Article

Economic Feasibility of Agricultural Biogas Production by Farms in Ukraine

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Abstract: Renewable energy generation in Ukraine is developing slower than state strategies and expectations, with the installations for energy generation based on biogas currently being among the lowest in terms of installed capacity. Most of those involved in energy generation from agricultural biogas are large enterprises, while the small and medium-sized farms are far less involved. Thus the article aims to assess the economic feasibility of biogas production from agricultural waste by specific farm types and sizes, with a special focus on small and medium-sized farms. The research results present findings in two dimensions, first defining the economic feasibility of biogas installations in Ukraine based on investment costs and the rate of return at both the current and potential feed-in tariff, and second, analyzing the influence of state regulation and support on the economic feasibility of agricultural biogas production in Ukraine. The results emphasize that the construction of small generation capacities does not provide sufficient funds under the current feed-in tariff to meet the simple return period expected by the domestic financing institutions. Except for the general support programs for agricultural activities, there are no support funds specifically for biogas producers, while there is tight competition with wind and solar energy due to diversified feed-in tariffs.

Keywords: agricultural biogas; farm; economic feasibility; investment; LCOE; state support; feed-in tariff; Ukraine

1. Introduction

Global climate change is increasing its tempo and impact [1] on humanity, while the origin of this change is primarily anthropogenic [2–5] due to the excessive negative influence of the intense use of fossil fuels and the consequent environmental pollution. A swift shift to renewable energy is among key solutions to this growing problem and needs to be implemented by all technically feasible means. These include energy generation from biogas, which is becoming an increasingly popular and important source of renewable energy from the standpoint of the circular economy [6–8], yet still falls behind the shares of solar and wind energy [9,10]. The global direct consumption of biogas in 2018 equaled ca. 35 Mtoe, including 16.1 Mtoe in Europe, 8.8 Mtoe in China and 4.0 Mtoe in North America [11].

While biogas can be generated from numerous types of organic waste, they can be aggregated into either of the two major ones: solid and agricultural. The latter includes the plant leftovers, weeds, leaf litter, sawdust, as well as the animal-originated solid, slurry and liquid waste. The utilization of biogas makes it possible to generate electricity and heat, reduce greenhouse gas emissions (methane and nitrous oxide from livestock waste), smooth overloads in the energy transfer grids and create new jobs in rural areas.
Ukraine is often referred to as a country with substantial agricultural development potential [12–14]. The same applies to bioenergy generation, yet in this case, a distinction needs to be made between different sources. While the biomass from crop production is increasingly available due to the subsector’s growth [15,16], the livestock sector has been declining drastically in the past 30 years [17,18]. Thus the production of biogas from livestock feedstock could simultaneously be a significant chance to intensify renewable energy generation [19,20], but a difficult task due to specific conditions of the livestock subsector’s development.

The integration of livestock production with the agricultural biogas installation could be especially beneficial for small and medium-sized farms, as it would allow them to use the livestock waste (utilization of which is currently an additional economic [21,22] and environmental burden [23]) in order to increase economic viability and achieve their own energy security, as well as aid the achievement of national goals of energy independence, regional energy generation diffusion and increasing the number and capacity of renewable energy sources.

The combined model of biogas production and use, in which biogas can be produced simultaneously from different types of feedstock, is a common approach in the global perspective [24]. While the average efficiency of electricity production (excluding heat) is ca. 34.6%, the simultaneous production of heat and electricity (i.e., co-generation) increases the efficiency of the production plant to 76.4% (provided there are heat consumers present on-site). Heat can be used for agricultural premises (e.g., farms, warehouses, greenhouses, processing), residential premises or the social infrastructure.

Despite the obvious advantages of biogas production for farm income diversification, the spread of biogas plants is still quite limited in Ukraine [20], especially compared to more economically developed European countries [25,26]. In particular, as of 1 January 2020, there were 49 biogas plants in Ukraine [27], of which only 21 were utilizing agricultural waste products as their feedstock, compared to almost 10,000 similar plants in nearby Germany [28]. Researchers say the limitations lie in the regulatory field [29–32], the lack of substantiated and efficient state support for energy generation from biogas [29,33] and a low level of understanding of the benefits of renewable energy generation by private entities and individuals [30,34]. In our opinion, there is still a gap within the research aimed at deepening the technological and economic feasibility of biogas production, taking into account national, regional and local conditions, and the suitability of installations to particular types of entities (according to their sizes and economic potential).

Until now, the typical approach in research articles regarding the development of biogas in Ukraine has been rather general [16,17,25,29,31] or technology-focused [21,35–38], still lacking a well-substantiated focus on farms, yet even more on their different sizes. Some research analyzed small energy generation installations that would be most suitable for small entities [37,39,40], but these focused rather on overview statistical and analytical data or technological issues, omitting the economic feasibility component. At the same time, work mentioning economic feasibility issues for various sizes of generation capacity does not tackle the state support system [34,41–43], or they take into account the feed-in tariff system for the energy generation from biogas [32,33,44] but do not view them from the perspective of farm size. This creates a research gap, especially for the small and medium-sized farms taking account of the economic elements of the support system, which would help understand the limitations and possibilities of development of small- and medium-scale bioenergy generation capacity by farming entities and individuals.

The study thus aims to assess the economic feasibility of biogas production from agricultural waste by farms, with a special focus on small and medium-sized farms involved in cattle, pig and poultry. The following research objectives were set for this:

- Investigate the state of the art of renewable energy in Ukraine;
- Assess the economic feasibility of biogas installations in Ukraine depending on their capacity, type and size of farms;
- Calculate the levelized costs of electricity and heat generation by biogas installations of various capacities and respective simple payback periods;
- Examine the impact of state regulation and support on the economic feasibility of agricultural biogas production in Ukraine, including the functioning of biogas installations under the feed-in tariff and the upcoming auction schemes.

The manuscript is divided into six sections. Following the introduction, Section 2 describes the current state, official plans and potential of renewable energy generation and biogas production in Ukraine. Section 3 presents the materials used and methods applied within the research. The results in Section 4 present findings of two dimensions: the assessment of the economic feasibility of biogas installations in Ukraine and the analysis of the influence of state regulation and support on the economic feasibility of agricultural biogas production in Ukraine. Section 5 discusses the results obtained and compares the current state of agricultural biogas development with selected EU experience. Section 6 summarizes the results and defines limitations and possible future directions of research within the topic.

2. Renewable Energy Generation and Biogas Production in Ukraine: Current State, Plans and Potential

The development of renewable energy in Ukraine is taking place in accordance with the National Renewable Energy Action Plan through 2020 (NREAP2020 [45,46]) and the Energy Strategy of Ukraine until 2035 (ESU2035 [47,48]). According to the strategic goals set in the NREAP2020, by 2020, it was expected that 11% of the final energy consumption would come from renewable sources, while the share of electricity from biomass should have reached 16.2% (of which 2.6% is biogas), and 85.5% in heating and cooling systems (of which 2.6% is biogas). By 2035, the share of energy from renewable sources is to reach 25%, in accordance with ESU2035. The total installed domestic capacity of bioenergy (including not only biogas-based installations but also other biomass plants) reached 0.98 GW in 2020, 1.3 GW in 2025, 1.67 GW in 2030 and 2.13 GW in 2035 [49].

Current achievements in renewable energy in Ukraine indicate it is falling behind the targets. In particular, in 2019, the share of energy generated by renewable energy sources in gross final energy consumption reached 8.1%. An increase in energy consumption from renewable energy sources in 2019 by 9.1% (0.36 Mtoe) compared to the previous year and the general reduction in energy consumption (by 2.6 Mtoe) made it possible to achieve some overall progress in the development of renewable energy (Figure 1), yet the rate of implementation is still not sufficient to meet the goals.

![Figure 1](image-url).

**Figure 1.** Renewable energy generation shares (actual vs. planned) in final energy consumption in 2014–2020 in Ukraine (in %). Source: own compilation based on [50].

During 2015–2019, the renewable electricity capacity in Ukraine (excluding the temporarily occupied territory of the Autonomous Republic of Crimea by the Russian Federation) performing under the set feed-in tariff increased by 5965 MW (from 967 MW to 6932
The overall capacity of renewable energy generation in Ukraine is currently (as of 1 January 2020) dominated by solar installations (71%), while biogas made up only 1.24% (Figure 2).

The development of renewable energy especially intensified in 2019. In that year alone, renewable energy facilities with a total capacity of 4642 MW were put into operation, which is five times the capacity installed in 2018. However, this was achieved mainly by expanding solar power plants: 76% of the total installed generation capacity in that year was from solar installations, while biomass and biogas grew by only 0.7% and 0.9%, respectively [50].

During 2019 the renewable energy facilities functioning under the feed-in tariff generated 5908 million kWh, of which: solar power plants generated 2932 million kWh, household photovoltaic stations generated 303 million kWh, wind power plants generated 2022 million kWh, small hydroelectric power plants generated 242 million kWh, biomass power plants generated 162 million kWh and biogas power plants generated 247 million kWh [50]. Thus the share of energy produced from biogas in 2019 amounted to 4.2% of the total from renewables. Of the total functioning 49 biogas plants, agricultural biomass is used as feedstock in 21 plants with a total installed capacity of 59 MW (Figure 3).

Energy generation based on agricultural biogas in Ukraine is currently carried out primarily by large agricultural or processing enterprises. Key factors of their intense involvement in this activity include large generation capacities, dependence on their own
feedstock, a relatively high rate of return, state support and a greater ability to overcome bureaucratic obstacles.

Despite the rather limited overall development of biogas production, Ukraine has significant potential due to both the availability of feedstock and a developed gas distribution system, with ca. 70% of the population having direct access to the natural-gas grid. In 2018, the annual potential of biogas from agricultural waste, food industry and enterprises’ wastewater was estimated at 7.8 billion m$^3$ of methane [52]. According to the Bioenergy Association of Ukraine, the development of biogas use in Ukraine could potentially replace 2.6–18 billion m$^3$ of natural gas annually [53], thus strengthening national energy security. The latter is a crucial issue in light of Ukraine’s high energy dependence on imported resources [54,55].

The use of agricultural biogas for energy generation in Ukraine has numerous advantages compared to other renewable energy sources [56]:

- The production of biogas and thus generation of energy from this source does not depend on weather conditions;
- The combination of biomass from farms operating in various seasons with the biomass from processing plants (e.g., sugar producers) allows energy generation throughout the year;
- The creation of new jobs for workers employed in agricultural processing plants, which in Ukraine are typically located in small towns and are often core/sole employers in those areas;
- Organic fertilizers as by-products of biogas production [57,58] can be further used for organic farming, which is increasingly lacking stable supply (the use of organic fertilizers in Ukraine decreased from 6.2 t/ha in 1990 to 0.27 t/ha in 2019, while the area of organic fertilizer application decreased from 5.5 to 0.8 million ha [59]);
- The efficient management of a wide range of agricultural waste [19,42,60], especially manure, thus helping to reduce odor, restore soil quality and preserve agricultural land that otherwise would be used for waste storage;
- The possibility to facilitate energy generation closer to agricultural waste production sites, thus reducing transport costs and emissions, while optimizing the efficiency of waste use (which loses its energy generation capacity over time [61]);
- The stabilization of the peak loads in the energy transmission grids and covering the possible failures of power generation created by intermittent renewable energy sources such as wind and solar [62];
- A gradual transition to a model of decentralized energy supply beneficial both in a national perspective and in particular for local communities;
- The reduction in methane emissions, which have a higher Global Warming Potential [63] than CO$_2$, is important from the standpoint of mitigating climate change.

Studies by the Institute for Economics and Forecasting of the National Academy of Sciences of Ukraine [56] show that with the steady development of biogas production and use, its economically feasible potential could reach 9.9 Mtoe by 2030. The use of biogas replacing fossil fuels could result in greenhouse gas emission reduction within the range of 11.5–19.1 Mt CO$_2$eq. In order to achieve this, the additional consumption of corn silage could reach 13.9 million tonnes. In order to implement the necessary biogas development projects, ca. EUR 4 billion is necessary for the heat and electricity generation field. The implementation of such projects in Ukraine could lead to numerous positive macroeconomic consequences, such as additional GDP growth of 0.3% in 2025–2029, structural changes, including the increased output of machinery and construction sectors, and a slowdown in coal mining. Despite the fact that biogas projects have almost no effect on the level of real household income (from −0.1 to 0.3%), they can potentially aid households by reducing their expenses, including those for heat and electricity.
3. Materials and Methods

Livestock manure is the most suitable feedstock for agricultural biogas production, with more liquified options such as slurry making it possible to increase methane output. It is being used as feedstock for reactors, where the fermentation process is initiated under appropriate conditions [64]. Pig manure is also well suited for biogas production but requires dilution with water. Poultry manure is suitable only in the cage systems, as the floor system increases the risk of the appearance of solid minerals in the manure, which adversely affects the reactor. However, poultry manure can be efficiently combined with livestock manure. By using pure poultry manure as feedstock, there is a danger of high ammonia concentrations; thus, it is crucial to adhere to the proper composition of the feedstock in accordance with the technological solution selected [65]. For small feedstock volumes, it is recommended to use biogas installations with a mesophilic temperature range and a twentieth of the daily load of the total feedstock volume accompanied by a slow stirring process (every 4–6 h).

As in agriculture, there are both specialized and mixed farms; the type determines the availability of feedstock for biogas production in terms of volumes and composition. In order to estimate the amount of manure available for production within a farm, data were used to estimate the yield of excrements depending on the animal species and their age [66]. These data were obtained from a specialized statistical survey of agricultural enterprises, which contains detailed information about 2860 farms in Ukraine keeping specific types of animals (cattle, pigs and poultry). The age structure of farm livestock was estimated on the basis of averaged data provided by the State Statistics Service of Ukraine and extrapolated for the farms analyzed. Coefficients of feedstock conversion into biogas made it possible to calculate the theoretical yield of biogas for each type of farm.

The study focused on the Ukrainian agricultural sector and took into account the following farm types: (1) agricultural enterprises and (2) farming households, yet only those that are either legal entities or private entrepreneurs (referred to in the text as registered farming households), thus excluding the smallest subsistence farms.

For the purposes of this research, the farm sizes were assumed based on the farm livestock (cattle, pigs and poultry) population. This assumption is necessary as Ukrainian legislation does not provide precise definitions of farm sizes, yet these are needed to understand the energy generation potentials based on their own available feedstock and typical features in biogas generation by small, medium-sized and large farms. Thus for cattle farms, the assumed distribution is as follows: small farms with a population up to 100 head, medium in the range between 100 and 1000 head, and large farms of over 1000 head. Small pig farms are assumed to have up to 200 head, medium farms have between 200 and 1000 head and large farms have over 1000 head. For poultry farms, the small ones are assumed to keep under 5000 head, medium farms keep between 5000 and 50,000 head and large farms keep over 50,000 head.

Given the technical limitations of manure use, the study assumes that a biogas installation uses 20% (in terms of energy content) of corn silage and 80% of manure as its feedstock. The capacity of a biogas installation that could be theoretically installed is estimated based on the availability of feedstock (volume of manure + silage). Thus the installation’s capacity equals the annual volume of biogas multiplied by two and divided by hours in a day multiplied by days in a year (capacity = annual volume × 2/(24 × 365)).

As emphasized in Section 2, the practical possibilities for the utilization of biogas potential (as is also the case for other renewable energy sources) are determined by profitability. The approach to its estimation in the research is based on the concept of the Levelized Cost of Energy (LCOE). In order to obtain the results, the following assumptions were made:

- A biogas installation’s utilization lifetime is 25 years. Its construction and entry into service is estimated at 1–2 years (depending on capacity) and is expected to start generating energy in the second year of operation;
- Estimates of the necessary investments for different capacity installations were calculated based on a simple return approach, and detailed results are shown in Table 1;
- Annual operating costs are set at 15% of the investment costs;
- The costs of construction and entry into service of small biogas installations are set at 40% of the total investment costs [67] and at 80% for large installations;
- Annual decommissioning costs are 5% of the installation costs;
- The installed capacity utilization factor (ICUF) is 34.6% for electricity generation and 41.8% for heat production. The sale of heat produced by small installations is rather unlikely, but it could be used for farm purposes, such as heating buildings and greenhouses;
- Generated 1 kW × h = 0.000860 Gcal, 1 Gcal cost equals UAH 1650 or EUR 54, biogas installation consumes 8% of the generated electricity for its own needs;
- Manure transportation cost is 2 UAH/t (0.065 EUR/t);
- Purchased or produced corn silage costs equal 25 EUR/t;

Wherever applicable, the currency exchange rate from UAH to EUR was conducted based on the average rate of the National Bank of Ukraine for 2020, [68] at 30.79 UAH/EUR.

In order to calculate the cost of investment capital, it is assumed that the risk-free rate of return (e.g., on deposits) is set at 9% in Ukrainian currency (UAH), the annual interest rate on a loan is 19% in UAH, the share of equity capital is 30% (the remaining 70% is the loan capital) and the income tax rate is set at 18%.

In order to assess the feasibility of biogas installation, the authors used a simple payback period approach. The latter matters, as biogas technologies have relatively high investment costs, and the commercial banks in Ukraine tend to provide only medium-term loans.

The materials used include the openly accessible data provided by the State Statistics Service of Ukraine [59], as well as an additional purchased database prepared by the State Statistics Service of Ukraine for 2015, which included solely the farms registered as medium- and large-scale agricultural enterprises, covering 59% of all cattle in the sector, 86% of pigs and 100% of poultry.

4. Results
4.1. Assessment of the Economic Feasibility of Biogas Installations in Ukraine

In Ukraine, the group of farms studied holds 33.4% of the total livestock, 59.1% of pigs and 57.4% of poultry (as of 1 January 2020). However, the availability of feedstock for biogas production is diverse, as farms differ substantially according to their livestock quantity. In particular, most farms that keep cattle fall into the categories of either 100–500 head and up to 50 head. However, farms with the largest number of cattle hold over 1500 head (Figure 4).

According to estimates, a 1 MW biogas installation requires ca. 6000 head of cattle. If only cattle manure were used (i.e., without corn silage), then ca. 10,000 head of cattle may be needed [69]. There are examples of such farms in Ukraine, such as the farm in Bziv village (Kyivska region), which has a biogas installation with a generation capacity of 330 kW, fed by 950 cows [70]. For 75 kW installations, ca. 500 head of cattle is sufficient [69].
There is a similar distribution for pig farms. The most numerous are small farms (up to 100 pigs) and medium farms (ranging between 200 and 499 pigs). However, the largest pig population is held on large farms with over 10,000 head (Figure 5).

Concentration is even more visible on poultry farms. Most small farms have fewer than 5000 head of poultry. However, the total number of poultry kept is significantly dominated by large enterprises with over 500,000 head (Figure 6).
As already mentioned, the design of a biogas installation should take into account not only the amount of available feedstock (which directly depends on the number of animals on the farm) but also its composition. Based on the farm data, the share of farms within each livestock type that would be self-sufficient in terms of provision of feedstock for their potential biogas installations was estimated. These values are 33% for cattle farms, 30.8% for pig farms, 6.3% for poultry farms and 29.9% for mixed farms. The required biogas installation’s capacity is calculated for each farm type based on the amount of its own available feedstock, maintaining a combination of 80% manure and 20% silage (Figure 7). The visualization shows the distribution of farms that can meet this constraint and makes it possible to see the shares of such farms from the smallest possible generation capacity.

Figure 6. Poultry farms in Ukraine grouped according to livestock quantity as of 1 January 2020. Source: own compilation based on data of the State Statistics Service of Ukraine [59].

Figure 7. Distribution of farms in Ukraine by potential biogas installation’s capacity based on availability of own feedstock. Source: own calculations based on data of the State Statistics Service of Ukraine [59].

The theoretical possibility of the construction of a biogas installation should be consistent with its economic feasibility. This assessment was carried out on the basis of LCOE.
Results of these calculations for different capacities of biogas installations are presented in Table 1.

Table 1. Levelized costs of electricity and heat generation by biogas installations of various capacities and corresponding investment return (simple payback) periods.

| Parameters                                                                 | Generation Capacity |
|----------------------------------------------------------------------------|---------------------|
|                                                                            | 25 kW   | 50 kW   | 100 kW  | 150 kW  | 350 kW  | 500 kW  | 1 MW    | 10 MW   | 20 MW   |
| Investments, EUR/kW [69]                                                   | 8400    | 8400    | 6000 [20]| 5000 [71]| 4500    | 4500    | 3500    | 1800    | 2000    |
| Levelised generation costs, EUR/kWh                                        | 0.837   | 0.837   | 0.603   | 0.500   | 0.465   | 0.465   | 0.370   | 0.220   | 0.145   |
| Simple return period, years                                                | 16.5    | 16.5    | 11.8    | 9.8     | 8.9     | 8.9     | 6.9     | 3.5     | 2.9     |
| Simple return period (in case of potential feed-in tariff at 0.3 EUR/kWh, years) | 8.4     | 8.4     | 6.0     | 5       | 4.5     | 4.5     | 3.5     | 1.8     | 1.4     |

Source: own calculations.

As the results in Table 1 show, with the current renewable energy support system from biogas installations in Ukraine in the form of feed-in tariff at 0.1239 EUR/kWh, the construction of small-capacity installations (in our case, all types below 500 kW fall into this category) is not feasible, because:

- The current feed-in tariff for biogas installations is too low;
- Typical bank lending is provided for a period significantly shorter (usually up to 5 years) than the foreseeable investment’s simple return period;
- Initial investment costs are relatively high.

Thus promoting the development of renewable energy generation from agricultural biogas by small and medium installations (from 100–500 kW) would require the introduction of additional stimulating measures for such farms.

Farms whose production of feedstock does not meet the necessary capacity of biogas installations of 100 kW and below could still be involved in the generation of renewable energy by cooperation with other farms. However, the economic feasibility of such cooperatives is limited by the transport costs; thus, the distance between them would need to be limited to ca. 20 km for liquid manure and ca. 50 km for dry manure. According to our estimates, in compliance with the above-mentioned criteria, it is possible to utilize up to 85.9% of feedstock from farms whose agricultural production volumes do not make it possible to meet the feasibility criteria for their own biogas installation.

4.2. Impact of State Regulation and Support on the Economic Feasibility of Agricultural Biogas Production in Ukraine

Currently, the main financial incentive for biogas projects in Ukraine is the feed-in tariff (called the “green tariff”) introduced by the Law of Ukraine “On electricity” [72] and substantiated by the Law of Ukraine “On the electricity market” [73]. The feed-in tariff is set at 0.1239 EUR/kWh, and the state guarantees this until the end of 2029. In 2019, the opportunity to generate electricity from biogas was introduced for cooperatives with a capacity of up to 150 kW [74].

The downside is that the set feed-in tariff can be applied only to installations put into operation by January 2023 [75]. This latest legislation change introduced in July 2020 means that from 2023, all biogas installations, including small ones, will have to participate in state auctions to receive state support and qualify for the feed-in tariff. Participation in such auctions will be accompanied by an additional financial burden for producers, as each bidder for the right to participate in the auction must pay 5000 EUR/MW and an additional 15,000 EUR/MW if they win in the auction. This will limit the current financial benefits from biogas installations and will certainly demotivate potential investors. Thus possible investment return periods for biogas installations were assessed both according to the current conditions as well as those set to come into force from January 2023 (Table 2).
Table 2. Possible return periods of biogas installations according to selected generation capacity.

| Parameters                                                                 | Generation Capacity |
|----------------------------------------------------------------------------|---------------------|
|                                                                            | 25 kW   | 50 kW   | 100 kW  | 150 kW  | 350 kW  | 500 kW  | 1 MW    | 10 MW   | 20 MW   |
| Simple return period under the current state support conditions, years     | 16.5    | 16.5    | 11.8    | 9.8     | 8.9     | 6.9     | 3.5     | 3.5     | 2.9     |
| Simple return period under the state auction system requirements (planned to be initiated from 2023), years | 16.6    | 16.6    | 11.9    | 9.9     | 8.9     | 6.9     | 3.6     | 3.0     | 3.0     |
| Auction costs, thousand EUR                                               | 0.5     | 1       | 2       | 3       | 7       | 10      | 20      | 200     | 400     |

Source: own calculations.

Participation in auctions thus extends the simple return period of projects, yet the effect is not substantial. For large biogas installations, the fact of participation in the auction increases the cost of the project from EUR 20,000 to 400,000. For small installations, the increase ranges from EUR 0.5 to 10 thousand. Compared to the cost of biogas installations, this is not a large additional burden, but the question remains about the participation in such auctions, their clarity and level of bureaucracy. The key advantage of the auction system is that it guarantees the provision of state support for the next 20 years, while currently, the feed-in tariff is set to expire in 2029. However, the disadvantage is that according to [75], the only feed-in tariff for electricity generated besides wind and solar installations cannot exceed the above-mentioned 12 eurocents/kWh, which means that biogas projects are unprofitable for small producers due to the lack of a flexible economic support mechanism. It was estimated that the feed-in tariff would have to be increased to at least 0.3 EUR/kWh if the state was aiming to support the development of small biogas projects based on livestock waste.

The legal basis for the introduction of feed-in tariff auctions in Ukraine was enacted in 2019 [74]. The pilot auction was to be held no later than October 2019, then it was postponed to April 2020, then to October 2021 [76] yet without success, and the new date is not yet known. For this purpose, annual quotas of support for particular types of renewable energy installations were to be determined. Given these implications and the need for significant investments, these auctions are obviously designed for large-capacity biogas installations, as the companies constructing them need to have access to large volumes of capital.

Another stimulating tool is also a premium on installations utilizing equipment produced domestically (Table 3). This premium is added on top of the feed-in tariff and depends on the share of domestic equipment used in the biogas project. At the same time, this premium is limited to 10% after six years of exploitation.

Table 3. Premiums for the use of domestic equipment in renewable energy generation projects.

| Benefit Level, % | Shares of Domestic Equipment Utilized within the Energy Generation Project, % |
|------------------|--------------------------------------------------------------------------------|
| 5                | between 30 and 50                                                             |
| 10               | between 50 and 70                                                             |
| 20               | over 70                                                                       |

Source: [75].

With the adoption of the Law of Ukraine “On the natural gas market” [77], biogas producers were granted the right to access gas transmission and distribution systems, gas storage facilities and LNG installations, as well as to connect to gas transmission and distribution systems, provided that technical and safety standards are met. The physical and technical characteristics of biogas should also meet the standards for natural gas.

In terms of electrical energy, according to the Law “On electricity market” [73], the taker (referred to in the legislation as the Guaranteed Buyer) is obligated to purchase electricity produced by households with installations of up to 50 kW capacity (the excess
electricity above their monthly consumption volume), with the price set as the feed-in tariff. Similarly, the regional service provider is obligated to purchase electricity from producers (including energy cooperatives with a capacity of up to 150 kW) of all electricity supplied, reduced by the amount of electricity consumed for their operational needs. It is estimated that biogas installations typically consume ca. 5–8% of the generated electricity to ensure their operation. According to the Bioenergy Association of Ukraine [51], if biogas plants could sell 100% of the generated electricity to the grid, it would slightly increase the investment attractiveness of biogas production. Estimates were thus made to assess the simple return period of biogas installations with different capacities depending on the selected support scenarios and conditions: (1) at current feed-in tariff rate and without the purchase of electricity for the installation’s operational needs; (2) at the current feed-in tariff rate and with the purchase of electricity for the installation’s operational needs; (3) at a potential feed-in tariff rate of 0.3 EUR/kWh and with the purchase of electricity for the installation’s operational needs (Figure 8).

Figure 8. Simple return period of different-capacity biogas installations depending on the support scenarios. Source: own calculations.

The assessment (Figure 8) shows that a simultaneous increase in the feed-in tariff from 0.1239 EUR/kWh to 0.3 EUR/kWh together with permission to buy electricity from the grid for energy needs of a biogas installation allow an acceptable return period (up to 5 years [78]) of for installations with a capacity starting at 150 kW. In order to achieve an adequate return period for smaller biogas installations (below 150 kW), it would be recommended to additionally compensate their investment (equipment) costs if renewable energy from this source is to be stimulated.

Despite the adoption of amendments to the Law of Ukraine “On heat supply” [79] providing a financial mechanism for non-natural-gas boilers (i.e., biogas in co-generation units), this mechanism has not provided a significant impetus for the development of biogas projects. It is advisable for agro-industrial enterprises in Ukraine to continue developing the generation of electricity and heat with the subsequent sale of heat to neighboring households, as the available feed-in tariff means this option of biogas utilization is most favorable in Ukraine’s economic conditions. However, farms are usually located at a distance from heat consumers (other farms and households), so the option of selling heat is rather an exception. Biogas projects can be located in areas where significant agricultural waste is produced, so the heat generated can be used in part to heat the farm itself. The key limitation here is that demand for heat is seasonal (at best half of a year in given climatic conditions), so it is impractical to focus solely on heat generation.

According to Ukrainian legislation [80], disposal of animal waste must be carried out exclusively by specialist companies and can not be performed by companies producing animal products for human consumption. Manure and animal residues belong to the second class of waste and can either be burned or converted into organic fertilizer after mandatory
sterilization under pressure or converted into biogas by pressure sterilization. Processing facilities for animal waste must be separate from companies producing foodstuffs. Class 2 waste can be used to make organic fertilizers and soil improvers that can be put on the market. Waste disposal companies are market operators. The law does not define the minimum and maximum size of such enterprises, which means that it also applies to small enterprises. Market operators are required to report their activities to the central veterinary authority on a monthly basis. They dispose of animal residues at their own expense or at the expense of state or local budgets that provide subsidies to businesses to partially compensate for the costs associated with the disposal and removal of animal by-products.

The procedure for using state funds to finance measures related to the disposal of animal by-products is approved by the Cabinet of Ministers of Ukraine. The State Budget of Ukraine for 2021 does not provide for such expenditure. Market operators who dispose of or remove by-products without pressure sterilization or without processing into biogas under pressure after sterilization can be fined. For legal entities, the fine is 23–30 minimum wages (in 2020, the minimum monthly wage in Ukraine equaled EUR 153); for private entrepreneurs, it is 8–15 minimum wages. For using unsealed containers for the transport of livestock waste by market operators, legal entities are subject to a fine of 8–12 minimum wages, and individual entrepreneurs are subject to a fine of 5–8 minimum wages. Sometimes companies prefer to pay a fine without further measures to dispose of livestock waste. However, large agribusinesses are subject to inspections by the Ministry of Health, the Prosecutor’s Office, the Sanitary and Epidemiological Service and the Environmental Inspectorate of the Ministry of Ecology and Natural Resources. In some cases, biogas installations using Ukrainian equipment are therefore not economically feasible even to cover the additional costs of waste disposal. For example, for a pig farm with 12,000 head, which produces 20,000 tonnes of waste, the manure disposal costs reach ca. EUR 10,000 annually [81].

In Ukraine, there are sectoral budget support programs for agricultural producers, with additional preferences for farms. In particular, the small farms are supported, which may be a synergy with the feed-in tariff for renewable energy generation utilizing biogas installations (Table 4).

Table 4. State farm-support programs of additional assistance to potential biogas producers.

| Programs | Maximum Support Value | Specific Features |
|----------|-----------------------|-------------------|
| Programs available to all types of agricultural producer | | |
| I. State support for livestock development | | |
| Reimbursement of the cost of livestock holding facilities | (1) For facilities up to UAH 500 million (EUR 16.2 million) excluding VAT—30% of the total costs; (2) For facilities with a value of over UAH 500 million (EUR 16.2 million) excluding VAT—30% of UAH 500 million (EUR 16.2 million); (3) For facilities creating 500 or more workplaces, regardless of their cost (excluding VAT)—30% of the total costs. | Costs for livestock farms and complexes keeping cattle, pigs, poultry; for enterprises processing agricultural products and/or by-products of animal origin not intended for human consumption, belonging to II and III categories. |
| Reimbursement of the cost of breeding animals purchased | Up to 50% of the purchase cost (excluding VAT), but not more than: - For breeding heifers, heifers, cows—UAH 31,500 (EUR 1000) per head; - For breeding pigs and boars—UAH 10,000 (EUR 325) per head. | Reimbursed is the share of loan for construction and/or reconstruction of livestock farms and complexes for keeping cattle, pigs and poultry; enterprises for processing agricultural products and/or by-products of animal origin, belonging to categories II and III, including the cost of equipment. |
| Reimbursement of the value of facilities financed by bank loans | Reimbursement of 25% of the loan of up to 5 years for legal entities and private entrepreneurs. | |
### Table 4. Cont.

| Programs | Maximum Support Value | Specific Features |
|----------|-----------------------|-------------------|
| Programs available to all types of agricultural producer | | |
| I. State support for livestock development | | |
| Partial reimbursement of costs for the purchase of agricultural machinery of domestic origin | Up to 40% of the costs of equipment purchased from domestic manufacturers, the list of which is determined by the Ministry of the Economy. | Twenty-five percent for all agricultural producers + 15% for registered farming households; the list includes equipment for the generation of renewable energy. |
| Loan reimbursements | UAH 15 million (EUR 487,000) for livestock producers, UAH 5 million (EUR 487,000) for other entities. | A 1.5 discount rate of the National Bank of Ukraine, but not higher than defined in the loan agreements, reduced by 5 percentage points. |

Programs dedicated to registered farming households

| Budget subsidy to registered farming households (except newly created) | UAH 40,000 (EUR 1300). | The head of the farm must be under 35 years old at the time of application. |
| Budget subsidy to newly created registered farming households | UAH 60,000 (EUR 1950). | Can be applied for in the first three years of the farm’s existence. |
| Partial reimbursement of costs associated with receiving services from advisory services | 90%, but not over UAH 10,000 (EUR 325). | Costs cannot be reimbursed under the “energy” section but can be reimbursed under “animal health” section. |
| Budget subsidy for keeping 5 or more cows | Up to UAH 250,000 (EUR 8120). | UAH 5000 (EUR 162) per head of cattle. |
| Reimbursement of Single Social Payments for registered farming households | | Within 10 years in the range of 0.1–0.9 of the minimum single social payment premium if the remaining share is paid by the head or by members of the registered farming household. |
| State loans under the Ukrainian State Fund for Support of Farmers [82] | UAH 500,000 (EUR 16,240). | For acquisition of fixed assets and replenishment of working capital. |

Source: compiled based on [83].

However, most of these programs are aimed at supporting agricultural production and could be treated as only supplementary support for the development of energy generation based on biogas. Moreover, the partial reimbursement of costs for the purchase of agricultural machinery of domestic origin includes a limited list of components for the generation of renewable energy (e.g., heat generators based on straw feedstock). At the same time, there should be dedicated state programs that would make it possible to take out a loan to finance biogas installations directly. It would also be advisable to extend the list of advisory services and include issues of renewable energy generation, as the lack of knowledge and advisory support to farms planning to engage and establish renewable energy installations is one of the key obstacles to their development.

In addition to government support, farmers and processors could benefit from a variety of sponsorships. In particular, the lending program through the Fund for Development of Entrepreneurship [84] was established jointly by the German state investment and development bank (KfW) [85], the Ukrainian government and the National Bank of Ukraine. Within this support, it is possible to apply for a loan of up to EUR 250,000 for five years to finance fixed assets of medium-sized enterprises (micro-crediting). Up to EUR 100,000 can be provided to enterprises, including for energy efficiency and energy saving, as well as job creation in depressed regions. The loan rate is calculated on the basis of the National Bank of Ukraine’s discount rate plus 5%; the loan’s timeframe is limited to six years [86]. Under the EU4Business program, it is possible to obtain a loan of up to EUR 5 million for up to ten years at a rate of 6–10% [87].

5. Discussion

By comparing the dynamics of energy generation based on biogas with the EU’s experience, it can be stated that in the past three decades, Ukraine has shown relatively slow progress. In the EU, renewable energy generation based on biogas is developing at a much higher rate [88]. In 2018, 18,202 existing biogas plants had a total capacity of
over 11 GW, producing 63,511 GWh of electricity [89]. In European countries, the main feedstock for biogas installations is crop residues and energy crops (almost half of the total feedstock) and livestock manure (ca. one-third) [11]. Germany is the European leader in the development of biogas energy, especially in terms of using the potential of agricultural feedstock. Thus, from 2014 to 2019, an annual average of 126 biogas installations were added, while the highest rate was from 2009 to 2011 (Figure 9). In addition, Germany is the European leader in the number of biomethane installations; as of 2018, the country had 195 units out of the total 540 units in the EU [90]. These installations are aimed at purifying biomethane and transferring it to the general distribution network.

![Figure 9. Biogas installations in Germany within 1992–2019. Source: own compilation based on [28].](image)

The dynamics of average annual biogas installation capacity in Germany show a rising trend (Figure 10). While by 2005, the average capacity of the new biogas installations was in the range of 150–200 kW, in 2005–2013, it increased to an average of ca. 0.5 MW, and after 2014, a tendency of large installations began, stabilizing around 2016.

![Figure 10. Average annual new biogas capacity in Germany (in MW). Source: own compilation based on [28].](image)
This development of biogas installations in Germany became possible not only due to the stimulation of renewable energy generation but also through the reduction in the attractiveness of fossil fuel. Thus, in the early 2000s, a tax on fossil fuels was imposed at 0.47–0.67 EUR/L of petroleum products and 0.015 EUR/kWh on electricity generated from other fossil fuels. There was a feed-in tariff of 0.0616–0.27 EUR/kWh, as well as 15–35% of additional subsidies for mini biogas installations [91]. As of 2017, the feed-in tariff for biogas from biowaste oscillated around 0.134–0.237 EUR/kWh, the feed-in tariff for biogas from organic fertilizers (manure) was at 0.2314 EUR/kWh for installations with a capacity of less than 75 kW. Feed-in tariffs are ranked overall depending on the size of biogas installation and the type of feedstock used; the energy producers are guaranteed the level of the feed-in tariff for ten years. In order to participate in the auctions, the installation capacity needs to be over 150 kW. If the auctions are won, state support is provided for up to 20 years [92]. By comparing Germany and Ukraine in terms of energy generation from biogas, it can be stated that Ukraine’s biogas market is in a similar condition and development level to Germany’s in the early 1990s. Maintaining such favorable policies for renewable energy generation in Germany has ensured the development not only of large biogas investment projects but also stimulated the appearance of numerous small and medium-sized installations, which is of considerable interest for Ukraine.

Most studies in Ukraine [34,41–43] stress the importance of biogas production development with a later generation of bioenergy, but they fail to take into account the investment issues depending on the size and availability of feedstock in small and medium-sized farms. What is more important, studies [32,33,44] that go deeper into the feed-in tariff analysis do not search for alternatives in order to propose more detailed approaches helping to create more beneficial conditions for various types of entities that might engage in biogas production. Thus there is a gap between theory and practice, as many researches do not differentiate between the above-mentioned dimensions, therefore failing to analyze the key predisposition—economic feasibility—to the full extent. The assessment presented in Section 4 makes it possible to understand these issues and shows that economic feasibility is missing from current state support conditions for all small and most medium-sized farms.

Obtained results go in line with the conclusions from [34] in terms of Ukrainian high potential for biogas generation, especially by farming households. The constant rise of natural gas prices emphasized upon in the aforementioned study support the necessity to tackle the issues hindering economic feasibility of energy generation from biogas by small and medium farms, as these entities would be the first to lose due to increased energy costs in case of further exploitation of fossil fuels. Another study [44] states that “a necessity to implement such projects is the introduction of an economically substantiated feed-in tariff for generation of energy based on biogas”, as with the current levels of the tariff, such feasibility is not reachable for most potential producers. These statements were proven true by the estimations conducted in the current study, as the small and most medium farms would not be able to return the investments in the expected timeframe based on the existing feed-in tariff for biogas installations.

The current state program aimed at supporting biogas energy generation does not differentiate the feed-in tariff, due to which there is a sharp polarization in investment—only large agricultural enterprises become involved in bioenergy based on biogas, and only 21 such installations have been established so far. Such a rate is not sufficient to make biogas energy a relevant renewable source, despite the existing agricultural potential defined in Sections 2 and 4.

Despite these implications, it is possible to seek solutions outside of solely the feed-in tariff. Farms whose feedstock production volumes do not allow profitable utilization of their biogas installations could potentially be merged into energy cooperatives based on the economic acceptability of feedstock transport costs. It is estimated that the economically feasible distance for the delivery of feedstock is up to 20 km for liquids and up to 50 km for solids [33]. Based on the previous administrative-territorial division [93,94], farms with biogas installations of up to 100 kW located in the same district as other farms could be
united into cooperatives. While there are possible limitations, in many districts, the 20 km range criterion would be maintained, although this aspect would need to be studied further.

Additionally, the establishment of energy cooperatives allows the construction of energy facilities at the expense of local communities. Ukraine established its first municipal renewable energy cooperative, “Solar City” in Slavutych (Kyivska region), in February 2020, which is a 200-kWh-capacity solar power installation [95]. In Ukraine, the creation of energy cooperatives may be particularly appropriate in rural areas, as they are home to over a third of the population, while the costs and quality of energy services are not always satisfactory. There are examples of uniting nearby communities according to the principles of an energy cooperative when the community uses waste from the production/cultivation of basic agricultural products as energy feedstock (for example, the Yagidnyi Krai cooperative in the Ternopilska region) [96].

The definition of “energy cooperative” in Ukraine is established by the Law “On alternative energy sources” [97]. Further, in accordance with the provisions of the Law of Ukraine “On the electricity market” [73], energy cooperatives can sell their electricity either to the Guaranteed Buyer or to private households through the regional energy service provider. The creation of energy cooperatives is in line with a number of global trends, including distributed energy generation, the use of renewable energy sources and the concentration of energy production near places of direct consumption. The largest energy cooperatives are in the United States, Germany, Denmark, Sweden, the Netherlands and Austria [98–100]. As of 2015, there were 1000 cooperatives in Germany, which owned 47% of the renewable energy capacity [101].

Wider use of biogas requires changes in infrastructure, such as new roads for the supply of feedstock. Long-term contracts between suppliers of feedstock and enterprises that process it are necessary, which is especially relevant for small and medium-sized projects. Priority grid connection could be introduced for biogas projects, with the small installations (up to 500 kW) having these permits lifted. The construction of biogas pipelines is required to supply biomethane to the gas transportation systems. A Ukrainian corporation (“MHP Agro and Industrial Holding”) has experience in building such biogas pipelines at ca. EUR 1 million per kilometer [102].

In the long run, it is possible to introduce the mandatory use of biogas by farms that produce the corresponding feedstock. This can be performed by introducing new national building standards for the construction of new agro-industrial companies whose activities are related to waste generation (farms, breweries) or the introduction of requirements for mandatory measures to reduce methane and carbon dioxide emissions. Legislation defining the need for sterilization of livestock waste under pressure should be repealed for biogas production, and existing fines for improper management of agricultural waste should be canceled.

Government loan guarantees would be beneficial. In order to enable the spread of biogas projects for small and medium-sized enterprises in Ukraine, interest rates on loans should be reduced through further cooperation of Ukrainian banks with international financial institutions such as the Global Environment Facility, the European Bank for Reconstruction and Development and the Clean Technology Fund.

There is poor dissemination of information and a lack of nationwide information campaigns on the use and construction of renewable energy sources in the agro-industrial complex. In our opinion, this barrier is no less important than financial barriers. Large agricultural corporations (referred to in Ukraine as agriholdings) already understand the benefits of using biogas and are launching large biogas projects. However, potential small and medium-sized producers need detailed information that not only provides information about the types of equipment but also about institutions providing financial support (state and private), as well as what would be the practical steps to construct a renewable energy installation and connect it to the energy grid or how to obtain the feed-in tariff for the energy. Changes should be made to requirements for obtaining state support, cutting bureaucracy and shortening the time lag between investments and actual support.
An important difference between small and large biogas projects (not to mention wind and solar energy) is access to development companies, which could be hired to prepare an investment feasibility study, change the land documentation to allow the placing of energy generation installations, obtain permits implementing the project, connect to the grid and start construction work [103]. Such functions are not widely available or affordable for small and medium-sized biogas projects, thus excluding them from investments in renewable energy generation. Detailed step-by-step information is needed to enable and speed up this process.

6. Conclusions

The study identified the economic feasibility of the development of renewable energy based on biogas projects in Ukraine, its key obstacles and legislation implications. Medium-sized and small farm capacities were focused upon as these types of farms in Ukraine are less economically viable. State support measures were analyzed to understand possible synergies between potential agricultural biogas projects and programs aimed at general or specific agricultural activities.

The analysis has shown there are relatively high initial investment costs, especially for small biogas installations. The smaller the installation, the higher the investment cost per unit of capacity. Loans and a special program for the implementation of small projects (up to 0.5 MW) are needed to aid small farms. This can be achieved in part through international financial institutions with energy efficiency and renewable energy generation programs, for example, by the International Finance Corporation or by the European Bank for Reconstruction and Development. The latter launched the EU4Business program in 2016 in cooperation with the European Commission, aimed at small- and medium-sized enterprises. It is also necessary to expand the Ukrainian state program to support farmers, including in terms of stimulating the purchase of certain types of machinery and equipment [104].

The feed-in tariff or the upper limit of the auction purchase price (currently the same as the feed-in tariff) is too low for biogas installations, which typically require high investment costs. The low feed-in tariff does not allow payback periods of biogas investment projects of less than seven years while, due to national currency volatility, inflation and the unstable political situation, bank institutions in Ukraine typically consider financing projects with a payback period of four to five years. In addition, it is advisable to differentiate feed-in tariff coefficients for biomass and biogas depending on the feedstock used so that the feed-in tariff coefficient or the upper limit of the auction price should be higher for biogas from agricultural waste than for biogas from by-products from alcoholic beverage production. In addition, the feed-in tariff or auction price should be differentiated depending on the installed capacity—the lower the capacity, the higher the tariff.

Currently, electricity from wind and solar energy installations is cheaper than that from biogas, while the feed-in tariffs in Ukraine for these sources of energy are higher. This is caused by significant differences in the costs of equipment, especially in the field of solar energy. It is likely that, with the introduction of liability for supply shortages, electricity from biogas would no longer be significantly more expensive, as upgrading meteorological stations to improve the quality of the forecast requires investment, and the question of who should invest in upgrading meteorological equipment in Ukraine has not been sufficiently considered. Moreover, wind and solar energy generation are dependent on seasonal and weather conditions, as well as daytime slots. At the same time, energy from agricultural biogas could be carried out either on a permanent basis or on-demand to cover gaps in the energy supply from more intermittent sources. Thus the lower feed-in tariffs for biogas are not well-grounded and do not take into account the importance and role of this source, yet this is a point for future research.

In conclusion, the state policy on biogas production and energy generation from agricultural sources is still fragmented and does not take into account the diversity of farms and their peculiarities, including the small and medium-sized ones. Within the
existing legal framework, even after the launch of auctions, small farms have no real financial incentives to launch biogas projects. The current feed-in tariff is too low to provide reasonable payback periods. The marginal auction price is also too low. Small and medium-sized farms also need to prepare the investment projects on their own, as well as have limited access to financing. In order to overcome these problems, a specialist state biogas development program with government loan guarantees is needed, as well as advisory support and services to enable small and medium-sized farms to overcome the barriers of a lack of information. Such a complex approach could improve the conditions and make investments in bioenergy generation based on biogas more feasible, at least for a larger group of farms of various sizes.

Conclusions based on the studied Ukrainian experience could also serve as recommendations for other countries aiming to develop renewable energy generation. Financial (state or otherwise) support for diffusion of such innovations plays a crucial role, as its intensification is not possible if economic feasibility is not achieved and transfer to more “green” energy generation technologies are not incentivized, either in financial or organizational dimension. As for the latter, the experience of renewable energy development in Ukraine highlights the importance of institutional aspects, proving that transparency, consistency, stability and long-term predictability of state support and regulations are as crucial for the appropriate investment climate and transition to more environmentally-friendly energy generation solutions.

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