste, in particular manure from cattle, pigs, sheep, horses and other animals, poultry manure, food waste, plant matter, and toilet waste, can significantly pollute the environment and lead to negative environmental pollution (penetration of various microorganisms into the soil and water bodies (bacteria, viruses), spores of fungi, and helminthic eggs, many of which are pathogenic for humans, animals and plants (the danger of the spread of diseases such as botulism, salmonellosis, dysentery, etc.)).

In total, in 2019, animals kept in Ukrainian households generated 40.65 million tons of waste (Table 6). In the case of loading this waste into individual biogas digesters, the theoretical output of biogas will be 1760.28 million m^3 of

environmentally friendly biogas. Waste manure after digestion can be used as a high-quality organic fertiliser.

Table 6. Number of animals and poultry in households in Ukraine in 2019 and calculation of potential biogas production

	Availability, thousand heads	**Accumulation of waste, tons / year per 1 head**	**Accumulation of total waste, million tons / year**	**Biogas yield from 1 ton of substrate, m³**	**Potential biogas output, total, million m³**
Cattle	2194.8	10.2	22.39	25	559.67
Pigs	2629.7	3.6	9.47	28	265.07
Sheep and goats	1086.3	1.1	1.19	55	65.72
Horses	229.8	7.3	1.68	63	105.69
Poultry (chickens, geese, ducks, turkeys)	92841.5	0.055	5.11	140	714.88
Rabbits	4560.2	0.18	0.82	60	49.25
Total			40.65		1760.28

Source: developed by the authors according to the State Statistics Service of Ukraine 2019.

The cost of building a biogas digester differs depending on the materials selected and the installed capacity. In China and India, where individual biogas plants are widespread, brick, concrete, plastic, and reinforced fibre are used for the construction of reactors. It should be noted that biogas plants have become widespread in these countries thanks to government subsidies for construction (Pryshliak 2011; Pryshliak 2019). The experience of China and India in constructing individual biogas digesters is important for Ukraine, as these countries have successfully solved the lack of energy resources in rural areas and pollution of the environment by introducing local waste-based biogas production.

In order to estimate the construction cost of an individual biogas digester, it would be worth clarifying the cost of its individual components.

For the construction of a cylindrical brick reactor (radius 2.0–2.1 m, depth 2.2 m), taking into account a masonry of 0.5 bricks (12 cm thick) and seam thickness (up to 10 mm), approximately 2000 bricks would be required, at a total cost of around 201.4 USD. The cost of cement would be roughly

27.0 USD. For better heat retention, additional use of heat-insulating material such as glass wool is required, the cost of which will be approximately 43.17 USD.

The calculation of the approximate cost of construction and launch of an individual biogas digester with a volume of 10 m^3 is given in Table 7.

Table 7. Estimate for the construction and launch of an individual biogas digester with a capacity of 10 m^3

Components	Price, USD
1. Building materials:	
cement	27.0
lime	1.8
sand	21.6
bricks	201.4
gravel	50.4
polyurethane foam	107.9
fibreglass	43.2
2. Pipes and fittings, meters	10.8
3. Appliances cost	
stabilisation device	20.1
device for controlling the level of temperature and pressure in the reactor	8.6
desulfuriser	16.2
compressor	25.2
gas stove	46.8
4. Labour cost	
skilled labour	71.9
unskilled labour	143.9
5. Transportation cost	28.8
Total	825.6

Source: calculated by the authors.

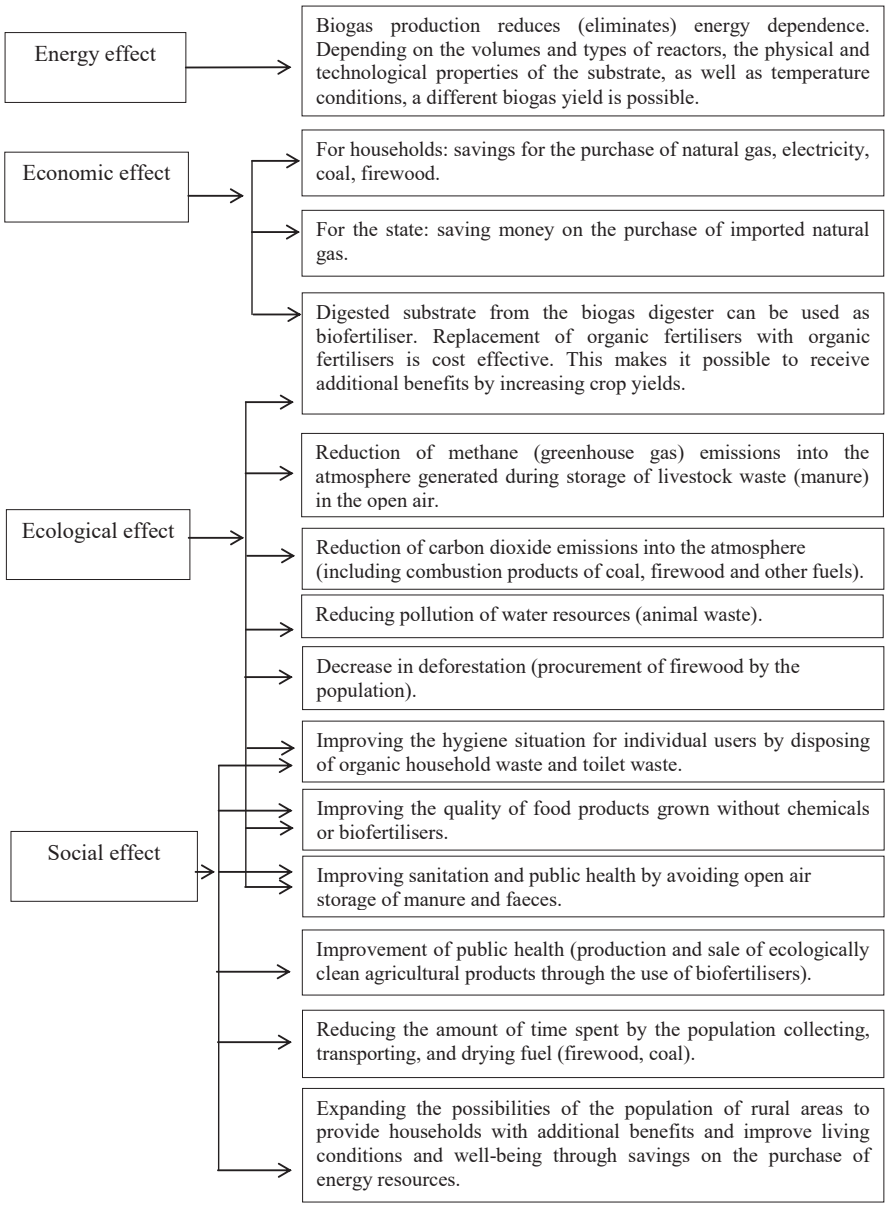
Thus, the total cost of a biogas digester is 825.6 USD, which is affordable even for households with a low income level. In order to calculate the payback period, it is necessary to assess the costs in terms of ensuring the energy independence of households.

In the warm period (April-October), a biogas plant with a volume of 10 m^3 produces an average of 2 m^3 / day. During the cold period (November-March), the volume of biogas production may slightly decrease and will average 1.5 m^3 per day. Thus, the average annual production of biogas in an individual plant will be 645 m^3. Considering the average price of natural gas in Ukraine (229.9 USD per 1000 m^3), the use of a biogas plant will save 144.1 USD annually on the purchase of natural gas. Given that the cost of building an individual biogas digester is 825.6 USD, its payback period will be 4.7 years. Since the exploitation period of an individual biogas plant digester made from bricks is 20–25 years, and the payback period is 4.7 years, the investment cost is feasible.

A necessary requirement for biogas production in individual digesters is compliance with the requirements for the construction and operation of such digesters. In China, domestic biogas production is controlled by 18 standards, including 6 national and 12 industrial standards, among which there are standards regarding materials for the construction of biogas digesters, construction regulations, verification and suitability for use, as well as standards regarding biogas stoves and auxiliary equipment. In Ukraine, there are still no legally adopted standards for the construction and operation of individual biogas digesters. However, in order to ensure safe production of biogas by households, the government should adopt a number of documents on the standardisation of biogas production by individual plants.

In addition to achieving an ecological and economic effect, the production of biogas in individual biogas digesters brings with it a significant social effect, which consists of improving the health of the population and expanding the possibilities of the population to provide households with appropriate benefits (Fig. 5).

Figure 5. Efficiency of introduction of biogas plants by households



Source: formed by the authors.

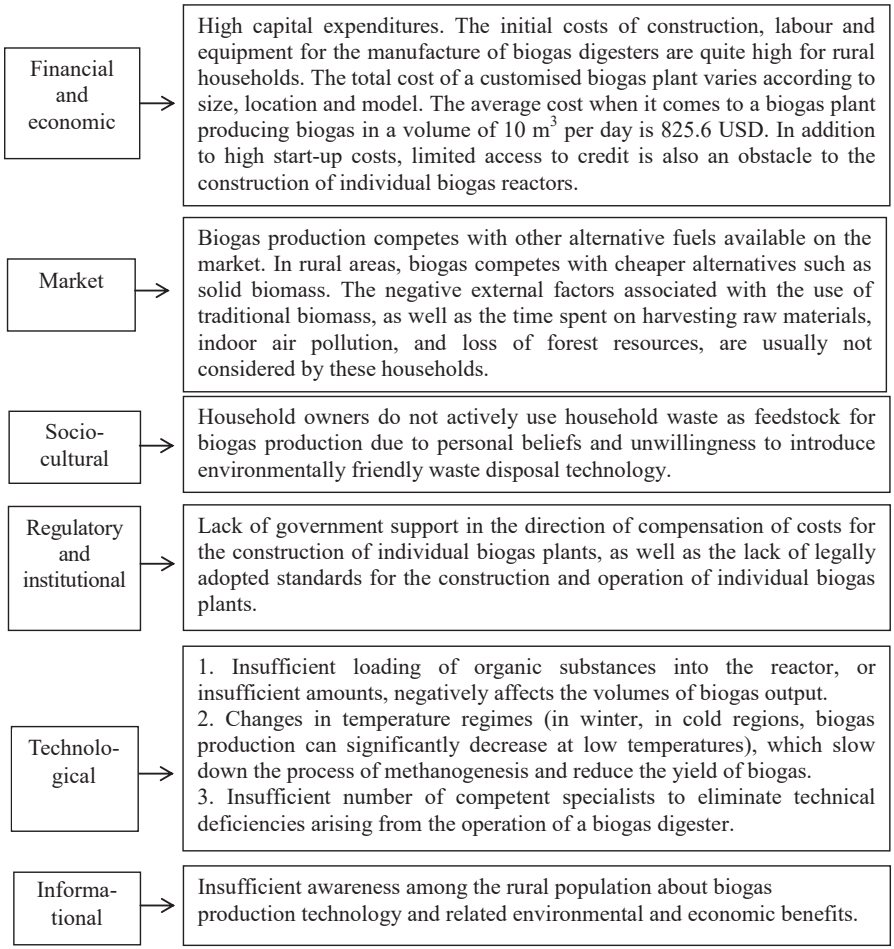
Thus, the positive aspects of the introduction of biogas technology include both economic, environmental and social aspects: utilisation of animal and crop waste, decontamination of waste, increasing life expectancy of the population and reducing the cost of medicines while also treating intestinal diseases, production of environmentally friendly organic fertilisers, energy supply of rural areas, employment of the population, development of animal husbandry, savings on gasification of the rural households.

Despite the environmental, economic and social benefits of biogas production and consumption, there are a number of barriers to the development of biogas technology which must be overcome. The classification and systematisation of factors hindering the development of biogas technology in households in Ukraine are summarised in Fig. 6.

For Ukraine, the development of individual biogas plants has significant potential to improve the economic, social and environmental conditions. The growth of the biogas sector in Ukraine depends on many factors, such as analysis of the strengths and weaknesses, as well as the prospects and threats of the biogas technology market, in order to determine recommendations for the further development of the industry (Fig. 7).

The above SWOT analysis matrix shows that strengths and opportunities are significantly greater compared to weaknesses and threats, the latter of which can be easily overcome through various regulatory mechanisms. Recommendations for accelerating the development of biogas technology and increasing the share of renewable energy sources in the overall structure of energy consumption are summarised in Table 8.

Figure 6. Barriers to the introduction of individual biogas plants in Ukraine



Source: formed by the authors.

Figure 7. Strengths, weaknesses, opportunities and threats of biogas production in individual biogas digesters in Ukraine

	Strength	Weaknesses
Internal environment	– renewable energy source; – proven and reliable technology; – the cheapest solution for sustainable energy; – energy-efficient process; – prevention of deforestation; – solving the problem of organic waste disposal; – disinfection of harmful pathogens; – organic fertilisers obtained from a biogas reactor have a higher nutritional value compared to conventional manure; – reduction of carbon emissions into the atmosphere; – obtaining biogas, which is used for cooking, lighting and electricity generation; – favourable climatic conditions of most regions for biogas production in individual reactors.	– preference among residents to use their usual types of energy (wood, coal); – imperfection of state support mechanisms (there is no programme that would support or subsidise construction of individual households, while individual biogas digesters also produce too small an amount of energy to apply for the "green tariff"); – difficulties in collecting feedstock for loading into a biogas reactor.
	Opportunities	**Threats**
External environment	– growth in demand for energy resources; – creation of jobs in rural areas (construction and maintenance of biogas digesters).	– in case of interruption of the constant supply of feedstock to the reactor or its excessive supply, arises the possibility of biogas yield reduction; – financial difficulties of the population when it comes to investing in the construction of individual biogas digester.

Source: formed by the authors.

Thus, state incentives for households to organise biogas production in Ukraine are necessary. These measures may include compensation for a certain part of the cost of construction of the biogas plant by the state, or the possibility of obtaining preferential loans for the construction of biogas reactors. It is also necessary to conduct educational work among the population on the benefits of biogas production and use and opportunities for project implementation at the level of individual households.

Table 8. Measures to accelerate the development of individual biogas digesters in Ukraine

Financial and economic	– providing loans for the purchase of cattle; – providing loans for the construction of biogas digesters.
Market	– development of local markets for technology and feedstock by attracting private investors to the biogas production sector in rural areas; – the emergence of competitors in the market, which will help reduce the cost of installing biogas plants and improve the quality of services provided.
Socio-cultural	– carrying out information campaigns aimed at raising awareness of the short- and long-term environmental impacts associated with indoor air pollution caused by traditional wood fuel, as well as informing the public about the benefits of clean energy for the environment and health.
Regulatory and institutional	– improving the system of state financial support for the construction of individual biogas digesters by taking into account the socio-economic characteristics of farms, such as income and agro-climatic conditions; – providing subsidies for the construction of joint biogas digesters (for several families) for those households that do not have enough animals and, accordingly, the accumulation of sufficient waste.
Technological	– cheaper technology for the construction of biogas reactors through the use of more affordable materials for construction.
Informational	– deeper penetration of information and communication technology in rural areas through career guidance activities. – introduction of demonstration objects and pilot projects; – introduction of training for local specialists on installation and maintenance of biogas plants.

Conclusions

The introduction of biogas digesters operating on livestock and crop waste in households in Ukraine is relevant and economically feasible. Biogas plants for the processing of animal manure are widely used all over the world. The use of individual biogas digesters contributes to solving the problems of agrochemistry, agriculture and energy. For households, the use of individual biogas digesters offers opportunities to improve living conditions and well-being. Biogas digesters utilise waste from the rural population and directly improve the hygiene situation for individual users and society in general. It is also worth noting the possibility of improving the quality of food products grown without chemicals or biofertilisers. Thus, biogas technology increases the life expectancy of the population and reduces the cost of medicines

and the treatment of intestinal diseases, thus increasing working capacity. The introduction of biogas plants in households will increase the energy independence of rural areas and Ukraine as a whole.

References

Achinas, S., Achinas, V., & G. J. W. Euverink 2017 'A technological overview of biogas production from biowaste', Engineering 3(3): 299–307.

Berezyuk S., Tokarchuk D. & N. Pryshliak 2019 'Resource Potential of Waste Usage as a Component of Environmental and Energy Safety of the Sate', Journal of Environmental Management and Tourism Volume X, 5(37): 1157–1167, DOI:10.14505/jemt.v10.5(37).23.

Fabiyanska, V. Yu. and N. G. Zdirko 2018 'The use of individual biogas plants in the formation of the energy supply system of rural areas', Economy. Finances. Right No. 8/1: 7–24.

Havrysh, V., Kalinichenko, A., Mentel, G., & T. Olejarz 2020, Commercial biogas plants: lessons for Ukraine', Energies 13(10): 2668.

Kaletnik, G.M., Zdyrko, N.G., & Fabianskaya, V. Yu. (2018). Biogas in households is a guarantee of energy independence of rural areas of Ukraine. Economy. Finances. Management: current issues of science and practice No. 8: 7–22.

Kaletnik, G., Honcharuk, I. and Yu. Okhota 2020 'The Waste-Free Production Development for the Energy Autonomy Formation of Ukrainian Agricultural Enterprises', Journal of Environmental Management and Tourism XI, 3(43): 513–522.

Kaletnik, G., Pryshliak, V., and N. Pryshliak 2019 'Public Policy and Biofuels: Energy, Environment and Food Trilemma', Journal of Environmental Management and Touris, X 3(35): 479–487.

Kaletnik, G.M., Zdyrko, N.G., and V. Yu. Fabianskaya 2018 'Biogas in households is a guarantee of energy independence of rural areas of Ukraine', Economy. Finances. Management: current issues of science and practice No. 8: 7–22.

Law of Ukraine "On Amendments to Certain Legislative Acts of Ukraine on the Conditions of Circulation of Agricultural Land". URL: https://zakon.rada.gov.ua/laws/show/552-20#Text.

Official website for natural gas consumers "CENTRGAS". URL: https://gas.kr.ua/statistichna-informacziya-pro-spozhivannya-prirodnogo-gazu-za-2017-rik.html.

Official website of the AgroBiogas, 2021. Mini Biogas Plants for Private Households. URL: https://agrobiogas.com.ua/ru/mini-biogas-plants-for-private-households/.

Official website of the European biogas Association, 2021. https://www.europeanbiogas.eu/the-european-biomethane-map-2020-shows-a-51-increase-of-biomethane-plants-in-europe-in-two-years/.

Official website of the National Joint Stock Company "Naftogaz of Ukraine". URL: https://www.naftogaz.com/files/Information/Dynamika-cina-2015-2019-Naselennya.pdf.

Official website of the State Agency for Energy Efficiency. URL: https://saee.gov.ua/.

Official website of the State Service of Ukraine for Geodesy, Cartography and Cadastre. URL: https://land.gov.ua/.

Official website of the State Statistics Service of Ukraine, 2019. URL: http://www.ukrstat.gov.ua/druk/publicat/Arhiv_u/17/Arch_cdhd_zb.ht.

Pryshliak, N. 2019 'Biogas production in individual biogas digesters: experience of India and prospects for Ukraine', Agricultural and Resource Economics: International Scientific E-Journal *5*(1): 122–136.

Pryshliak, N. and D. Tokarchuk 2020 'Socio-economic and environmental benefits of biofuel production development from agricultural waste in Ukraine', Environmental & Socio-economic Studies 8(1): 18–27, DOI: https://doi.org/10.2478/environ-2020-0003.

Pryshliak, N.V. 2011 'China's experience in building individual biogas plants', The Economy of Agro-Industrial Complex No. 1: 165–169.

Tokarchuk, D., Pryshliak, N., Tokarchuk, O. and K. Mazur 2020 'Technical and economic aspects of biogas production at a small agricultural enterprise with modeling of the optimal distribution of energy resources for profits maximization' INMATEH-Agricultural Engineering. Vol. 61, No. 2: 339–349.

Wąs, A., Sulewski, P., Krupin, V., Popadynets, N., Malak-Rawlikowska, A., Szymańska, M., and M. Wysokiński 2020 'The Potential of Agricultural Biogas Production in Ukraine-Impact on GHG Emissions and Energy Production', Energies 13(21): 5755.

Weiland, P. 2010 'Biogas production: current state and perspectives', Applied microbiology and biotechnology 85(4): 849–860.