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ORIGINAL ARTICLE

Feasibility analysis of small-scale biogas plants usage in the Syrian coast through agricultural crop residues and co-digestion of manure

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Abstract

Due to the ever-increasing demand and high energy prices (and lack of access), the search for alternative and local energy sources is essential for developing countries; therefore, this study reveals the economic feasibility of using organic waste for biogas production on the Syrian coast. The data was collected through a questionnaire survey among farmers and field visits to the biogas units in Tartus and Latakia provinces from June 2020 to February 2021. The results showed that the total annual return of the biogas unit that depends on plant residues is higher than the total annual return of the biogas unit that depends on animal waste. The study found that every dollar invested in the biogas production unit from animal waste achieves a net return of 0.89 USD without discount factors. In the biogas production unit using crop residues, it was 2.08 USD. The payback period of the small-scale biogas unit is 2.9 years in the animal waste unit and 1.9 years in the plant residues unit. When costs increase disproportion by 20% and revenue slumps by 20% less than expected, every dollar invested in small-scale biogas plants using animal wastes achieves 0.26 USD as a net return without discount factors. On the other hand, every dollar invested in small-scale biogas plants using plant residues earns 1.06 USD as a net return without discount factors. With discount factors, each dollar invested in a small-scale biogas plant using animal wastes achieves 0.012 USD as a net return. Each dollar invested in small-scale biogas plants using crop residues earns 0.13 USD as a net profit. The study found that biogas units that use crop residues are more profitable and should be considered in programs supporting renewable energy, especially with the government's interest in renewable energies and the widespread availability of crop residues in the Syrian environment.

Keywords Biogas plants · Plant residues · Animal waste · Feasibility analysis · Sensitivity analysis

1 Introduction

Energy is the primary driver of all economic activities. The civilized existence of the human race depends mainly on energy. Because of its importance in everything, energy is the global currency [41]. Factors like the continued rise in oil prices and the future depletion of fossil fuels, as well as rising global interest in climate change, has led to the search for cheap alternatives to energy with less environmental damage. Biofuels in the developing world is considered a "new" source of energy due to many reasons: its ability to support global energy security, being environmentally friendly, and its affordability and sustainability. These reasons help meeting the 2030 United Nations Sustainable Development Goals (SDGs). Moreover, it is economically creating jobs with adequate capital and is one of the cheapest, environmentally friendly technologies. It also contributes to reducing greenhouse gas emissions such as carbon dioxide, consequently increasing good living conditions.

Furthermore, it contributes to environmental goals, particularly SDG7, through clean and affordable energy sources [8, 14, 49]. In addition, biofuel usage helps alleviate other environmental problems, the most important of which is the disposal of agricultural waste and animal manure. As a developing Arabic country, Syria is one of the first Middle

Highlights

- Economic analysis of different biogas plants is investigated in Syria.
- Biogas plants using crop residues achieve higher profit in Syria.
- Biogas production is economically feasible in Syrian rural areas.
- The importance of governmental policies to enhance biogas technology adoption.

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Eastern countries to understand the importance of integrating the environmental factor into the sustainable development process. As a result, in 1991, the Ministry of Local Administration and Environment was established, followed by Protection and Sustainable Development Council to follow the requirements of the local environmental agenda [32]. However, the development of the adoption and application of biogas technology is considered modest. Since 1990, the Ministry of Agriculture and the Arab Centre established some experimental biogas units in Syria to study Dry Areas (ACSAD). These experiments demonstrated the possibility of using animal and plant organic waste to produce biogas and the investment of energy generated for rural uses, in addition to converting the deposit resulting from anaerobic digestion into fertilizer of good specifications. In 2008, the National Energy Research Center on the Damascus-Sweida Road established 19 small-scale household plants to encourage small digesters usage in rural areas and introduce rural communities to this technology regarding its benefits and how it works. However, the feedstock used in biogas production was limited to animal waste, i.e., these units have not been used to ferment other types of organic waste, such as crop residues, food residues, and presses residues [1]. In 2010, biogas unit numbers in Syria reached 43 biogas units (with a volume of between 13 and 20 m^3) [1].

Since the conflict erupted in Syria in 2011, solid waste collection services and disposal methods have been disrupted in many cities. Energy crises are intensifying in Syria with severe loss of oil derivatives from gas and heating oil and power outages due to the outflow of Syrian oil sources from use and tough international sanctions on the energy sector [16]. The ongoing war did not prevent multinational organizations from working in Syria. Intending to produce biogas and organic fertilizers, the Food and Agriculture Organization of the United Nations (FAO) has helped establish biogas units for 60 rural households in five governorates [33]. Additionally, 120 household biogas plants have been installed by global communities in Idleb governance northern Syria [17].

Several technical–economic assessment studies have been carried out in biogas production to achieve various local and global objectives. Locally focused studies covered ways to benefit from plant residues and their economic effects in the Latakia province [30], analysis of the factors that affect the yield reactor to produce biogas from residues country house in the Tartus Province [1],and production of biogas (methane) from co-fermentation of mixtures of white sugar corn and animal waste [9]. Globally, the studies focused on large-scale life cycle assessment and home biogas plants in northwest China [44],economic assessment and life cycle of methane production from the application of biogas technology [13], and environmental impact assessment for liquid waste treatment of palm oil plants using life cycle assessment approach: a fertilization-based case study and a combination of biogas techniques in North Sumatra, Indonesia [31].

Existing literature focused only on biogas production techniques or particular local studies in the context of Syria. Our study, therefore, fulfills the current gap by highlighting the potential post-conflict energy solutions, including an in-depth economic feasibility study and sensitivity analysis of the use of biogas technology based on animal and crop residues.

2 Methodology

2.1 Target area

The study was conducted in rural communities on the Syrian coast, represented by the provinces of Latakia and Tartus. On the one hand, these two provinces are agricultural stabilization areas due to the availability of water. On the other hand, these two provinces are safe areas in the light of the war in the country. The site had a population of 2.4 million in 2019, of which more than 60% worked in agriculture [11]. According to the report of the Syrian Central Bureau of Statistics, livestock consists of cows (68,782), goats (31,931), and sheep (193,675) [11].

2.2 Data collection

Data on the average family size, land owned on average, agricultural production and livestock, and their waste spills were obtained from the Ministry of Agriculture, the Central Bureau of Statistics, and the General Authority for Agricultural Scientific Research. In addition, the prevalent prices were also obtained as a result of the multiple field visits to a biogas production unit in Tartus.

2.2.1 Survey

The data of biogas units in Syria were obtained in cooperation with the Directorate of Renewable Energies in the Ministry of Agriculture, which provided information on biogas units in Syria and their types. With the aim of analyzing the financial indicators of the small scale biogas plant, statistical comparisons are not needed. Young [46] explained that typically in feasibility studies, statistical analysis is not warranted.

2.2.2 The research sample

The target group involved 247 household farmers and 8 BGP owners in the Latakia and Tartus provinces by using stratified random sampling. A crop residues survey was carried out to highlight the potential of biogas production in the coastal region. Survey results showed that these families usually own 1–2 cows in addition to 5–10 poultry (chickens) and 3–5 sheep. Most of them buy their chemical fertilizers from the local market and sell their agricultural and animal wastes to large factories.

2.2.3 Sampling and characteristics of the research sample

Data on crops were obtained from the Ministry of Agriculture, the Central Bureau of Statistics, and the General Authority for Agricultural Scientific Research. In addition, mapping the spatial distribution of agricultural and animal waste on the Syrian coast was done using ArcGIS 10.7.

2.3 Analysis of the economic feasibility of the small-scale biogas unit construction project (profit and cost indicators)

The financial-economic feasibility of animal waste and crop residues in small-scale biogas units was analyzed to determine financial profitability. Several profitability indicators have been investigated, such as:

- Cost–benefit ratio (1) used as evaluation and decision-making tool for looking at results retrospectively.

  If cost/benefit <1, then investors accept a biogas unit project.

  If cost/benefit > 1, then investors reject a biogas unit project.

$$\text{Cost}/\text{benefit} = \frac{\text{operation} + \text{investmentcost}}{\text{revenues}} \tag{1}$$

- Average rate of return (ARR):

$$ARR = \frac{\sum_{i=1}^{n}(\text{netprofitaftertax} + \text{interest})/n}{TIC/2} \times 100 \tag{2}$$

  where TIC is the net project costs (tax + interest)

  If *ARR* > bank interest rate, investors accept biogas unit project.

  If *ARR* < bank interest rate, investors reject biogas unit project.

- Simple rate of return (SRR) is the net income expected by comparing the costs and the project's gains during its life cycle.

$$SRR = \frac{(\text{netprofitaftertax}i + \text{interest}i)/n}{TIC} \times 100 \tag{3}$$

  If *SRR* > bank interest rate, investors accept biogas unit project.

  If *SRR* < bank interest rate, investors reject biogas unit project.

- Internal rate of return (IRR) is an estimation tool for the profitability of potential project investments by making the net present value (NPV) of all cash flows equal to zero [47].

$$IRR = DR_L + \frac{NPVL}{NPVL + |NPVH|} \times \left(DR_H - DR_L\right) \tag{4}$$

  where DR_L is the low discount rate, DR_H is the high discount rate, *NPV L* is the net present value at a lower discount rate chosen, *NPV H* is the net present value at a higher discount rate.

  If $IRR > IR$ (interest rate), investors accept the biogas unit project.

  If $IRR < IR$, investors reject the biogas unit project.

- Net cash flow is a profitability tool to measure the amount of money produced or lost by the project

$$\text{NetCashFlow} = \text{TotalRevenue} - \text{TotalCosts} \tag{5}$$

- The payback period is used to specify the amount of time it takes to recover the cost of the project

$$\text{Paybackperiod} = \frac{\text{Initialinvestment}}{\text{Netcashflowperperiod}} \tag{6}$$

- The discount factor is used to determine the expected profits and losses for the project based on future payments

$$\text{Discountfactor} = \frac{1}{1 * (1 + \text{discountrate})^{\text{periodnumber}}} \tag{7}$$

2.4 Costs of a 10 m^3 biogas plant

This research was carried out in (June 2020–February 2021) prices can change due to the instability of the Syrian currency. The cost of constructing a biogas unit of 10 m^3 (commonly used size in the region and based on the Chinese model) was obtained from the survey. On the other hand, the cost requires to operate the plant was calculated with an assumed life span of 15 years and 13% of total construction costs according to the popular prices in the

Table 1 Construction costs of biogas plant (10 m^3) at Syrian market prices in 2020

Costs	USD
Construction cost (construction + building materials)	477.5
Cost of the biogas tank	267.5
Operating requirements	114.5
Total	859.5

Syrian market shown in the Table 1. In addition to the calculation of the total depreciation of fixed capital, including the cost of the devaluation of civil construction, which represents about 1.3% per annum of the total cost of civil construction, the cost of the depreciation of the biogas tank which represents about 2% per annum of the total cost of the gas tank. The cost of depreciation of operating requirements represents about 7% of the total cost of operating requirements, as well as the daily inputs represented by agricultural and animal waste (average figures according to Syrian market prices). Figure 1 show the components of the biogas unit.

This figure represents Zahed biogas station, and consists of four parts. The inlet chamber, the digester (diameter is 4 m, and its volume is 14 m^3), the outlet chamber (with a diameter of 4 m and a height of 1.5 m), and the biogas tank, with a height of 1.85 m and a diameter of 2 m.

2.5 Revenues

Revenues include biofertilizer and biogas revenues as fuel. Revenue from biofertilizers was calculated by multiplying the amount of biofertilizer produced on an annual basis from a 10m^3 biogas unit (this unit produces 5.2 tons of fertilizer per year); this size (10m^3) was used because it is the most popular in Syria. Similarly, revenues from biogas production were also calculated by multiplying the quantity produced from a 10m^3 biogas unit (the unit produces 3m^3 per day, equivalent to 1095m^3 per year), according to its price, which is based on the single price of biogas of 0.6 USD per m^3 (according to the report of the Central Bureau of Statistics 2019, CBS). This is done according to the price of the Syrian market. Typically, the price of producing biogas ranges between 0.22 USD and 0.39 USD per m^3 of methane for manure-based biogas production, and 0.11 USD to 0.50 USD per m^3 of methane for industrial waste-based biogas production [24], equivalent to 864 Syrian pounds using the exchange rate in the survey.

The expected revenue sought for these biogas units were used to calculate the income statement, and the cash flow statement was then used to calculate profitability indicators.

2.6 Cost and revenue analysis

Analysis of the financial feasibility of a small biogas unit in rural areas depends on the following assumptions: (1) The unit's life is 15 years (the life span can be 20 years, but in Syria, with a lack of expertise, the life span was set up to be 15 years). (2) The biogas unit is located near the house; as a result, there are no transportation costs. (3) The biogas unit did not pay any tax costs. (4) The construction period is about one year (in fact, it is less than one year, but it is considered one year since the calculations are made annually). Since different prices were found for each type of crop residue obtained from the survey, the average price and the cost of agricultural crop residues were calculated. All costs and revenues were in Syrian Pound and US dollars using the exchange rate (1 USD = 2400 SYP) at the research time. Thus, the following assumptions were considered (because of the volatile economic situation and the constant change in the exchange rate): (1) Costs and revenues suddenly increase as a maximum of 20% for animal waste and at a discount rate of 10–15%. (2) Costs and revenues increase to a maximum of 20% for plant residues and at a discount rate of 20–25%.

3 Results and discussion

Although there is a real crisis in securing energy resources in Syria due to the negative consequences of the war and the strong embargo, biogas production technology has not

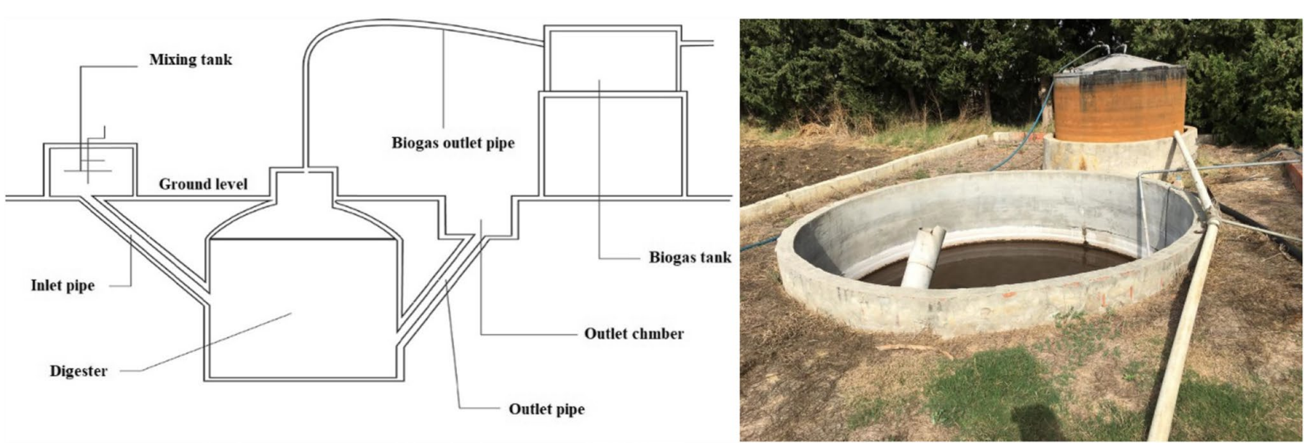

Fig. 1 Zahed biogas station — Tartus Governorate — Syria

Table 2 Chosen examples of biogas plants in Syria

No	Biogas plant's name and location	Size (cubic meter)	Year of construction	Model	Number of units	Sponsor	Used feedstock in the BGP	Biogas production usage
1	The first Gouta station in Damascus	100	1990	Indian	1	Ministry of Agriculture	Cow manure	Electricity and cooking
2	The second Gouta station in Damascus	14	1991	Indian	1	United Nations Economic and Social Commission for Western Asia (ESCWA)	Cow manure, kitchen waste	Cooking
3	The third Gouta station in Damascus	14	1991	Chinese	1	(ESCWA)	Cow manure, deciduous herbs and fruits	Cooking
4	Faradis biogas station in Hamaa	14	1994	Chinese	2	(ESCWA)	Cow manure, kitchen waste	Cooking
5	Ezraa biogas station in Daraa	14	1996	Chinese	1	Islamic Development Bank	Cow manure	Cooking
6	Daraa biogas station in Daraa	14	1995	Chinese	1	Private sponsor	Cow manure, kitchen waste	Cooking
7	Ibtaa biogas station in Daraa	20	2001	Indian	1	Private sponsor	Cow manure	Cooking
8	Khrabo biogas station in Faculty of Agriculture in Damascus	30	2003	Indian	1	Damascus University	Cow manure	Research studies purposes
9	Alwafaa station in Swaida	14	2008	Indian	2	United Nations	Cow manure, kitchen waste	Cooking
10	Zahed station in Tartus	14	2008	Indian-Chinese	1	Syrian Agricultural Research Authority	Cow manure	Cooking
11	Alsimakiat Station in Daraa	14	2008	Indian	1	Syrian Agricultural Research Authority	Cow manure, kitchen waste	Cooking
12	Aliaduda station in Daraa	30	2008	Indian	1	Syrian Agricultural Research Authority	Cow manure	Electricity and cooking
13	Rassas station in Swaida	18	2010	Indian	3	United Nations	Cow manure, deciduous herbs and fruits	Cooking
14	Fedio station in Latakia	22	2014	Indian	1	Syrian Agricultural Research Authority	Cow manure	Cooking

[1, 3, 6, 7, 20, 21, 25]

been widely deployed yet [19]. For more, see Table 2, where retrieved information was cross-referenced with publicly available information from the internet.

3.1 Potential of organic waste suitable for biogas production

The population of the coastal area (Latakia and Tartus) reached 2,444,000 people in 2019. The area of cultivated land is 226,000 ha. Note that a cow produces 16 kg of manure daily, which may be up to 20 kg [6]. This area

Table 3 Agricultural and animal crop residues on the Syrian coast

Type of waste	Production (ton/year)
Dry cow manure	935,435
Residues of cereal crops (barley, wheat, yellow corn)	11,212
Legumes (lentils, chickpeas)	4,293
Vegetables	32,696
Fruit trees	9,057,383
Total	10,041,019

is the largest fruit producer in Syria, in addition to a few quantities of cereal and legumes. Crop residues amounted to 9,105,584 tons per year (Table 3).

The total waste of sewage in this area is 369,000 m^3 per day. As the average daily waste per person is estimated at 0.5 kg, the amount of day-to-day waste generated is 1222 thousand kg per day, 60% organic, i.e., 733.2 thousand kg per day. This makes the area a natural environment for the establishment of biogas units. According to the data, the agricultural and animal waste data was displayed on the Syrian coast (Table 3). Agricultural crop maps are made using the GIS maps program shown in Fig. 2, which helps future planning invest in biogas units.

We note from Fig. 2a that the highest spatial distribution of plant residues was found in Tartus, followed by south and west Latakia areas, making it an ideal center for establishing biogas units. In contrast, we note from Fig. 2b that the animal wastes are distributed in most areas of the Syrian coast, with its large intersection in places distributing crop residues. Therefore, it can be determined that the areas of Tartus, south and west of Latakia are ideal places to create biogas units.

3.2 Feasibility analysis

The results were analyzed based on two scenarios: (i) the feasibility of a biogas unit based on animal waste and (ii) a biogas unit based on plant residues.

3.2.1 Analysis of the feasibility of small biogas units that use animal waste only (size of 10m^3)

Costs Total construction costs are estimated at 859 USD, Table 1, 478 USD of which is the cost of civil construction with a life span of 50 years at most (age only for construction), this includes bricks, cement and manufacturing materials such as sheeting, plastic, fiberglass, hoses, and pipes. All of which represents about 56% of the total cost of the biogas unit. At the same time, this ratio reached in a study by Ali et al. [4] to 69.35% and about 70% of the total cost in the Biogas Development Guide published by the United Nations [42] and 35–40% in a GTZ project Information and Advisory Service on Appropriate Technology (ISAT) report (1999). The cost of constructing a 10-m^3 biogas unit tank is 267.50 USD which is 31% of the total construction costs estimated at 859 USD. In a study conducted by Sarker et al. [38] in Bangladesh, the total cost of 10m^3 biogas unit was 821 USD, while in Egypt, the total investment cost of 6m^3 biogas unit was 1151.31 EUR [37]. Besides, operating requirements with a 15-year life span cost about 115 USD, with 13% of total construction costs consistent with a study by Ali et al. [4] where the ratio was 12.72%.

The total depreciation of fixed capital is estimated at 19 USD per year. This includes:

1- The depreciation of civil construction and represents about 1.3% per annum at 6 USD of the total cost.

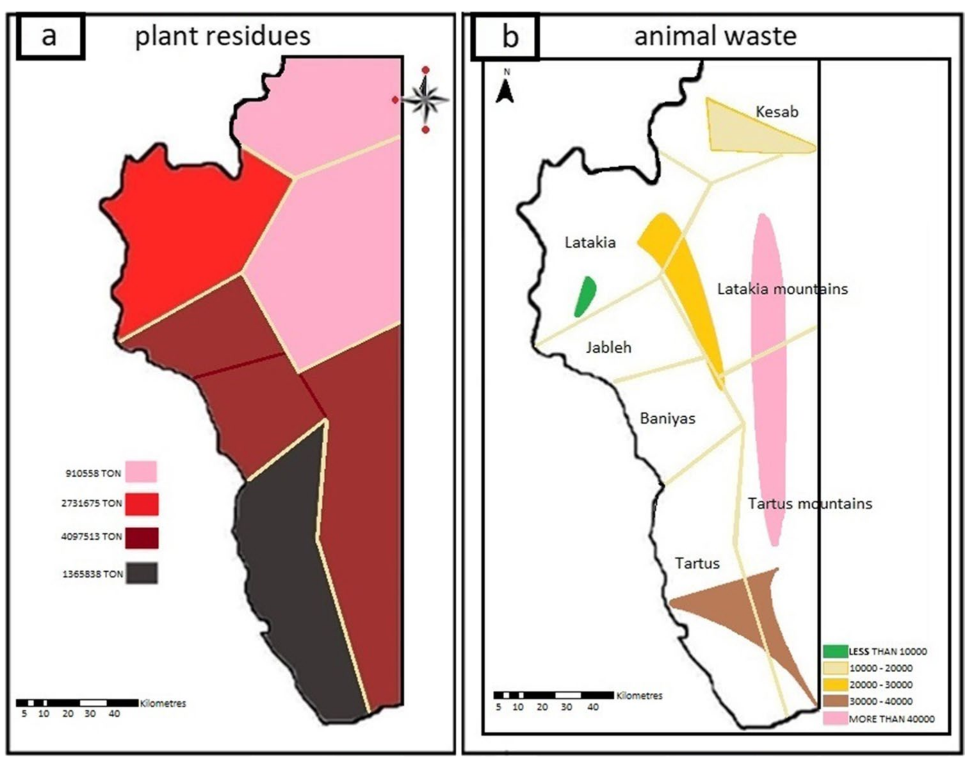

Fig. 2 GIS maps showing the distribution of (**a**) plant residues figure and (**b**) animal waste figure (tons per year) in the Syrian coast where Google Maps was used for the coastal area. Data were entered into the GIS software to determine the distribution of agricultural and animal waste

2- The cost of the depreciation of the gas tank represents about 2% per annum at 5 USD of the total cost of the gas tank (267*2/100).
3- The depreciation cost of operating requirements represents about 7% per annum at 8 USD of the total cost of operating requirements (115*7%).

According to the data from the biogas units in Tartus, the daily input of wet manure is about 80–90 kg or 16 kg dry manure, with a cash value of about 0.29 USD/day equivalent to 105 USD/year. The percentage of waste should not exceed 10% of the unit size, depending on the humidity. Therefore, a farmer can get the amount of manure free of charge and save the price of buying it if he has five cattle heads, increasing his average annual return and reducing the coverage period of construction costs.

Although the total cost is 859 USD, as a Syrian society, this amount is considered very large due to the inflation that exists in the country due to economic sanctions and exchange rate change, so it is necessary to provide governmental legislation for both governmental and private financial institutions that support the establishment of biogas units by providing loans and technical support in this area. This is consistent with the recommendations by Ioannou-Ttofa et al. [23] regarding the importance of the role of government support and the creation of an appropriate environment through the integration of the role of decision-makers to stimulate the construction and installation of biogas units.

Revenues The household production unit outputs of biogas and fertilizer are represented at a rate of $3m^3$ biogas/day, where the fermentation of $1m^3$ of waste gives $0.3m^3$ of biogas. According to Bagi et al. [10], biogas production was measured in biogas units in Tartus by the water displacement method. The biogas output is equivalent to $1095m^3$ biogas/year. Due to the lack of an official price of biogas, its cost has been estimated according to the volume of thermal energy that biogas generates compared to that generated by kerosene. Each m^3 of biogas contains a thermal energy equivalent to 0.6 L of kerosene [40], and if the free price of a liter of kerosene is 0.11 USD/ $1m^3$ of biogas is worth about 0.07 USD,thus, the value of biogas generated by the unit is about 77 USD per year, while the average price per ton of biogas fertilizer is 51 USD, i.e., the total value of biogas fertilizer produced by the production of biogas is estimated at about 265 USD per year which is sufficient to fertilize 4 to 8 Dunums (Dunum is a unit of land area measurement used in Middle east, which is equivalent to $1000m^2$). Thus, the total output value of both biogas and biogas fertilizer is about 342 USD/year, while the total input value for fixed capital depreciation and animal manure is about 125 USD/year. At deducting the total input value from the total output value, the average annual net return is estimated at about 217 USD, in a study by Zhang et al. [49] of 59.4 million yuan or 8.91 USD million as a total return, the internal rate of return increased by 7.89%.

The amount of 217 USD per year is considered as a small value return for the Syrian family, which needs an average of 300 USD to live in the minimum [50]; this return can increase as a result of the trend towards it as an alternative market, especially in a market that has difficulty obtaining chemical fertilizers monopolized by agricultural associations that suffer from a lack of resources as a result of the war in the country. If the availability of government support and the rise of this rate, we will find an excellent trend for families to use biogas technology; this is indicated by the study of Roubík et al. [35], which confirmed that the motivation of farmers is a crucial variable that influences the final decision regarding purchasing (or not) a biogas plant and keeping it (or not). In general, various authors such as Jan and Akram [26],Chen and Liu [12] and Qu et al. [51] agree that the government also plays a vital role in biogas technology development.

Financial index calculation Figures 3 and 4 show the analysis of the expected economic return using discount factors over 15 years, which is the life span of the biogas unit used by the farmer with a virtual capacity of 10 m^3, where we note that total cash flow and revenues are higher than costs starting in the second year where the total fixed construction costs are estimated at 859 USD plus 105 USD, which is the value of the manure needed to feed the biogas unit per year. This makes the total cost in the first year to 964 USD. Starting with the second year, the total variable costs required for operation added to depreciation in fixed capital are estimated at about 125 USD per year until the end of the unit's life span. The total unit revenue per year is about 342USD, of which 77 USD is gas, about 265 USD for fertilizer at 22.51% and 77.49% of total annual return, respectively.

By estimating the total value of cash flow during the life span of the biogas unit using the two discount rates 30% and 35% (by using Eq. (7) with discount rate 10% or 15% and notice that it is higher than the 5% discount for plant residues respectively), the total current value of cash flow at a 30% discount rate is about 64 USD, while at a 35% discount rate is about 8 USD.

The ratio of total revenue to total costs without discount factors is estimated at 1.89 USD. Since this ratio is more than the correct one, this means that the project returns exceed its costs, i.e., every 1 USD invested in the biogas production unit achieves a net return of 0.89 USD, while in a similar study from Bangladesh, Sarker et al. [38], it was 0.61, which is estimated to total net cash flow during the life of the project without the use of discount factors of about 2416 USD (Eq. (5)).

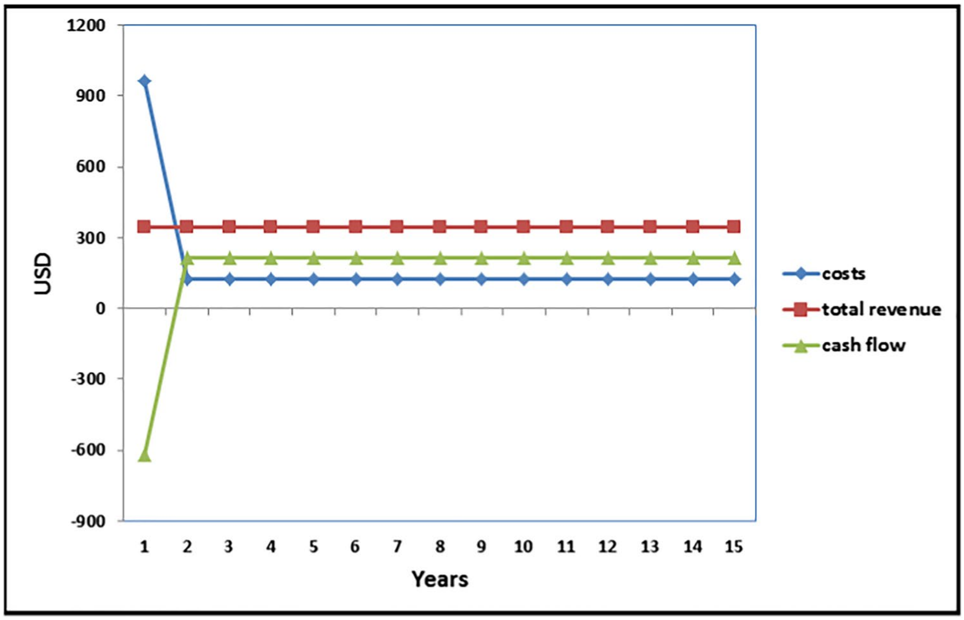

Fig. 3 Total costs, revenues and cash flows of a biogas unit that uses animal waste without discounting factors

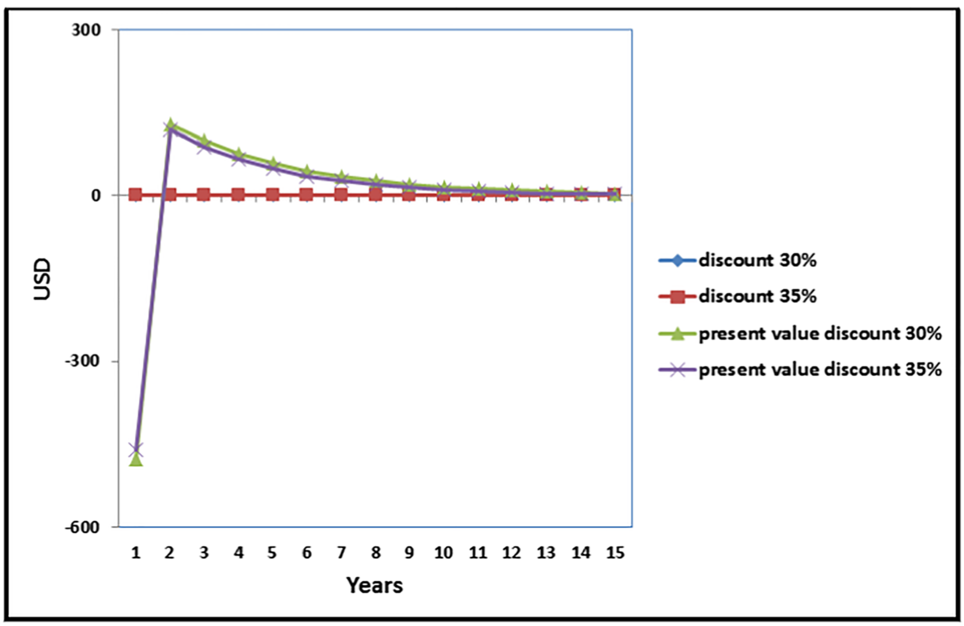

Fig. 4 Analysis of the expected economic return using animal waste discount factors over 15 years. Note: Since numbers between 0 and 1 are on top of each other, as well as in hundreds on top of each other, the lines in the figure lay partially on top of each other

While the ratio of total revenue to total costs is estimated using a 30% discount rate by dividing the current value of total revenue by the present value of the total cost at a 30% discount price, it was found to be 1.06. Since this ratio exceeds the value of 1, then the project returns exceed its costs. Therefore, each 1 USD invested in biogas production achieves a net return of 0.06 USD at a 30% discount. Overall, investing in the biogas project is profitable even with the use of discount factors, and given the reality of Syrian families, which are mostly poor, they must be supported. Looking at the expected return compared to costs makes biogas technology the preserve of middle- and high-income families. On the other hand, it deprives most of the society of technology, as indicated by a study by Qin and Bluemling (2013).

To determine the capacity of the funds used to produce biogas throughout the life of the production unit, the internal rate of return (IRR) by using Eq. (4). The IRR was found to be 34%, i.e., the maximum benefit the project could give to the resources used if the project was to recover investment and operating costs at the same time and achieve parity between income and expenses of 34%, which is similar to a study by Gonzalez-Arias et al. [52] at 36.97%.

The payback period (PBP) of the biogas unit using Eq. (6) is 2.9 years. This means that the 10m^3 household biogas production unit project brings a high benefit to the farmer. At the same time, recover the capital invested in it after 2.9 years which corresponds to a study by Khoshgoftar Manesh et al. [27] where the recovery period is less than 3 years. The payback period determined for the current community type fixed-dome biogas digester project was found to be lower than that reported by Goodrich et al. [18] (5.7 years), Walla and Schneeberger [43] (7.5 and 11 years), Patmanomai et al. [34] (4.11 years), Lungkhimba et al. [28] (4.81, 7.57, and 7.20 years), Dereli et al. [15] (7.2 years), Sahu and Abatneh [36], (6.27 years), Scano et al. [39] (5.4 and 7.25 years), Agostini et al. [2], (6 and 7 years), Al-Maghalseh. [5], (8 years), and Imeni et al. [22] (< 10 years). A short payback period was emphasized to be very valuable from the standpoint of the profitability analysis by the United Nations [42] and Werner et al. [53].

Through the previous data, SRR (Eq. 3) equals 25.26%. Therefore, the criteria for economic evaluation indicate that the farmer's production of biogas from animal waste is a "feasible and profitable" project from a financial point of view. The internal rate of return and the simple rate of return on invested capital, estimated at 25%, surpass the interest rate, which does not exceed 7% on long-term deposits, or 10.5% as an alternative loan to save capital invested in commercial banks. Therefore, the project of producing biogas achieves net value for the farmer at a discount rate of 30% equals 64 USD.

We note that the discount rate in both cases is 30%, and 35% is approximately applicable, and in terms of the decrease in the current value, it is due to the reduction in the discount rate by increasing the years (Eq. 7).

Sensitivity analysis when costs for biogas units using animal waste rise by 20%, and revenue falls by 20% Due to the situation in the country (price volatility — inflation, other war factors), previous evaluation criteria were calculated based on specific assumptions regarding the future conditions that the project is expected to face in the future, such as decreased gas unit productivity, the life span of the project, and the prices on which revenues, costs, and discount rates were calculated, given the "existence or lack of technology" that surrounds the project in the future, which certainly affects the assumptions on which the project was assessed. Therefore, it is important to re-evaluate with the expectation that one or some of the previous assumptions will change to give a picture of the project's profitability, considering the possibility of changing the premises on which the analysis was based. Therefore, the reassessment of the project is defined by the assumption of change of returns and benefits due to the belief of changing circumstances by analyzing the project's sensitivity. To what extent is the project responsive or sensitive to the change in factors affecting its profitability.

Given the assumptions on which the project evaluation was based, the change in circumstances reflects the different possibilities for changing the returns and costs of the project. Hence, it was assumed that costs (construction costs and waste price) would increase by 20% more than expected, and revenues would be reduced by 20% simultaneously due to one or more factors Table 3. This is one of the worst possibilities that the farmer can be exposed to when producing biogas from animal waste at the beginning of the project, using the two discount prices of 10% and 15%. The current value of cash flow during the life span of the biogas unit at a 10% discount rate is about 25 USD, while at a discount rate of 15%, it is about 153 USD. By estimating the ratio of total revenue to total costs without discount factors, it was equal to 1.26. Since this ratio exceeds the correct one, the project returns exceed its costs. Therefore, every 1 USD invested in the biogas production unit achieves a net return of 0.26 USD estimated total net cash flow during the project's life without using discount factors of 847 USD.

Since the ratio of total revenue to total costs using a 10% discount price, which is calculated by dividing the current value of total revenue by the present value of total costs at a 10% discount rate, turns out to be 1.012. Since this ratio exceeds the correct one, the proceeds of the project exceed its costs. Therefore, each 1 USD invested in biogas production achieves a net return of 0.012 USD in the worst circumstances at a discount of 10%.

Internal rate of return by using Eq. (2) equals 10.70%, i.e., the maximum benefit the project can give to the resources used if the project wants to recover investment and operating costs simultaneously and achieve parity between income and expenses 10.70%.

The payback period (PBP) of the biogas unit by using Eq. (6) is 9.35 years, i.e., the 10 m^3 home biogas production unit project can pay the highest interest rate to the farmer and, at the same time, recover the capital invested in it after 9.35 years. The simple rate of return on invested capital by using Eq. 3 is 14.44%. The economic assessment criteria used to assess farm production of biogas from animal waste are considered a "feasible" and profitable project from an economic point of view, despite a 20% higher-than-expected overall cost and a 20% lower-than-expected revenue at the same time. This is because the internal rate of return and the simple rate of return on the capital invested rise above the interest rate, which does not exceed 11% for the alternative opportunity to make savings in commercial banks. In addition to that, the project of biogas production achieves for the farmer a net current value at the discount rate of 10%, equal to 25 USD. Thus, with a 20% increase in costs and a 20% decrease in revenue, the project of producing the biogas unit of the 10 m^3 household unit is profitable and economical for the farmer; thus, in the worst of circumstances, the biogas project will be supportive of the economy at the family and community level, as noted in a study conducted by Sarker et al. [38] in Bangladesh, where it was found that biogas units remain economically stable even in the worst conditions.

3.2.2 Analysis of the feasibility of small biogas units that use plant residues only (size of 10m^3)

Costs Suppose the manure used in the biogas production unit is replaced by the equivalent of agricultural crop residues (Rice straw, other crops), i.e., about 21 kg/day of crop residues, which amount to approximately 0.25 USD per day. In that case, the monetary value of these residues is estimated at 91 USD per year. Therefore, the total inputs equal 111 USD per year, while the total output is estimated at 342 USD, i.e., the average net annual return equals 231 USD.

Revenues If the farmer has 4 Dunums and cultivates it twice a year, once in the winter lug and then again in the summer lug, he can save about 3.5 tons per year of crop residues, and this amount is sufficient to provide him with the waste needed to operate the biogas unit for about 166 days. Thus, it saves the price for this period and buys the necessary waste sits on the remaining days of the year, which amounts to about 199 days' worth of 35 USD; i.e., the farmer will save part of the crop residues from the land he cultivates and buy a part to provide daily nutrition for the biogas unit. In this case, the total input value is 55 USD per year; then, the average annual net equals 287 USD per year. Therefore, it is higher than the average yearly return using animal waste at 217 USD, although still unnecessary for families.

Financial index calculation Economic analysis was made using discount factors of 50% and 60% (using Eq. (7) with a discount rate of 5%) for the biogas unit fed with crop residues when the farmer owns 4 Dunums of land that he cultivates twice a year. The total fixed construction costs are estimated at 859 USD plus 35 USD, which is the value of crop residues that he purchases annually. This brings the total costs in the first year to 894 USD. Starting from the second year, the total variable costs required for operation and the depreciation value of fixed capital are estimated at about 55 USD per year until the end of the year unit's life span. Thus, the total return of the biogas unit is about 342 USD per year.

Estimating the current cash flow value during the life span of the biogas unit using 50% and 60% discount factors shows that the current value at a 50% discount rate is about 13 USD, while at a 60% discount rate, it is about 46 USD. Furthermore, by estimating the ratio of total revenue to total costs without discount factors 3.08; i.e., each 1 USD invested in the biogas production unit achieves a net return of 2.08 USD, which is higher than the biogas unit using animal waste at 0.89 USD. This is estimated to total net cash flow during the 15-year life span of 3466 USD.

The ratio of total revenue to total costs using the 50% discount rate, which is estimated to be dividing the current value of total revenue by the total present value of costs at a 50% discount rate, was found to be 1.02. Since this ratio is more than the correct one, the project returns exceed its cost, so each 1 USD invested in biogas production achieves a net return of 0.02 USD at the 50% discount rate. As a result, the IRR internal rate of return (Eq. 4) is 52.2%.

The maximum benefit the project can give to the resources used if the project is to recover investment and operating costs simultaneously and achieve parity between revenue and expenses is 52%. In comparison, by using animal waste, it was 34%. The payback period of the unit of biogas (Eq. 6) is 1.9 years. In other terms, the 10 m^3 home biogas production unit project can pay the highest interest rate to the farmer and at the same time recover the capital invested in it after 1.9 years. The simple rate of return on invested capital (Eq. 3) is 33.4%.

Analysis of sensitivity when plant residue costs increase by 20%, and revenue decreased by 20% Assuming a simultaneous 20% increase in costs and a 20% decrease in revenue, Table 4 shows the use of 20% and 25% discount rates to estimate the current cash flow value during the life span of the biogas unit.

By estimating the ratio of total income to total costs without discount factors, the ratio of revenue to costs is 2.06. Since this ratio is more than the correct one, the project returns exceed its costs. Therefore, each 1 USD invested in the biogas production unit achieves a net return of 1.06 USD. Thus, the total net cash flow is estimated during the life of the project without the use of discount factors at about 2104.07 USD.

By estimating the ratio of total revenue to total costs using a 20% discount rate and by dividing the present value of total revenue by the present value of total costs at a 20% discount price, it was found to be 1.13. Since this ratio exceeds the correct one, the project returns exceed its costs. Therefore, every 1 USD invested in the biogas production unit achieves a net yield of 0.13 USD at the 20% discount price.

IRR internal rate of return (Eq. 4) is 24.85%. Therefore, the maximum benefit the project can give to the resources used if the project is to recover investment and operating costs simultaneously and achieve parity between revenue and expenses is 24.85%. The payback period of the unit of biogas (Eq. 6) is 4.02 years, while in a study by Zhang and Xu [48], the recovery period is 5.34 years. In other terms,

Table 4 Analysis of the economic return of the 10 m^3 biogas production unit by using animal waste, assuming a 20% increase in costs and a 20% reduction in revenues at the same time (in USD)

Years	Costs	Revenue	Cash flow	Discount 10%	Present value discount 10%	Discount 15%	Present value discount 15%
1	1157	274	− 883	0.9091	− 803	0.8696	− 768
2	150	274	124	0.8264	102	0.7561	93
3	150	274	124	0.7513	93	0.6575	81
4	150	274	124	0.683	84	0.5718	71
5	150	274	124	0.6209	77	0.4972	61
6	150	274	124	0.5645	70	0.4323	53
7	150	274	124	0.5132	63	0.3759	46
8	150	274	124	0.4665	58	0.3269	40
9	150	274	124	0.4241	52	0.2843	35
10	150	274	124	0.3855	48	0.2472	31
11	150	274	124	0.3505	43	0.2149	27
12	150	274	124	0.3186	39	0.1869	23
13	150	274	124	0.2897	36	0.1625	20
14	150	274	124	0.2633	33	0.1413	17
15	150	274	124	0.2394	30	0.1229	15
Sum	3257	4104	847		25		− 153

the 10 m^3 home biogas production unit project can pay the highest interest rate to the farmer, and at the same time, recover the capital invested in it after 4.02 years.

The simple rate of return SRR on invested capital (Eq. 3) is 24.2%. Analysis of sensitivity when costs increase by 30% and revenue decreased by 30%. Assuming the worst-case scenario, which is a simultaneous 30% cost increase and a 30% reduction in revenue, the table shows the use of 15% and 20% discount rates to estimate the current cash flow value during the life span of the biogas unit.

By estimating the ratio of total income to total costs without discount factors, the ratio of revenue to costs is 1.66. Since this ratio is more than the correct one, the project returns exceed its costs. Therefore, each 1 USD invested in the biogas production unit achieves a net return of 0.66 USD. Thus, the total net cash flow is estimated during the life of the project without the use of discount factors at about 1428 USD.

By estimating the ratio of total revenue to total costs using a 15% discount rate and dividing the present value of total revenue by the present value of total costs at a discount price of 15%, it was shown to be 1.02. Since this ratio exceeds the correct one, the returns of the project exceed its costs. Therefore, every 1 USD invested in the biogas production unit achieves a net return of 0.02 USD at the discount price of %15.

IRR by using Eq. (4) is 16.05%. Therefore, the maximum benefit the project can give to the resources used if the project is to recover investment and operating costs simultaneously and achieve parity between revenue and expenses is 16.05%.

The payback period PBP of the unit of biogas (Eq. 6) is 6.2 years. In other terms, the 10 m^3 home biogas production unit project can pay the highest interest rate to the farmer, and at the same time, recover the capital invested in it after 6.2 years. The simple rate of return on invested capital (Eq. 3) is 19.56%.

The results (Table 5) show that the economic assessment criteria used in the evaluation of farm production of biogas from plant residues show that it is a feasible and profitable project from an economic point of view, despite the increase in total costs by up to 30% higher than expected, and a 30% lower revenue than expected at the same time. The internal rate of return exceeds the alternative opportunity cost, estimated at 10%, and the farmer's biogas production project achieves a net current value at a 15% discount rate equal to 33 USD. Besides, the simple rate of return on invested capital exceeds the interest rate of 11% for the alternative opportunity to save money in commercial banks.

Given the results of the biogas unit, which relies on plant residues, it is better than that of animal waste. This differs from the opinion of the researchers Westerholm et al. [45], where they stressed the use of animal manure and possibly because of the different sizes of livestock between the two countries. From the authors' point of view, the nature of the Syrian country rich in agricultural resources compared to animal resources requires the use of biogas units based on plant residues first and in the case of the availability of animals are used in feeding those units.

Table 5 Analysis of the economic return of the 10 m^3 biogas production unit by using plant residue assuming a 20% increase in costs and a 20% reduction in revenues at the same time (in USD)

Years	Costs	Revenue	Cash flow	Discount 20%	Present value discount 20%	Discount 25%	Present value discount 25%
1	1073	274	−799	0.8333	−666	0.8	−639
2	66	274	208	0.6944	144	0.64	133
3	66	274	208	0.5787	120	0.512	106
4	66	274	208	0.4823	100	0.4096	85
5	66	274	208	0.4019	83	0.3277	68
6	66	274	208	0.3349	70	0.2621	54
7	66	274	208	0.2791	58	0.2097	44
8	66	274	208	0.2326	48	0.1678	35
9	66	274	208	0.1938	40	0.1342	28
10	66	274	208	0.1615	34	0.1074	22
11	66	274	208	0.1346	28	0.0859	18
12	66	274	208	0.1122	23	0.0687	14
13	66	274	208	0.0935	19	0.055	11
14	66	274	208	0.0779	16	0.044	9
15	66	274	208	0.0649	13	0.0352	7
Sum	1997	4104	2107		132		−4

3.3 The economic benefits of generating energy from agricultural and animal waste in Syria

The total crop residues in Syria are estimated at 12.3 million tons per year, approximately 50% of which is spent in energy production in a rudimentary low-efficiency manner. Suppose every 3 m^3 of biogas is generated from 21 kg of plant residues. In that case, 50% of the plant residues in Syria, equivalent to 6.15 million tons of crop residues, will be sufficient to produce 0.88 billion m^3 of biogas per year, worth 61.6 USD million annually. This contributes significantly to solving the energy problem of farmers and limits the consumption of petroleum hydrocarbons and their derivatives. Thus, maximizing the per capita energy in rural Syria. Suppose one family in rural Syria needs the equivalent of 5 m^3 of gas per day. In that case, its annual needs are about 1825 m^3, so the amount of biogas produced annually from 6.15 million tons of crop residues, which amounts to about 0.88 billion m^3, is enough to cover the needs of 48,219 households. If the average number of members of the Syrian family is about 5, the amount of biogas produced is sufficient for about 2.4 million people in rural Syria. Adding to that, the ability to produce about 2.009 million tons per year of biogas fertilizer worth 102.459 USD million.

While the total animal waste in Syria is estimated at 44.6 million tons per year, about 30 million tons of which is cow waste that is depleted, and about 25% of which is spent on energy production nationwide, which is equivalent to 7.5 million tons per year. This amount is sufficient to cover the energy needs of 772,602 households, which is equivalent to about 3.86 million people in rural Syria, while in a study conducted by Mensah et al. [29] in Benin, the total imported energy from biogas can serve approximately 145,291 people and brought an estimated annual benefit of USD 3,039,879.10.

4 Summary and conclusions

In this paper, a techno-economic analysis was carried out to establish biogas units on the Syrian coast, and a feasibility study for Syria is provided. This is particularly valuable, as no other study in Syria in terms of biogas has been done so far. The study shows that the areas of Tartus, south and west of Latakia, are ideal places to create biogas units. The study also indicates that there is quite a high potential for the processing of plant and animal residues for biogas. The ratio of total revenue to the total costs of the biogas unit (with and without discount factors) based on animal and crop residues has achieved attractive ratios and lower recovery periods than in other countries, which calls for attention to these projects. Our study also found that the internal return rate of the biogas unit, which relies on crop residues, has achieved a high rate of 52% compared to those dependent on animal waste which reached a 34%. Furthermore, the biogas project would still be profitable in the worst of circumstances, even with higher costs and lower revenues. It is noteworthy to mention that the economic, as well as geopolitical reality of Syria, is experiencing an economic decline (inflation, exchange rate change, low energy), which is leading towards the spread of poverty, unemployment, brain drain, decline in the standard of living, and therefore calls for governmental support in terms of subsidies or other project activities. Finally, this paper recommends assessing the economic feasibility of biogas units of different sizes and a survey of the extent to which the Syrian society accepts this technique. The findings of our study contribute to the post-conflict recovery of the energy sector in Syria with the help of renewable energy resources generated in the agricultural sector.

Author contribution Ghaith Hasan: methodology, verification, investigation, data collection, formal analysis, writing — original draft, writing — review and editing, and visualization. Jana Mazancova: validation, data curation, writing — review and editing, and project administration. Jan Banout: writing — review and editing. Raed Jafar: investigation, data collection, and writing — review and editing. Hynek Roubík: conceptualization, methodology, validation, formal analysis, resources, data curation, writing — original draft, writing — review and editing, supervision, project administration, and funding acquisition.

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Declarations

Competing interests The authors declare no competing interests.

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