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Trash to Hryvnias: The economics of electricity generation from landfill gas in Ukraine

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ABSTRACT

Utilization of landfill gas for electricity generation should be an attractive option for Ukraine in light of the country's rapidly growing municipal solid waste problem, the influx of intermittent renewable electricity into the national grid, and renewable energy adoption commitments. However, the deployment of landfill gas power plants has been slow vis-à-vis other alternative energy technologies despite the existing government incentives. This article aims to help understanding this trend by investigating the economic feasibility of landfill gas power plants. The research focuses on determining the Levelized Cost of Electricity of these electricity generation facilities and comparing it to the feed-in tariff available to landfill gas electricity producers. The results show making an investment into a landfill gas-fired power plant is an appealing strategy due to a potential high and quick return on investment in 5.1 years. This leads to the ultimate conclusion that economic feasibility is not a cause for the slow adoption of landfill gas as a source of renewable electricity generation in Ukraine. In addition, the article identifies several potential barriers to landfill gas electricity generation deployment to be investigated in future research.

Keywords

Landfill gas;
Renewable electricity;
Waste management;
Energy policy;
Ukraine.

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1. Introduction

Over the past few years, municipal solid waste (MSW) generation has seen a steady increase in Ukraine. Whereas many countries ramp up their recycling programs and infrastructure [1,2], Ukraine's progress in this regard remains pedestrian, thereby exacerbating the problem of MSW growth. Presently, the disposal of MSW in landfills is the dominant method of waste management in the country. Due to the lack of a coherent waste management strategy of the Ukrainian government, the country's municipal landfills are rapidly running out of capacity since 93.7% of all MSW in the country is disposed in them [3].

The growing MSW problem in Ukraine has a silver lining – a plentiful resource base for electricity and generation. As international experience demonstrates, collecting and utilizing landfill gas for this purpose is an effective way to minimize environmental impact of MSW while extracting economic value from waste [4,5].

Landfill gas generally consists of 40%-45% carbon dioxide (CO_2) and 50% to 55% methane (CH_4). The latter transforms noxious landfill gas with a high global warming potential into a flexible fuel that can be used, among other things, for electricity and heat generation. In addition, responsibly utilizing this valuable resource can create a pathway for developing sustainable waste

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management in Ukraine while attaining significant environmental benefits [6,7].

Domestic methane production from landfill gas would indeed be a welcome addition to the Ukraine's current energy mix because 42% of the country's natural gas comes from abroad [8]. Currently, there are 28 operating landfill gas power plants (LGGPs) in Ukraine. In contrast, there are 564 LGGPs in the United States, which became a net natural gas producer in 2018 [9].

Equally important is addressing the negative environmental impacts of municipal landfills, especially curbing greenhouse gas emissions. Municipal landfills are a powerful source of methane emissions, the global warming potential of which exceeds that of carbon dioxide 28 times [10].

As of 2019, methane emissions from municipal landfills in Ukraine accounted for 16% of the country's total methane emissions ranking, third behind the energy and agriculture sectors that contributed 65% and 17%, respectively [11]. However, while methane emissions in the energy sector have remained flat over the last few decades, and in the agriculture sector, they have decreased, emissions in the waste management sector have seen steady growth. In addition, utilizing landfill gas to produce energy will help Ukraine to achieve the renewable energy targets outlined in the programmatic policy statement entitled "The Energy Strategy of Ukraine until the year of 2035" (Energy Strategy 2035) [12].

The construction of a LGPPs require significant capital investment. Therefore, because of the difficulties in access to and cost of private financing for renewable energy projects in Ukraine, LGPPs deployment requires support from the government in various incentive mechanisms [13,14,15]. Such tools, the main of which is the feed-in tariff, were introduced over a decade ago but are yet to result in LGPPs deployment on a meaningful scale.

The overarching objective of this paper is to contribute to the understanding of potential reasons for the slow proliferation of LGGPs in Ukraine. We aim to determine whether economic feasibility is among such reasons. To accomplish that, we calculate the Levelized cost of electricity (LCOE) produced at an LGPP in Ukraine, compare it to the feed-in tariff, at which a producer can sell electricity, and estimate the payback time for LGGP projects. We begin the paper with a brief literature review and the background on the trends in MSW management and incentives for renewable energy development in Ukraine because Ukrainian law designates landfill gas as a renewable energy resource. We continue with outlining our methodology, data, and assumptions. We conclude by discussing our results, policy implications, and avenues for future research.

2. Literature review and background

As we elaborate in more detail below, the literature on the economic feasibility of electricity generation from landfill gas in Ukraine is scarce, with only a few articles available in English-language academic journals. Thus, we examined grey literature such as white and position papers, as well as technical reports. In addition to literature featuring the utilization of landfill gas for electricity production in Ukraine, we reviewed literature on renewable energy incentives in the country.

Although our literature review produced modest results, the relevant works can still be categorized in three groups. These groups include works that: (1) describe the trends in LGGP adoption; (2) explore the need for and benefits of LGGPs; and (3) assess the technical and economic feasibility of utilizing landfill gas for electricity generation.

To contrast our results with the literature regarding LGGPs in other countries we conducted a Google Scholar survey (but not review) that was not limited to Ukraine. In addition, to place the results of the literature review in the broader context of the national waste disposal and energy policies, we identified key statistics from Ukrainian government sources and compared these data with the relevant E.U. statistics. To obtain the necessary data regarding the applicable financial incentives and conditions for obtaining them, we completed the following steps. First, we identified the recent programmatic policy statements and law. Second, we analysed the applicable law to correlate the incentives with the LCOE inputs.

2.1. Literature review

A notable representative of the first category of the relevant literature is Korpoo's 2007 study that highlights the deployment of LGPPs in Ukraine as Joint Implementation (JI) projects under the Kyoto Protocol in 2007 [16]. Korpoo notes a much lower rate of landfill gas utilization for electricity production in Ukraine compared to Russia despite its environmental and social benefits, as well as the presence of financial incentives.

Geletukha et al. [17] explore LGGPs in the larger context of biomass use for electricity production.

Among other things, they list all operating LGGPs in Ukraine and the existing landfills that collect landfill gas for utilization.

In contrast, Zhuk provides a narrowly focused update on the state of landfill gas facilities, including the technical solutions therein [18]. Zhuk also notes the new requirements for the landfill gas and the challenges of methane recovery from older landfills LGGPs. The update reports some encouraging developments, among them the use of specialised modelling software.

An article by Makarenko and Budak highlighting Ukraine's MSW problem represents the literature on the need for and benefits of LGGP deployment [19]. The authors view landfill gas as a source of air pollution, contributing to environmental deterioration and negatively impacting public health. Winkler and Zharykov make similar observations based on a case study of a municipal waste disposal area [20].

The third category consists of technical and economic assessments of landfill gas use for electricity generation. Remarkably, we were unable to locate sources that a combined, technoeconomic analysis. A notable representative technical assessment is the "User's Manual Ukraine Landfill Gas Model" prepared by a U.S. engineering firm on behalf of the U.S. Environmental Protection Agency for the Ukrainian government [21]. The manual provides a thorough description of the model to estimate landfill gas generation and recovery in the entire country.

Udovyk and Udovyk also examine the technical feasibility of landfill gas utilization but place their assessment of LGGPs potential in the context of the prospects for sustainable energy development in Ukraine [22].

A notable representative of the economic assessments and perhaps the closest to the subject of this study is an article by Trypolska's entitled "Feed-in tariff in Ukraine: The only driver of renewables' industry growth? [23]. Trypolska makes a broad assessment of opportunities for renewable energy development in Ukraine, including landfill gas, in the aftermath of the aforementioned feed-in tariff legislation in Ukraine. However, due to the broad scope of the study, her analysis is limited to a single paragraph in which she projects the broad deployment of LGGPs across the country.

The scarce body of literature on electricity generation from landfill gas in Ukraine, let alone on the economic feasibility thereof, stands in contrast with the vast literature on this subject featuring other countries. The subject remains novel (and therefore undersearched) in Ukraine – the oldest study that mentions LGGPs dates back to 2007 [16]. There are some studies, for example, centring on the United Kingdom that were conducted in the 1970s [24]. This is not surprising because electricity generation from landfill gas in Ukraine remains in its infancy whereas in the United Kingdom landfill gas for power generation became a reality in the mid-1980s with nearly 50 LGGPs in service in just a decade [25].

It is not just Western countries, there have been numerous studies focusing on utilization of landfill gas for power in Korea[26] Taiwan [27], and South Africa [28], among other countries that predate the 2007 Korpoo study. The scarce body of literature and the aforementioned studies from other countries state environmental and social benefits of landfill gas utilisation for electricity generation. In addition, the literature provides evidence that LGGPs are a mature commercially-sclable technology that has been widely deployed worldwide for several decades. However, the literature does little to explain the reasons for the slow LGGP adoption in the Ukraine. In particular, it lacks an in-depth analysis of the economics of LGGPs, which is often cited as the main reason for government and corporate decision-makers for not developing an energy project.

2.2. Trends in the MSW generation and recycling in Ukraine

Over the past few decades, despite the steady population decline, there has been a steady increase in MSW generation in Ukraine. Currently, the national average MSW generation rate per person is 250-300 kilograms a year. Depending on the source, the annual amount of municipal solid waste generation is estimated from 11 to 13 million tons [12, 29].

The primary method of waste management in Ukraine is the removal and disposal of MSW in landfills. In 2020, 93.7% of all MSW was landfilled, only 4.6% recycled, and 1.7% incinerated (we did not find any evidence that the inceneration included heat recovery). (Figure 1) [3].

By 2020, more than 200 million tons of MSW had accumulated in 5455 authorized landfills, the combined area of which exceeded 8500 hectares. About 258 of all landfills in Ukraine (4.25%) have exceeded their capacity, thereby violating the allowable amounts of waste accumulation. About 905 of all dumps (15%) do not meet environmental safety standards [3]. What makes the waste management situation in Ukraine even more

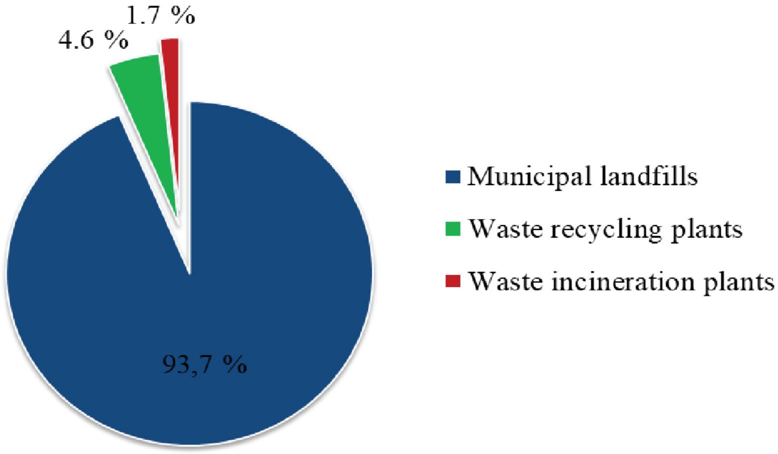

Figure 1: Municipal solid waste management in Ukraine in 2020 [3]

problematic is that almost 22% of Ukraine's population lack access to MSW disposal services. It has led to widespread dumping, with as many as 27,000 smaller illegal waste disposal sites appearing every year [3, 18].

Ukraine's MSW problem is one of the causes of significant environmental degradation in the country. As noted above, landfills are sources of carbon emissions and cause ambient air quality deterioration. In addition, uncontrolled emissions and the ability of MSW to self-combust lead to unpredictable and often uncontrollable landfill fires that emit harmful substances such as dioxins, chloride and fluoride hydrogen, carbon monoxide, nitrogen, sulphur dioxide, etc. Public health concerns do not end there – chemicals found in the discarded car and household batteries, fluorescent lamps, electronics can leach into the soil and contaminate ground and surface water.

The legal and regulatory framework governing recycling has failed to provide sufficient incentives for firms to recover raw materials from MSW [18]. In this regard, Ukraine is far behind some European Union countries – Germany, Austria, Switzerland, the Netherlands, Belgium, Slovenia, Denmark, and Italy – that recycle more than 50% of their MSW [30].

In light of Ukraine's environmentally unsound and economically unproductive way of managing MSW, harvesting landfill gas for electricity generation appears to be a particularly effective step to address both shortcomings. Landfill gas is a product of anaerobic digestion of organic substances by a natural methane-producing bacterium. Landfill gas is a multicomponent gas, the composition of which may vary depending on the morphological composition of waste in a landfill. As noted above, methane (50-55%) and carbon dioxide (40-45%) are the two main components of landfill gas, with the remainder (about 5%) consisting of nitrogen compounds, hydrogen sulphide, other organic compounds, and water vapor [31,32].

The volumetric potential for gas generation is one of the primary considerations for determining the prospects for constructing a landfill gas collection and utilization system. Currently, the 90 largest landfills contain nearly 30% of all MSW in Ukraine. The potential for landfill gas suitable for electricity production at these landfills is about 400 million m^3/year [18,20].

2.3. Governance of renewable energy development in Ukraine

The long-term goals and pathways for developing the renewable energy sector are outlined in the aforementioned Energy Strategy 2035. According to the Energy Strategy 2035, the share of energy from renewable resources in the country's final use is projected to increase to 12% and 25% in 2025 and 2035, respectively [12]. Therefore, subsequent numbering should be changed in chronological order.

The main policy drivers aimed at encouraging electricity generation from landfill gas were first introduced in 2009. These policy drivers include incentive mechanisms such as the feed-in tariff, tax incentives, and customs privileges [34]. We assess their effectiveness in more detail below.

Feed-in tariff. According to "On the Electricity Market," the feed-in tariff is a special rate at which electricity generated from RES, including from landfill gas, is purchased [35]. "On the Electricity Market" designates landfill gas as gas from biomass. Biomass is a renewable organic substance, including forestry, agriculture, fish farming waste, and biologically decomposable industrial and domestic waste [35].

The feed-in tariff is calculated according to the formula provided in “On the Electricity Market” [35]. It is adjusted every month by the National Commission for State Regulation of Energy and Public Utilities of Ukraine and converted to EUR according to the official exchange rate of the National Bank of Ukraine to protect electricity producers from inflation.

“On the Electricity Market” provides an additional incentive for using domestically manufactured equipment. This incentive is calculated based on the feed-in tariff in proportion to the percentage of equipment used in the completed LGPP, as depicted in Table 1.

Table 1: An additional incentive for using Ukrainian equipment in a LGPP [35]

Additional incentive calculated as a percentage of the eligible feed-in tariff	Percentage of the Ukrainian equipment, used
5	30
10	50

The manufacturing of such equipment in Ukraine is confirmed by a certificate of origin issued by the Ukrainian Chamber of Commerce and Industry or its regional office. The aim of this additional incentive is to encourage the development of domestic manufacturing capacity, reduce dependence on imported equipment, and create a foundation for exporting Ukrainian-made equipment abroad. The feed-in tariff for landfill gas electricity is not capped and will remain in effect through 2029.

The Tax Code [36] and Customs Code of Ukraine [37] provide the following incentives and privileges for LGPP construction:

- Value-added tax exemption for the equipment and components used for LGPP construction;
- Customs duty exemption for the imported materials, equipment, and components used for LGPP construction.

The tax incentive and customs privilege are available as long as such materials, equipment, and components are not produced in Ukraine.

These incentive mechanisms provided a much-needed boost for the deployment of LGPPs in Ukraine, as shown in Figures 2-3.

Despite the marked progress, LGPPs still lag behind other renewable sources – in 2019, LGPPs were last with only 1.4% of all renewable electricity generated in Ukraine (Table 2).

To further emphasize the insignificant share of landfill gas electricity in Ukraine’s generation mix – renewable energy sources, except for large hydro, contributed only 4.8% of the total electricity generated in Ukraine in 2019. Presently, the vast majority of electricity in Ukraine continues to come from conventional power plants. In 2019, nuclear power plants provided 55.7% of the total amount of electricity generated in the country, fossil fuel power plants provided 35.7% (27.2% from thermal power plants and 8.5% from combined heat and power plants), and large hydropower plants provided 3.8% [39].

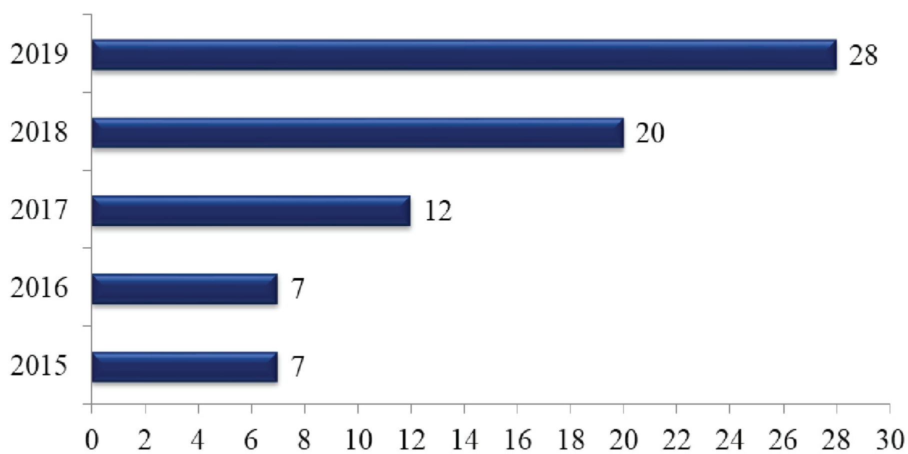

Figure 2: Number of LGPPs in Ukraine in 2015-2019 [38]

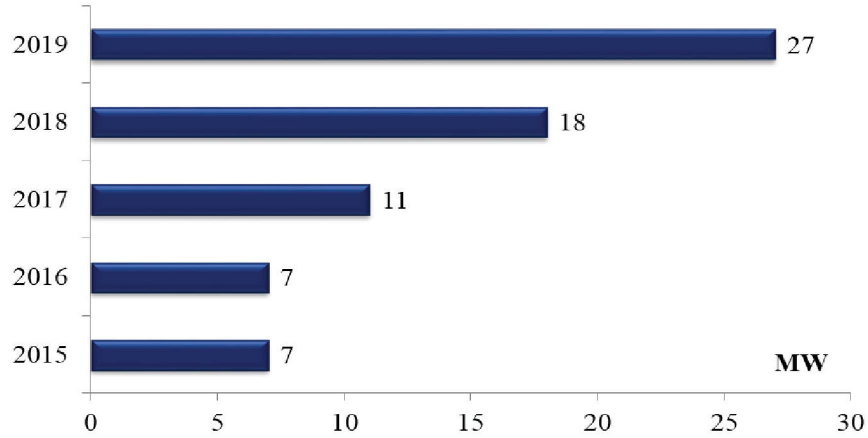

Figure 3: The total installed capacity of LGPPs in Ukraine in 2015-2019, MW [38]

Table 2: The total mix of electricity generated by renewable power plants in Ukraine as of 2019, % [39]

Type of renewable power plants	The contribution to electricity generation, %
Solar power plants	52.1
Wind power plants	35.5
Small hydropower plants	7.2
Bioenergy power plants (solid biomass)	2.6
Bioenergy power plants (agricultural biogas)	2.1
Bioenergy power plants (landfill biogas)	1.4

Because the primary tool to promote electricity gen¬eration from landfill gas is the feed-in tariff, we will estimate the cost of electricity generation by an LGPP to compare it with the current rate of the feed-in tariff to make sure that it sufficiently covers the electricity generation cost, to provide profit for LGPP owners and to return the initial investment.

3. Data and methods

3.1. Methodology

As noted above, to determine whether economic feasibility contributes to the slow deployment of LGGPs in Ukraine, we calculate the LCOE produced by an LGPP, compare it to the feed-in tariff, at which a producer can sell electricity at the electricity market, and estimate the payback time for LGGP projects.

The LCOE is the most common tool used to measure and compare the economic competitiveness of various electricity generation technologies [40]. The LCOE reflects the minimum price at which electricity must be sold to guarantee that investment will pay off. The LCOE generated from renewable energy resources should serve as the basis for setting feed-in tariffs to stimulate renewable energy growth [41].

The LCOE is determined by dividing the total cost of a power plant by the electricity generated by the power plant over the project's lifetime. It is customary to use the financial lifetime of an energy project in the financial depreciation term and not the actual or useful engineering life of a power plant. At times, the financial lifetime of a power plant corresponds to its engineering lifetime, and at times, it does not. The cost of funding for this paper, we will refer to the LGPP lifetime as the financial lifetime of the project. It is important to note that LCOE is ultimately a modeling exercise based on many assumptions. For example, the discount rate and electricity price are presumed to be constant during the project lifetime [42].

To determine the LCOE for an LGGP, the investment cost, operation, and maintenance cost, the amount of generated electricity, decommissioning cost, and the discount rate are entered as follows:

$$LCOE = \frac{\sum_{t=0}^{n}\left((I_t + Q_t + D_t)\cdot(1+r)^{-t}\right)}{\sum_{t=0}^{n}\left(E_t\cdot(1+r)^{-t}\right)}, \quad (1)$$

where *LCOE* is the fixed cost for electricity generation during the LGPP lifetime, EUR/MWh; *Et* is the amount of generated electricity by the LGPP in *t*-year, MWh; *It* is the investment cost in *t*-year, EUR; *Qt* is the operation and maintenance cost in *t*-year, EUR; *Dt* is the decommissioning cost of the LGPP in *t*-year, EUR; *n* is the LGPP's lifetime in years; *r* is the discount rate; *t* is the year of the project implementation.

The discount rate is calculated based on the Weight Average Cost of Capital (WACC) as follows [43]:

$$WACC = K_S \cdot W_s + K_d \cdot W_d \cdot (1 - tx), \quad (2)$$

where *Ks* is the cost of equity for investment project implementation; *Ws* is the part of equity by balance; *Kd* is the cost of debt for the investment project implementation; *Wd* is the part of the debt by balance; tx is the profit tax rate for the enterprise.

The feed-in tariff is determined pursuant "On the Electricity market" [35]. Thus, according to the statute, the minimum rate of the feed-in tariff is calculated according to the following formula:

$$FT_{min} = \frac{T_{con.II\ 01.01.2009} \cdot k_{FT}}{E_{01.01.2009}} \quad (3)$$

where FT_{min} is the minimum feed-in tariff for electricity generated from landfill gas; $T_{con.II\ 01.01.2009}$ is the retail price for electricity for the second-class-voltage consumers as of January 2009 (0.58 UAH/kWh); k_{FT} is the feed-in tariff coefficient for the LGPPs outlined in "On the Electricity Market" [35]. $E_{01.01.2009}$ is the exchange rate of UAH to EUR, officially set by the National Bank of Ukraine on January 1, 2009 (1085.55 UAH per 100 EUR).

The feed-in tariff coefficients for electricity generated by LGPPs in Ukraine during 2017-2029 are shown in Table 3 [35]. The enabling legislation sets forth a gradual decline in the feed-in tarrif, 10% from 2015 to 2024 and 20% from 2015 to 2029. The legislation does have electricity cost escalation rate.

Table 3: The feed-in tariff coefficients for electricity generated by LGPPs in Ukraine during 2020-2029 [35]

The feed-in tariff coefficients for electricity, generated by LGPPs, put into operation:	
from 01.01.2020 to 31.12.2024	**from 01.01.2025 to 31.12.2029**
2.07	1.84

Based on the FT_{min}, the *FT* at which the electricity generated by LGPPs is sold is calculated:

$$FT = FT_{min} \cdot E_{30}, \quad (4)$$

where *FT* – tariff at which electricity is sold (UAH for 1 kWh without VAT); E_{30} – the average exchange rate of UAH to EUR for the last 30 calendar days preceding the date of calculation of the FT, UAH per 100 EUR.

It should be noted that the primary purpose of converting the FT into EUR is to protect the investors from fluctuations in UAH against EUR and possible inflation.

The discounted payback period of the LGPP investment project is calculated as follows:

$$DPP = \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \geq IC_0, \quad (5)$$

where *DPP* is the discounted payback period of the investment project; IC_0 is the initial investment during year zero of the project, EUR; CF_t is the net cash flow in *t-year*, EUR; *r* is the discount rate; *n* is the project lifetime, years; *t* is the year of the project implementation.

3.2. Techno-economic assumptions and data

As noted above, calculating LCOE is inherently a modeling exercise. The data and assumptions can vary depending on the country, the region within a country, and the timeframe. In this study, we relied on the most recent available data aggregated nationally by reputable organizations. Thus, we relied on the LGPP projects implemented in Ukraine [44], recommendations of the European Bank for Reconstruction and Development under the Ukrainian Sustainable Energy Lending Facility (USELF) program [45], the International Energy Agency (IEA) [46], and the Danish Energy Agency [47]. Based on the provided data, the techno-economic characteristics of an average LGPP in Ukraine are listed in Table 4 below:

It should be noted based on the data that we used, the efficiency of Ukrainian LGGPs is in line with modern plants deployed worldwide.

Although LGPPs with combined heat and power production have a much higher total efficiency, this study relates only to electricity production. It is due to the fact that according to Ukrainian legislation, heat generation is not supported by the FIT [35]; as a result, investors prefer only electricity production.

The cost of landfill gas required for the technological needs of an LGPP was taken as zero because it is standard practice in Ukraine that the developer gets the gas for the operational needs of plants for free.

The average LGPP construction time in Ukraine is 1 year; this period was used in this study. Its increase or

Table 4: The techno-economic characteristics of an average LGPP in Ukraine

Category	Characteristic	Value
Technical	Total electricity output capacity	1 MW
	Projected annual amount of electricity generation	8,150 MWh
	Time in construction	1 year
	Lifetime	20 years
Expected investment cost	Feasibility study cost	170,000 EUR
	Installation and construction cost, including landfill gas collection equipment and all supporting infrastructure	537,000 EUR
	Generator cost	1,162,100 EUR
	Interconnection cost	80,000 EUR
	Cost contingency	20,000 EUR
Operation and maintenance cost	Salaries	6,560 EUR/year
	Service and consumables	95,000 EUR /year
	Other cost (insurance, security, etc.)	30,000 EUR /year

decrease in each specific investment project may affect the LCOE value.

It is worth noting that Table 3 does not list LGPP decommissioning cost because the RE sector is still in its infancy in Ukraine there are no country-specific data. According to the IEA, decommissioning costs are part of LCOE calculation and equal the sum of all costs associated with ceasing RE power plant operations, including dismantling and removing all the equipment and infrastructure and site remediation [48]. If the ecommissioning costs are unavailable, the IEA recommends estimating 5% of all investment costs [48]. Therefore, 98,455 EUR/MW is estimated for decommissioning costs.

The discount rate calculated according to formula (2) is 4.7%. The 40:60 equity to debt ratio and the cost of debt (8%) used to calculate the discount rate were determined in accordance with the standard terms offered by the USELF program to finance RE projects in Ukraine. Because the interest on such a loan is attributable to the prime cost of production, debt capital was adjusted by the percentage of profit tax to reduce the tax base. According to the Tax Code of Ukraine, the corporate tax rate is 18% in 2021 [36]. The cost of equity (1.8%) was determined on the basis of the average maximum annual interest rates on EUR deposits for companies in banks of Ukraine as of 01.05.2021 [49].

4. Results and discussion

Based on the data noted above and according to Formula 1, the LCOE generated by an LGPP in Ukraine is 34.48 EUR/MWh.

Next, we will calculate the FT at which electricity generated an LGPP will be sold. For this, we will use the coefficient of FT – 2.07 for LGPPs, put into operation from 01.01.2020 to 31.12.2024 (Table 3) and the average exchange rate of UAH to EUR for the period from 01.04.2021 to 01.05.2021, which amounted to 3351.01 UAH per 100 EUR [50]. Therefore, the FT, calculated according to formulas (3) and (4), is 99.58 EUR/MWh or 0.1 EUR/kWh.

Thus, in Ukraine, the feed-in tariff for electricity generated by LGPPs exceeds the LCOE by a factor of 3.3. Furthermore, according to the above data and equation 5, the payback period for an investment in a LGPP project at the feed-in tariff is 5.1 years.

The results show that LGPP projects in Ukraine present an attractive investment opportunity. The current feed-in tariff – LCOE ratio makes a high and quick return on investment a real possibility. Therefore, it is reasonable to conclude that economic feasibility is not a cause for the slow adoption of LGPPs in Ukraine.

The results confirm the growing consensus among energy research regarding the heterogeneity of drivers and motives behind adopting RE technologies, including biogas-fired electricity generation [51, 52, 53]. While in some countries, entrepreneurial considerations might be the predominant drivers behind RE adoption, in others, environmental, education, and gender considerations appear to be driving the shift towards renewable sources [54].

The fact that the aggressive feed-in tariff has not resulted in a more rapid proliferation of LGPPs questions the Ukrainian government primary strategy to support LGPPs deployment. It is not to suggest that the current support is unimportant – there is plentiful evidence suggesting that aggressive government incentives are necessary for RE adoption [55]. Instead, because the current support is insufficient, it should be viewed as a part of a package solution in which several mechanisms complementing each other. Determining such a package solution in substantive detail is outside the scope of this study.

The following is a list of directions that researchers and public authorities managing RE sector should consider when making decisions:

- *Access to capital and transactional costs*

In addition to the aforementioned USELF program, Ukrainian commercial banks offer two credit programs: Eco-Energy and Green Energy, to support RE development [56,57]. However, these two programs do not include support for LGPPs. As a result, potential investors are confronted with interest rates in the 19-25% range. Although LGPP projects qualify under the USELF program, the financial, technical, and environmental project documentation required by USELF leads to high transactional costs. Because of the small scale of LGGP facilities, high transactional costs undermine the financial viability of these projects, despite the attractive interest rate. A potential solution may include mechanisms that would allow smaller entities to consolidate financial resources and organizational capacities, such as energy cooperatives [58].

- *Stability of the governing legal and regulatory framework*

It is not uncommon to see the legal and regulatory regime of a former Soviet nation in a constant state of flux. Unfortunately, Ukraine is no exception. Although the existing incentive framework has been in place for a decade, the coefficients mentioned above have been adjusted several times without considering the technological development and changes in the cost of LGPPs [35].

In addition, the grid interconnection rules for LGPPs remain a moving target, whereas the stability of the current incentive framework is threatened by the emergence of green auctions [60]. The concern here is that they will replace the feed-in tariffs, thereby exacerbating the dominance of mainstream commercially proven technologies at the expense of grid stability. It is reasonable to envisage the chilling effect on investor and developer confidence due to a lack of legal and regulatory stability. A potential solution for these concerns is adding and not substituting incentive mechanisms to create more effective matches of established, emerging, and novel technologies and incentives used to support them.

- *Alignment of government incentives and system benefits*

The current system of incentives for RE support in Ukraine largely fails to recognize the value that different RE technologies bring to the grid [35]. As a result, developers appear to favour commercially proven scalable technologies such as wind and solar photovoltaic power.

In addition, insufficient attention has been given to developing grid stability measures such as energy storage, weather forecasting, and strengthening transmission and distribution networks [62]. These shortcomings manifested during the recent drop in electricity demand caused by the COVID-19 pandemic when the stability of the United Energy System of Ukraine was put at risk. To mitigate it, the system operator was forced to shut down several nuclear reactors that currently generate the cheapest electricity in the country [62]. It likely lead to an increase in residential, commercial, and industrial electricity rates [63]. Unlike solar and wind, LGPPs do not have an intermittency. In addition, LGPPs are usually located near load centres, thereby eliminating costly transmission and distribution expenditures. Yet, the current incentive system fails to offer pathways for monetizing the grid benefits that LGPPs provide.

- *Fragmentation of environmental and energy policies*

The advantages that LGPPs bring to Ukraine's electric grid are not the only benefits that the current policy, legal, and regulatory framework fails to recognize. The lack of such recognition is due to the fragmentation of energy and environmental policies in Ukraine that effectively lock renewable technologies in policy silos. Landfill gas has been legislatively placed in the renewable electricity silo despite offering the flexibility of cooking, heating, and even transportation fuel [35], which is in contrast with the value-maximizing approach taken in several countries. For example, combined heat and power LGGPs constitute the predominant operational model of LGGPs in Germany because of their overall efficiency [64].

In addition, the potential benefits of LGGPs as revenue-generating units of the struggling MSW sector have been largely overlooked. As noted above, the environmental benefits of LPPGs extend well beyond their

GHG reducing potential, which is something that the current incentives also fail to recognize fully. There are creative approaches to this problem deployed internationally that could also be deployed in Ukraine. For example, Lybæk and Kjær highlight the role of municipalities in bridging the gap between environmental and energy policies when they serve as energy consumers, regulators, and facilitators of biogas adoption [65].

- *Uncertainties due to the ongoing military conflict*

The impact of the ongoing military conflict in the east of the country is not unique to LGPP projects of the renewable energy sector. Yet, it is not difficult to see the abundance of caution by developers and investors in projects where capital expenditures represent the bulk of the cost. It is effortless to see such notification in the parts of the country that can be directly impacted by combat operation, even considering the short payback period of LGGPs.

5. Conclusions

LGPPs bring a host of benefits including, GHG mitigation, improvements in the ambient air quality, and flexibility as an electricity generation source. They appear to be particularly appealing for deployment in Ukraine due to the escalating MSW crisis, ambitious RE deployment targets, and aging national grid struggling to accommodate the influx of intermittent generation from renewable sources. Yet, LGGPs have seen slow growth vis-a-vis other RE technologies despite government support.

In this article, we investigate whether economic feasibility constitutes a barrier to LGPP deployment. To accomplish that, we determine the LCOE of landfill gas-fired generating facilities in Ukraine and compare it to the feed-in tariff at which the electricity from these facilities is sold at the electricity market. We also estimate the payback period investors in LGPP facilities should expect under the current LCOE and feed-in tariff.

Based on the results of our study, it is reasonable to conclude that economic feasibility is not among the factors hampering LGPP deployment in Ukraine. The feed-in tariff for electricity generated by LGPPs exceeds the LCOE by a factor of 3.3, whereas the payback period in an LGPP project stands at 5.1 years. Both indicators should make landfill gas generation facilities a prime target for investors as they promise a quick and plentiful return on capital.

This paradox warrants further research, for which we offer several directions. We recommend that researchers consider access to capital and transactional costs, stability of the governing legal and regulatory framework, alignment of government incentives and system benefits, fragmentation of environmental and energy policies, and uncertainties due to the ongoing military conflict as potential barriers to LGPP deployment in Ukraine.

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