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Social and economic assessment of small-scale biogas plants in Syria

Dissertation thesis

Ph.D. Candidate: Ghaith Hasan

Department: Department of Sustainable Technologies

Supervisor: Doc. Ing. Hynek Roubík, PhD
Co-supervisor 1: Ing. Jana Mazancová, PhD

Co-supervisor 2: prof. Ing. Jan Banout, PhD

In Prague, June 23rd, 2023

"One, remember to look up at the stars and not down at your feet.

Two, never give up work. Work gives you meaning and purpose and life is empty without it.

Three, if you are lucky enough to find love, remember it is there, and don't throw it away."

~ *Stephen Hawking*

"The good thing about science is that it's true whether or not you believe in it."

~ Neil deGrasse Tyson

"Shall I refuse my dinner because I do

not fully understand the process of digestion?"

~ Oliver Heaviside

Social and economic assessment of small-scale biogas plants in Syria

-Dissertation thesis

Declaration

I declare that this dissertation thesis titled: "**Social and economic assessment of small-scale biogas plants in Syria**" has been composed by myself and has not been submitted for any other degree or professional qualification.

I confirm that the work submitted is my own, except where work that has formed part of jointly-authored publications has been included. My contribution to each of the publications has been explicitly indicated at the beginning of each such chapter. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others.

In Prague, June 23rd, 2023

Ghaith Hasan

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I would like to dedicate this work to the soul of my beloved father who accompanied me every day through this journey.

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Abstract

The circumstances created by the civil war in Syria led to negative results that were reflected in all sectors, especially the energy sector. Before the war, the proposed plans were to adopt renewable energy from an environmental standpoint, but after the almost complete collapse of the energy sector, the aspiration for renewable energy became an inevitable reality. Therefore, the current situation opens up the interest in biogas technology as a solution to the potential energy crisis.

This research aims to shed light on the prospects and challenges of biogas technology in Syria, study the society's acceptance of biogas technology conducted from agricultural and animal waste, provide an economic feasibility analysis of small-scale biogas plants using organic waste, and analyze the best areas to establish small-scale biogas units. 300 farms were surveyed by using stratified random sampling from three geographical areas that were safe at the time of sampling between 2019-2020 with a response rate of 85%, in total 255 farmers were considered for the study. The study found that basic factors necessary for the successful deployment of biogas units are present, such as a moderate climate and appropriate amounts of organic waste. There is a willingness to apply biogas technology if financial and technical support is provided. Although there is good knowledge among farmers about biogas technology, there are concerns about the inability to maintain biogas units. The feasibility study achieved attractive ratios and indicated that there is quite a high potential for the processing of biogas plants.

The AHP (Analytic Hierarchy Process) and SWOT analysis showed that the acceptance and desire of the Syrian society to adopt biogas technology were the primary criteria. The southern region was at the forefront of alternatives to the studied areas followed by the central region and the last coastal region. The study suggests that there is a need to increase government support for alternative energy technologies, in the form of tax exemption and regulation laws, and to provide possible financial support and facilities for the establishment of small-scale biogas plants serving rural farmers.

Therefore, this research came to be one of the original research projects in the field of biogas production in Syria, as one of the most important renewable energies that could play a key role in the reconstruction phase.

Keywords: Anaerobic digestion, socio-economic aspects, Biogas quality, waste utilization, Methane content, developing countries.

الملخص

أدت الظروف التي خلقتها الحرب الأهلية في سوريا إلى نتائج سلبية انعكست على جميع القطاعات، لا سيما قطاع الطاقة. قبل الحرب، كانت الخطط المقترحة تعتمد على التوجه لدعم الطاقات المتجددة من وجهة نظر بيئية، ولكن بعد الانهيار شبه الكامل لقطاع الطاقة، أصبح التطلع إلى الطاقات المتجددة حقيقة لا مفر منها. لذلك، فإن الوضع الحالي يفتح باب الاهتمام بتكنولوجيا الغاز الحيوي كحل لأزمة الطاقة المحتملة.

يهدف هذا البحث إلى تسليط الضوء على آفاق وتحديات تكنولوجيا الغاز الحيوي في سوريا، ودراسة قبول المجتمع السوري لتكنولوجيا الغاز الحيوي التي يتم إنتاجها من النفايات الزراعية والحيوانية، بالإضافة إلى تحليل الجدوى الاقتصادية لوحدات إنتاج الغاز الحيوي الصغيرة باستخدام النفايات العضوية بشتى أنواعها وتحليلها. حيث تم تحديد أفضل المناطق لإنشاء وحدات غاز حيوي صغيرة الحجم في سوريا. وجدت الدراسة أن العوامل الأساسية اللازمة للنشر الناجح لوحدات الغاز الحيوي موجودة، مثل المناخ المعتدل والكميات المناسبة من النفايات العضوية. وجدت الدراسة أن هناك استعداد لتطبيق تكنولوجيا الغاز الحيوي إذا تم توفير الدعم المالي والتقني. على الرغم من وجود معرفة جيدة بين المزارعين حول تكنولوجيا الغاز الحيوي، إلا أن هناك مخاوف بشأن عدم القدرة على صيانة وحدات الغاز الحيوي. حققت دراسة الجدوى نسبًا جذابة وأشارت إلى وجود إمكانات عالية جدًا لإنتاج الغاز الحيوي.

أظهر تحليل SWOT وعملية التحليل الهرمي AHP أن قبول المجتمع السوري ورغبته في تبني تكنولوجيا الغاز الحيوي كانا في مقدمة المعايير المهمة المؤثرة على تبني التكنولوجيا. وكانت المنطقة الجنوبية في مقدمة بدائل المناطق المدروسة تليها المنطقة الوسطى والمنطقة الساحلية الأخيرة. تشير الدراسة إلى أن هناك حاجة إلى زيادة الدعم الحكومي لتقنيات الطاقة البديلة مثل الإعفاء من الضرائب، وسن القوانين التنظيمية الناظمة لدعم الطاقات المتجددة، وتوفير الدعم المالي المحتمل والتسهيلات الإئتمانية لإنشاء مصانع الغاز الحيوي الصغيرة التي تخدم المزارعين الريفيين.

لذلك، جاء هذا البحث ليكون من المشاريع البحثية الأصلية في مجال إنتاج الغاز الحيوي في سوريا، كواحد من أهم الطاقات المتجددة التي يمكن أن تلعب دورًا رئيسيًا في مرحلة إعادة الإعمار.

الكلمات المفتاحية: الهضم اللاهوائي، الجوانب الاجتماعية والاقتصادية، جودة الغاز الحيوي، استخدام النفايات العضوية، محتوى الميثان، البلدان النامية.

Abstrakt

Okolnosti vzniklé občanskou válkou v Sýrii vedly k negativním výsledkům, které se projevily ve všech odvětvích, zejména v energetice. Před válkou byly navrhované plány na přijetí obnovitelné energie z hlediska životního prostředí, ale po téměř úplném kolapsu energetického sektoru se snaha o obnovitelnou energii stala nevyhnutelnou realitou. Současná situace proto otevírá zájem o bioplynové technologie jako řešení případné energetické krize.

Tento výzkum si klade za cíl osvětlit vyhlídky a výzvy bioplynové technologie v Sýrii, studovat, jak společnost přijímá technologii bioplynu prováděnou ze zemědělského a živočišného odpadu, poskytnout analýzu ekonomické proveditelnosti malých bioplynových stanic využívajících organický odpad a analyzovat nejlepší ploch pro zřízení malých bioplynových jednotek. Studie zjistila, že jsou přítomny základní faktory nezbytné pro úspěšné nasazení bioplynových jednotek, jako je mírné klima a přiměřené množství organického odpadu. V případě finanční a technické podpory existuje ochota aplikovat technologii bioplynu. I když jsou mezi zemědělci dobré znalosti o technologii bioplynu, existují obavy z neschopnosti udržovat bioplynové jednotky. Studie proveditelnosti dosáhla atraktivních poměrů a naznačila, že existuje poměrně vysoký potenciál pro zpracování bioplynových stanic.

Analýza AHP SWOT ukázala, že akceptace a přání syrské společnosti přijmout technologii bioplynu byly primárními kritérii. Jižní region byl v popředí alternativ ke studovaným oblastem, následoval centrální region a poslední pobřežní region. Studie naznačuje, že je potřeba zvýšit vládní podporu pro alternativní energetické technologie ve formě daňových úlev a regulačních zákonů a poskytnout možnou finanční podporu a zázemí pro zřízení malých bioplynových stanic sloužících venkovským farmářům.

Proto se tento výzkum stal jedním z původních výzkumných projektů v oblasti výroby bioplynu v Sýrii jako jedné z nejdůležitějších obnovitelných energií, která by mohla hrát klíčovou roli ve fázi rekonstrukce.

Klíčová slova: Anaerobní digesce, socioekonomické aspekty, kvalita bioplynu, využití odpadů, obsah metanu, rozvojové země.

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Introduction

With the depletion of natural energy resources and the perception of the danger of environmental pollution resulting from meeting the requirements of human activities. It has become necessary to search for new sources of energy that must be more environmentally friendly, such as biogas, that will deal with the increase in waste generation, especially in developing countries (Yang & Lu, 2021).

With the world's population exceeding eight billion, overpopulation and the imbalance between people, resources, and services pose a significant challenge to sustainable development and a greater threat to the climate (UN, 2022).

Biogas helps people in rural areas reduce and valorize waste, providing fuel, electricity, and clean fertilizer free from odors, insects, germs, and exotic seeds (Pizarro-Loaiza et al., 2021). Furthermore, reducing deforestation, which would otherwise cause habitat damage, loss of biodiversity, and aridity (Rasimphi et al., 2022).

As a developing country, Syria is one of the countries where agriculture occupies an important position, with an area of 185,180 km^2. The agricultural area is 139,210 $km^{2,}$ with varied vegetation cover and a medium to semi-dry climate (FAO, 2017). In 2019, the contribution of agricultural production to the national income increased from 17% to 39 %, and 60 % of total exports are agricultural products, according to the report of the Syrian Central Bureau of Statistics (CBS, 2019). Before the civil war, Syria ranked as the tenth-largest cotton producer in the world and the sixth-largest olive producer. In addition to high vegetable and fruit production (FAO, 2017).

Syria has a Mediterranean climate with multiple sources of energy (sun, wind, oil, water, etc.) with significant potential to produce biogas because it is an agricultural country that contains a large amount of organic waste (liquid manure, silage, sewage sludge, organic waste, straw, etc.) (Almikdad, 2015).

The approximate production volume of animal dung in 2009 was about 44 million tons of manure and urine. If fully exploited, it will produce approximately 2.27 billion m^3 of biogas; this percentage varies depending on the type and amount of feed (Al Afif and Amon., 2011).

On the other hand, the country occupied sixth place in the world in the number of olive trees in 2010 and production of olive oil, where the average production of olive residues was 391,999 tons. Although the total production of date palm waste in 2010 was 4,749.3 tons (Alafif et al., 2010). The average production of citrus fruit residues reached about 111,798.6 tons in 2010, and these wastes are disposed of by burning without being invested and profiting from them (Alafif et al., 2010).

These resources must be exploited sufficiently to develop renewable energy sources and accelerate and spread their adoption in Syria, especially after the country's civil war outbreak, which extended its effects to all aspects and sectors, including the resource sector. The circumstances of the war and the urgent need for energy resources have led farmers and people in rural areas to look for alternatives and solutions to the problem of the inaccessibility of gas and electricity (Almikdad, 2015).

When comparing alternative energy projects in Syria with Arab oil countries whose economy is mainly dependent on oil, we find that the contribution of alternative energy to the total energy supply did not exceed 1% (30 megawatts) in Syria in 2019 (IRENA, 2021). While the UAE production in 2022 amounted to 2.6 GW of renewable energy, especially solar systems. Saudi Arabia's production in 2022 is 0.78 GW. While in Egypt, the production reached 3.5 GW (Behrsin et al., 2022). To achieve the Syrian renewable energy goals until 2030 (1.5 GW of wind power, 0.25 GW of biomass-based power, and 0.250 GW of photovoltaic power) (Krepl et al., 2020), it is necessary to highlight the importance of renewable energy by focusing on biogas technology in countries that suffer from war effects such as Syrian case, explore strengths and opportunities and exploit them, and work to overcome obstacles and threats facing the adoption of this technology.

Given the facts mentioned, it is noticeable that there is a real gap between the declared goals and the results achieved in Syria. There is a dearth of literature on bioenergy systems adaption in developing countries witnessing exceptional circumstances such as civil wars (Yemen, Iraq, Lybia, Lebanon, Syria. etc.) (Krepl et al., 2020).

The chosen topic is derived from the importance of biogas production and use in developing countries and countries suffering from exceptional circumstances, such as the civil war in Syria.

This research is considered original, as it is one of the few research projects that has been done on this topic in Syria. This study was carried out in safe areas in Syria. This research highlights the vital role of biogas production and its use in Syria from a social and economic point of view and its future role as an essential energy source, especially during the reconstruction period.

State of the art

1. Overview of the current situation of renewable energies in Syria

With an area of 185,180 square km, Syria has a varied terrain, flora, and fauna. Syria ranks as one of the oldest sites of the cradle of human civilization.

The climate in Syria is classified into two major divisions: Mediterranean climate in the coastal region and the nearby areas, and dry climate in other regions (Selby et al., 2017).

The vegetation cover in Syria is diverse in the central and western regions and contrasts in Badia al-Sham and the whole eastern part. The country contains thirty nature reserves; Latakia Governorate is considered the richest Syrian governorate in terms of forests and vegetation cover by 31% (Ghanem et al., 2020).

The population of Syria, according to estimates from the United Nations at the beginning of November 2021, was 21,324,367 people (World bank, 2021).

Syria is suffering from an energy crisis in light of the ongoing civil war since 2011, the embargo, and its growing need for electricity and fuels, the high prices of energy in the world market, the decreased rates of local production, and the increase in domestic demand.

Before the war, Syria's production reached nearly 10,000 megawatts. During the war, the production declined to 4,000 megawatts, in addition to the loss of 80% of the public network due to the destruction of these stations and the exit of several areas out of service in rural Aleppo, the Homs countryside, and the Damascus countryside (Elistratov and Ramadan, 2018; Al Halabi et al., 2021).

With difficulty securing the fuel needed to operate the stations, alternative energies have become an inevitable solution.

In the Syrian case, there are many alternative energy options, the first and most important of which is solar energy in a country where the sun shines throughout the year for hours.

Until 2017, 20 small and medium solar photovoltaic projects were in service with a total production of 2 megawatts. These projects have been established in Damascus and its countryside, Hama, Homs, and Tartous, with an estimated life expectancy of 25 years (Krepl et al., 2020).

The main large solar project is the photovoltaic project in the Industrial City of Adra (Figure 1), which was opened in the last quarter of 2022 to generate 100 megawatts of electricity through solar panels when finished. So far, a production of 10 megawatts has been installed through more than 18 thousand solar panels.

Figure 1: Adra photovoltaic project, source: SANA, 2022.

In Tartous city, a private solar project with a capacity of 6.2 megawatts was established in 2019. According to this experience, the project owner stated that one of the most important reasons for the small number of private solar energy projects is the lack of the necessary financing for these vital projects. In addition to the instability of the monetary sector, the fluctuation of exchange rates, and the existence of a large gap between the official price of the Syrian pound and the price equivalent in the black market. Also, the fluctuation of the prices of renewable energy equipment in the local market is due to economic sanctions (Hammad, 2020).

Resolution No. (1113) of 2020 defined the purchase prices for electricity produced from renewable energy projects that can be connected to the distribution network (Syrian Investment Authority., 2020):

- The price of solar collector electricity is 7 cents (euro) / kilowatt hour.
- The price of electricity produced from wind turbines: is 6 cents (euro) / kilowatt hour.

- The price of electricity produced from wind-solar hybrid projects is 6.5 cents (euro) / kilowatt hour.
- The electricity from landfill gas costs 5.7 cents (euro) / kilowatt hour.
- The price of electricity from biomass (by combustion, chemical decomposition, or biogas) is 10 cents (euro) / kilowatt hour.
- The price of electricity produced from hydroelectric turbines is 6 cents (euro) / kilowatt hour.

The prices applied to determine the value of net electricity injected into the public distribution network are based on the prices specified above in the euro currency. However, payments are made in the Syrian pound according to the foreign exchange implemented by the Central Bank of Syria on the due date, constituting approximately half of the equivalent price in the black market (Hammad, 2020). This increases the payback period for private projects related to renewable energies.

Additionally, home-scale solar energy systems are a necessary solution due to the period of power outages that range from 16 to 20 hours a day (Elistratov and Ramadan, 2018, Al Halabi et al., 2021).

On the other hand, wind energy has not been effectively implemented in Syria so far despite its great potential. In a study by Amer et al. (2012), the theoretical and actual potential of wind energy in Syria was estimated at 80 gigawatts, which requires modifications to the electrical grid and its connection with neighboring countries. According to the global wind, the wind power potential is 337 W/m2 with average wind speeds of 6.3 m/s (Krepl et al., 2020), Figure 2.

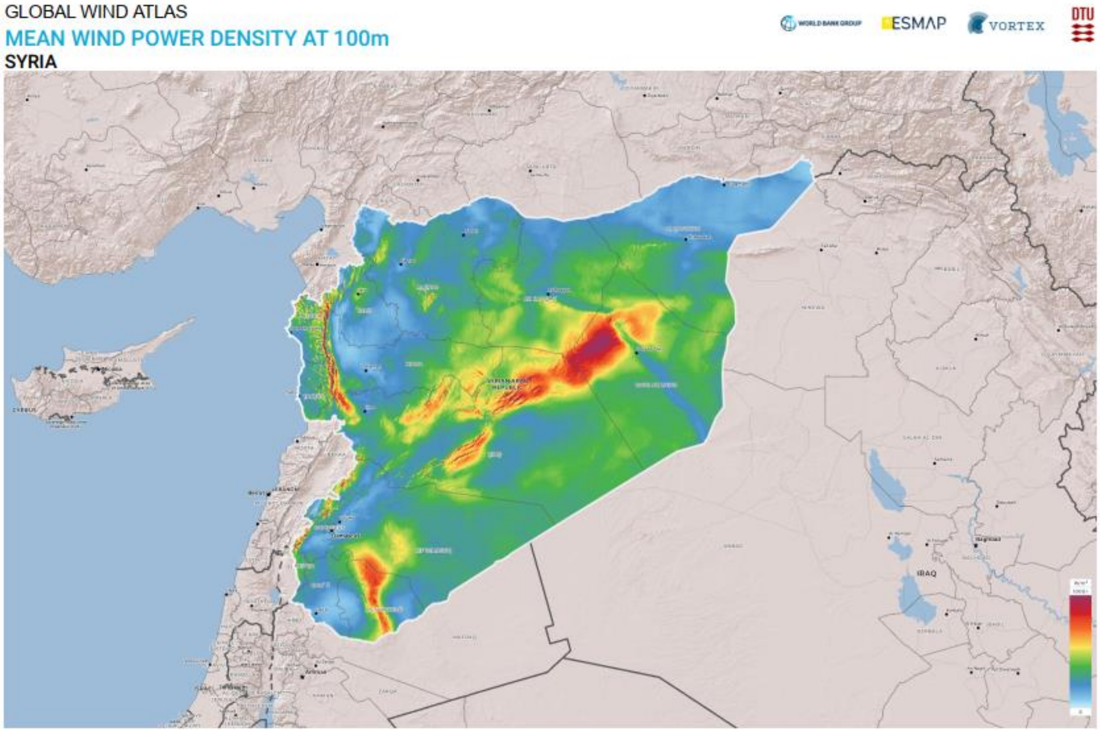

Figure 2: Mean wind power density at 100m in Syria, source: GWA 2022

Homs and Hama regions (specifically the Al-Ghab Plain) and the Qalamoun Mountains, extending along the Lebanese-Syrian border to Quneitra, are suitable for establishing windmills (Krepl et al., 2020).

Despite the critical role of renewable energy sources in bridging the energy shortage gap in Syria, and despite government legislation and directives regarding supporting renewable energy projects before the war on Syria, it is noticed that there is a real gap between the planned goals of vital energy in Syria and what was achieved even before the ongoing war in the country (Abdo et al., 2015). Examples of projects that did not see the light: a wind farm that was scheduled to be established in 2009 with a capacity of 100 megawatts in the Al-Sukhna region, east of Homs, and a wind farm with a total of 50 megawatts in Qattina in 2010, whose implementation was not completed due to the suspension of foreign companies that were supposed to carry them out due to the conflict started at the beginning of 2011 in Syria (Krepl et al., 2020).

Up to 2022, there are only two windmills in the country in Homs Governorate, implemented by the first Syrian wind turbines company with 2.5 megawatts capacity per windmill and a payback period of three years. WDRVM (2021), see Figure 3, represents the installed capacity of the two windmills in Syria.

Figure 3: Windmills installed in Al-Dhahabia area, west of Homs, Syria, source: WDRVM 2021.

2. The potential resources of biogas production in Syria

In 2011, the amount of organic waste (animal, agricultural and human waste) in Syria reached 379.5 million tons (Ali et al., 2011). This huge biomass and its organic compounds cause air and groundwater pollution. In addition to the enormous environmental problems due to many reasons such as lack of experience in how to treat organic waste, lack of specialized experts to work in this field, the absence of a clear strategy by relevant authorities in the field of using biomass energy as a source of energy and the lack of awareness programs and mechanisms to support the spread of this technology in rural areas (Hasan et al., 2019) (Almikdad, 2015). These reasons prevented the deployment of biomass energy usage significantly in the Syrian countryside. Table 1 shows the amount of animal waste and its expected methane emissions in 2010.

Table (1) The amount of animal waste and its expected methane emissions in 2010

Animal waste	**Cows**	**Sheep**	**Goat**	**Birds**
Average estimated production Mil.Ton / Year	7.92	4.18	0.72	0.62
Average estimated amount of organic matter Mil.Ton / Year	0,8	1.9	0.17	0.28
The concentration of methane %	52	56	59	61
The expected volume of biogas mil.m3/year	159.95	486.64	63.24	107.7

Source: (Ali et al., 2011; Sheibli et al., 2016)

The pre-war period results show the amounts of organic waste and biogas expected to be produced and whether all this waste is used in producing natural gas. In light of the deteriorating circumstances that Syria is going through, investing in organic waste treatment will contribute significantly to the support of the energy sector in Syria (Jafar and Awad, 2021).

On the other hand, agricultural waste is considered a promising source for producing biogas. Table 2 indicates the amount of agricultural waste and its expected methane emissions in 2010.

Table (2) The amount of agricultural waste and its expected methane emissions in 2010

Agricultural waste	**Cottonwood**	**Olive mill wastewater and pomace**
Average estimated production Mil.Ton / Year	2.6	1.1
Average estimated amount of organic matter Mil.Ton / Year	2.35	0.21
The concentration of mean methane %	53	58
The expected volume of biogas mil.m3/year	1.1	49.6

Source: (Ali et al., 2011), (Sheibli et al., 2016)

In Table 2, only two types of agricultural waste were scanned, and the results show an impressive amount of agricultural waste that, if used in biogas production, will produce a large volume of biogas.

Sewage, industrial, and municipal waste can be used in Syria to produce biogas. The solid matter ratio in Syria's wastewater is 3%, creating a quantity of solid waste equal to 34,635 thousand tons per day (Almikdad, 2015; Al Afif et al., 2009). Table 3 shows the amount of human waste and its expected methane emissions in 2010.

Table (3) The amount of human waste and its expected methane emissions in 2010

Human waste	Sewage waste	Solid municipal waste
Average estimated production Mil.Ton / Year	357.6	4.6
Average estimated amount of organic matter Mil.Ton / Year	9.7	2.3
The concentration of mean methane %	53	55
The expected volume of biogas mil.m3/year	2,510.4	651.7

Source: (Ali et al., 2011; Sheibli et al., 2016)

The animal production sector causes many environmental problems, such as global warming, soil, air, and water pollution, and a decline in biological diversity (Singh et al., 2022).

The problems resulting from these wastes can be solved using multiple techniques, such as biogas production technology.

If not treated anaerobically, these wastes result in high levels of phosphorus, nitrogen, and greenhouse gases, exacerbating global warming, agricultural land degradation, water pollution, and biodiversity decline (Samoraj et al., 2022).

In Syria, various pilot units and research centers established by government organizations like the Ministry of Agriculture, ACSAD, UN-ESCWA, and the

National Energy Research Center (NERC) have contributed to the advancement of biogas technology (Abdo et al., 2015). The General Commission for Scientific Agricultural Research (GCSAR) has established four biogas experimental guidance research units located in different regions, which have become the basis for similar projects in the Syrian countryside, meeting the demand for biogas and clean fertilizer while aiming for a cleaner and healthier environment (Jafar and Awad, 2021).

Biogas production is still in a primitive stage, mainly occurring in small-scale household digesters. The government has implemented 43 biogas plants of various sizes (14–100 m3) nationwide.

Since the onset of the Syrian conflict in 2011, the provision of solid waste collection services and disposal methods has been disrupted in numerous cities. The energy situation in Syria has worsened, with significant shortages of oil derivatives, such as gas, heating oil, and power outages, primarily due to the depletion of Syrian oil resources and stringent international sanctions on the energy sector (Ford, 2020). Despite the ongoing war, multinational organizations have continued their operations in Syria. For instance, the Food and Agriculture Organization of the United Nations (FAO) has assisted in establishing biogas units for 60 rural households in five governorates, aiming to produce biogas and organic fertilizers (OCHA, 2017). Furthermore, global communities have installed 120 household biogas plants in the Idleb governorate of northern Syria (Global Communities report, 2018).

Due to the small sizes of biogas plants, in developing countries like Syria, the most common uses for biogas are limited to lighting and cooking. These small-scale biogas plants cannot generate enough biogas volume to support Combined Heat and Power (CHP) or bio-methane production for other purposes (Hasson et al., 2019).

Structure of the dissertation

The research began with a review of the literature on the summary of the current state of knowledge on renewable energy sources in Syria.

Based on Decision No 2/2017, at the Faculty of Tropical AgriSciences, Czech University of Life Sciences Prague. This thesis is structured in the form of scientific papers published or currently under review.

The results are presented in the following articles:

i. Hasan, G., Mazancová, J., Banout, J., Jafar, R., Roubík, H. Feasibility analysis of small-scale biogas plants usage in the Syrian coast through agricultural crop residues and co-digestion of manure. Biomass Conv. Bioref. (2022) IF: 4,103. https://doi.org/10.1007/s13399-021-02112-6.
The author was responsible for Methodology, Verification, Investigation, Data collection, Formal analysis, Writing - original draft, Writing – review & editing, and Visualization.

ii. Hasan, G., Mazancová, J., Roubík, H. Assessment of individual acceptance of biogas technology by Syrian farmers - evidence from Coastal, Central and Southern regions. It was submitted to Renewable Energy (2023) IF: 8.634.
The author was responsible for Methodology, Verification, Investigation, Data collection, Formal analysis, Writing - original draft, Writing – review & editing, and Visualization.

iii. Hasan, G., Mazancová, J., Roubík, H. Assessment of the incubating environment for investment in biogas technology in Syria by using AHP and SWOT. Environment, Development, and Sustainability (2023) IF: 4.080. https://doi.org/10.1007/s10668-023-03137-9
The author was responsible for Methodology, Verification, Investigation, Data collection, Formal analysis, Writing - original draft, Writing – review & editing, and Visualization.

Objective of the thesis

This research aims to (Figure 4):

- To analyze the socio-economic aspects of biogas production in rural Syrian areas;
- To investigate whether the biogas technology produced from small-scale units can be considered a solution to energy problems resulting from a lack of resources;
- To analyze the status and the importance of biogas production and its positive and negative economic, social, and environmental impacts ;
- To analyze the policy supporting the production of biogas and its economic feasibility;
- To investigate the potential contribution of biogas production to developing the agriculture sector in Syria.

In the light of the above, research questions were proposed:

- How can biogas production in a small scale as alternative energy contribute to and affect the energy market from a social and economic point of view? What is the future role of biogas use and production as an essential energy source, especially during the reconstruction period?

For this key research problem, the following sub-questions are being asked:

- Is there willingness/motivation among the Syrian rural population to operate biogas units?
- What are the advantages and disadvantages of biogas production as a renewable energy source compared to conventional sources during the war?
- Is the small-scale biogas plant economically viable for being implemented in rural areas in Syria?
- What direct economic and social benefits can the small-scale biogas plant provide Syrian farmers?

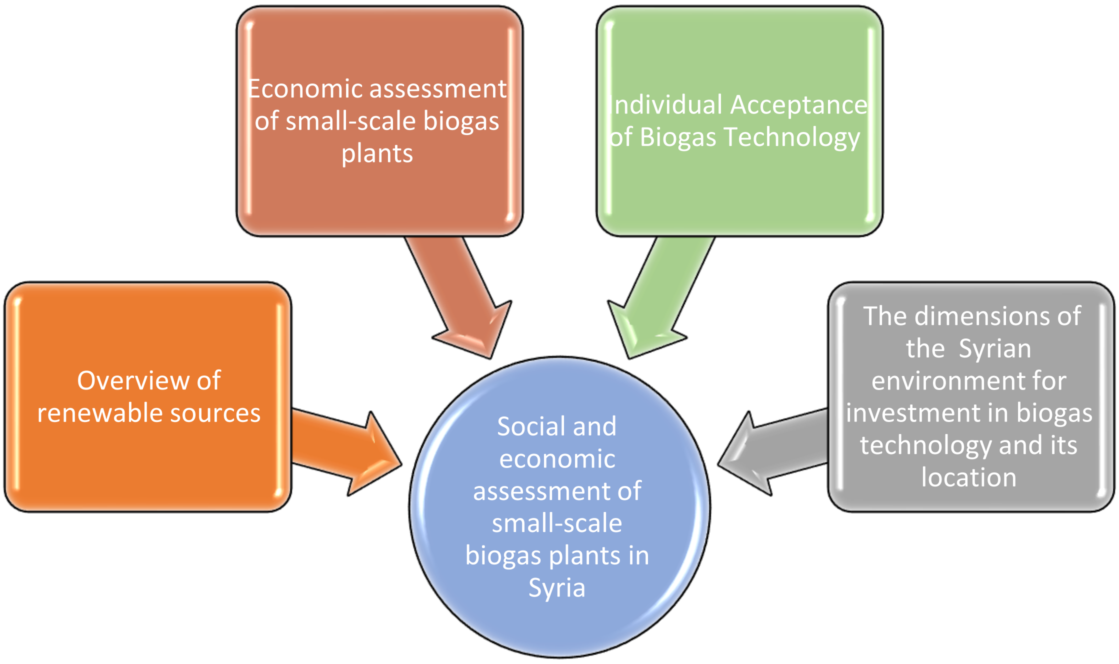

Figure 4. Summary of the research objectives

Methodological approach

Target area

The research included safe areas to reach during the research period between 2019 and 2020. Seven governorates (Latakia, Tartus, Homs, Hama, Damascus, Sweida, and Daraa) were covered in three geographical regions (Coastal, Central, and Southern regions) (figure 5).

The feasibility analysis of small-scale biogas plants usage on the Syrian coast through agricultural crop residues and co-digestion of manure was conducted in rural communities on the Syrian coast, represented by the provinces of Latakia and Tartus. The coastal area was chosen as it is an agricultural stabilization area and was considered accessible and safe at the time of the study.

On the other hand, the assessment of Individual Acceptance of Biogas Technology by Syrian Farmers and the incubating environment for investment in biogas technology was conducted in Coastal, Central, and Southern regions.

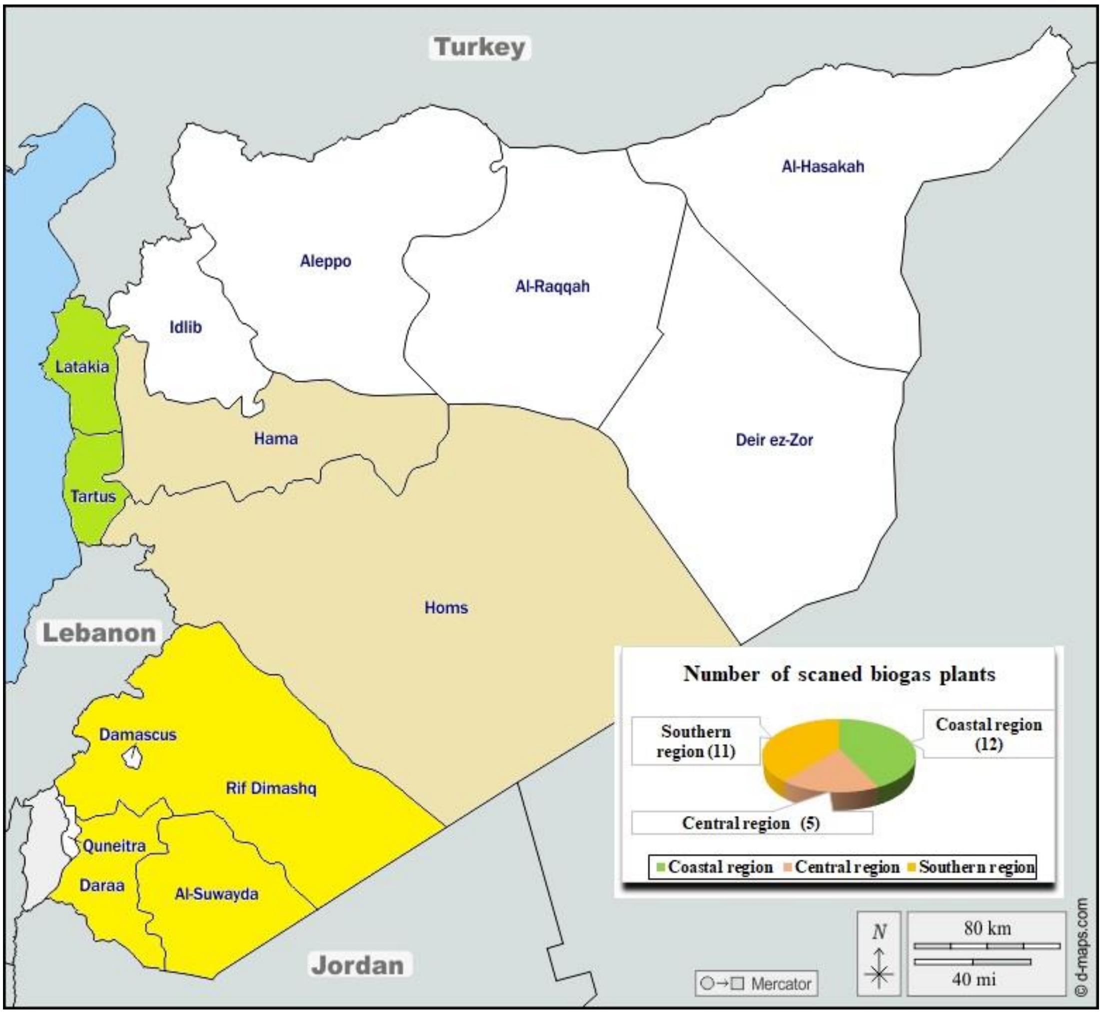

Figure. 5. Map of target study areas (Syria).

Data collection

The official data from the Ministry of Agriculture, the Central Bureau of Statistics, and the General Authority for Agricultural Scientific Research were used. In addition, a survey was conducted and involved 300 farms by using stratified random sampling from three geographical areas that were safe at the time of sampling between 2019-2020. The response rate was 85%; 255 farmers were considered for the study, distributed in 84 farms in the Coastal region, 69 in the Central Region, and 102 in the Southern region. The questionnaire included six parts covering the following: (i) the respondent's knowledge of biogas (incl. biogas production processes, biogas technology, and its costs); (ii) the biogas technology respondent's actual and potential acceptance level; (iii) the respondent's approach to the use of both biogas and organic fertilizer; (iv) the attitude of the respondent toward the management of the biogas unit (individual vs. collective, private vs. governmental); and (v) the knowledge and attitude of the respondent about the financial aspects of biogas technology (costs and expected profits).

Data Analyses

The collected data were statistically analyzed after editing and categorizing the collected data through the Microsoft Excel program, SPSS V20 Statistical Package for Social Sciences Program, and AMOS statistical software.

ArcGIS 10.7 program was used to map the spatial distribution of agricultural and animal waste on the Syrian coast.

Several profitability indicators have been used to analyze the financial-economic feasibility of animal waste and crop residues in small-scale biogas units (cost-benefit ratio, average rate of return, simple rate of return ,internal rate of return ,net cash flow, the payback period and the discount factor).

Cronbach alpha was used to measure construct variability, and the validation of responses by Cronbach alpha coefficient exceeded 60% for all the questionnaire chapters. The Kolmogorov-Smirnov test was used to compare the sample with a reference probability distribution; the natural distribution of the questionnaire terms was tested using the KS test, and the distribution was normal (p-value>0.05).

Variance analysis ANOVA was used to measure the significance of the differences between averages. Furthermore, Path analysis was used, a form of multi-statistical regression, to evaluate causal models by examining the relationships between the dependent variable and the two or more independent variables.

SWOT analysis was used to specify effective strategies for implementing biogas technology in Syria, take advantage, empower and work on weak points, avoid threats, and analyze areas of strength, weakness, opportunity, and threats.

Finally, Analytic Hierarchy Process (AHP) was used as a method of multi-criteria decision analysis (MCDA) explicitly to evaluate multiple criteria in the decision-making process to accept the biogas technology in Syria, as the acceptance of this technology is linked to many factors affecting it.

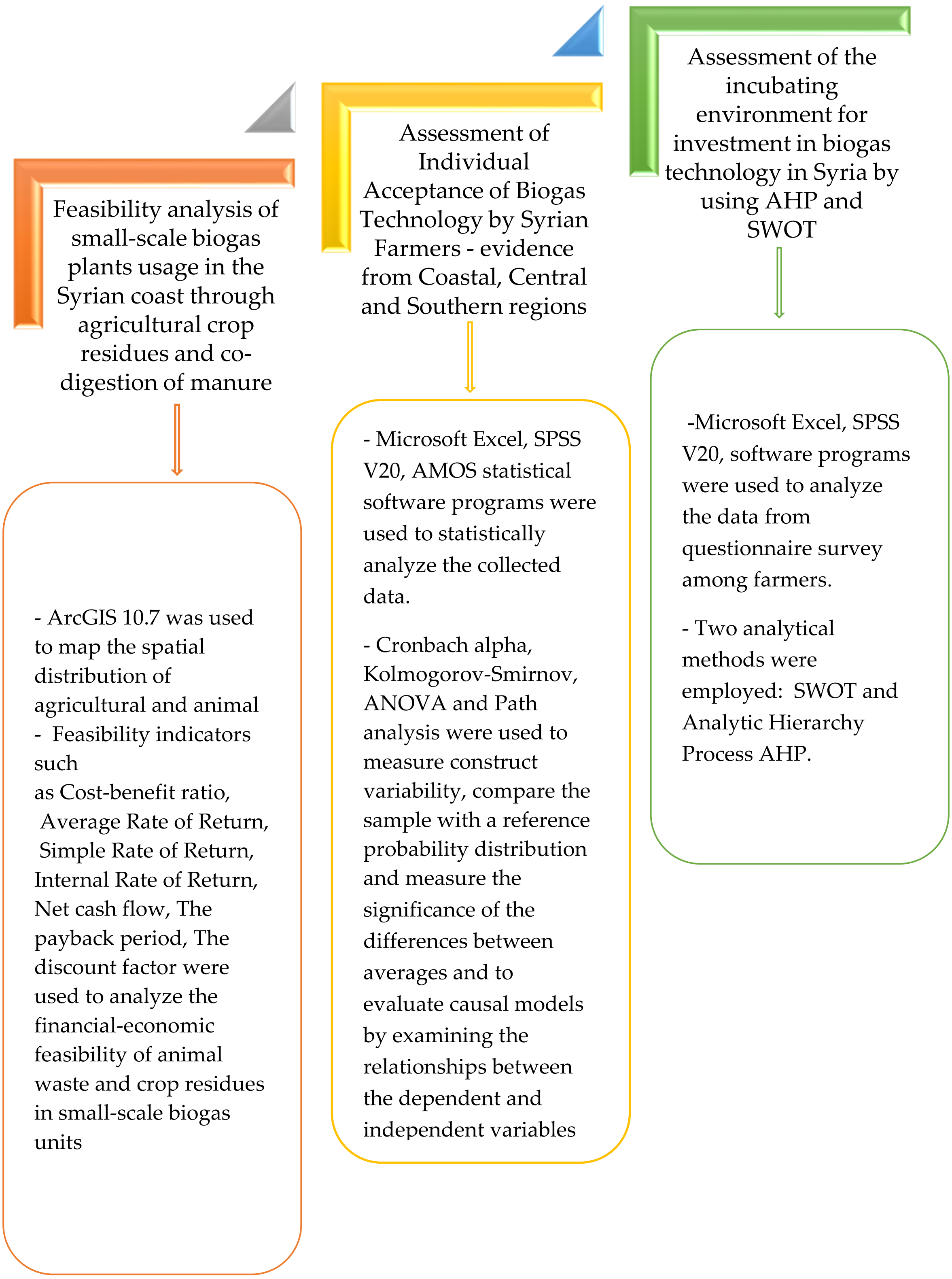

Figure 6: The applied methods that covered the main research articles

Results in form of chapters

Chapter 1. - Feasibility analysis of small-scale biogas plants usage in the Syrian coast through agricultural crop residues and co-digestion of manure

Adopted from: Hasan, G., Mazancová, J., Banout, J. Jafar, R., Roubík, H. Feasibility analysis of small-scale biogas plants usage in the Syrian coast through agricultural crop residues and co-digestion of manure. Biomass Conv. Bioref. (2022) IF: 4,103. https://doi.org/10.1007/s13399-021-02112-6.

Author was responsible for the methodology, verification, investigation, data collection, formal analysis, writing — original draft, writing — review and editing, and visualization.

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

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.

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 (Smil, 2017). 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 (Dada and Mbohwa, 2017; Zhang et al., 2020; AlQattan et al., 2018). 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 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 (NCSA, 2007). 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 (Abdo

et al., 2015). In 2010, biogas unit numbers in Syria reached 43 biogas units (with a volume of between 13 and 20 m3) (Abdo et al., 2015).
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 (Ford, 2020). 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 (OCHA, 2017). Additionally, 120 household biogas plants have been installed by global communities in Idleb governance northern Syria (Global Communities report, 2018).
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 (Naama and Saker, 2014); analysis of the factors that affect the yield reactor to produce biogas from residues country house in the Tartus Province (Abdo et al., 2015); and production of biogas (methane) from co-fermentation of mixtures of white sugar corn and animal waste (Al-Zuabi et al., 2018). Globally the studies focused on: large-scale life cycle assessment and home biogas plants in northwest China (Wang et al., 2018); economic assessment and life cycle of methane production from the application of biogas technology (Collet et al., 2018); 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 (Nasution et al., 2018).
Existing literature focused only on biogas production techniques or particular local studies in the context of Syria. Our study, therefore, fulfils 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, 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 (CBS, 2019). According to the report of the Syrian Central Bureau of Statistics, livestock consists of cows (68,782), goats (31,931) and sheep (193,675) (CBS, 2019).

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, (2005) 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.

$$Cost/Benefit = \frac{operation + investmentcost}{revenues} \quad (1)$$

- Average Rate of Return (ARR):

$$ARR = \frac{\sum_{i=1}^{n}(net\ profit\ after\ tax + interest)/n}{TIC/2} \times 100 \quad (2)$$

Where TIC=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.

$$SRR = \frac{(net\ profit\ after\ tax\ i + interest\ i)/n}{TIC} \times 100 \quad (3)$$

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 (Zawde, 2017).

$$IRR = DR_L + \frac{NPV\ L}{NPV\ L + |NPV\ H|} \times (DR_H - DR_L) \quad (4)$$

Where DRL=low discount rate, DRH=high discount rate, NPV L=net present value at a lower discount rate chosen, NPV H=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

$$Net\ Cash\ Flow = Total\ Revenue - Total\ Costs \qquad (5)$$

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

$$\text{Payback Period} = \frac{\text{Initial Investment}}{\text{Net Cash Flow per Period}} \qquad (6)$$

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

$$Discount\ factor = \frac{1}{1*(1+discount\ rate)^{period\ number}} \qquad (7)$$

2.4 Costs of a 10 m3 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 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.

Table (1) Construction costs of biogas plant (10 m3) 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

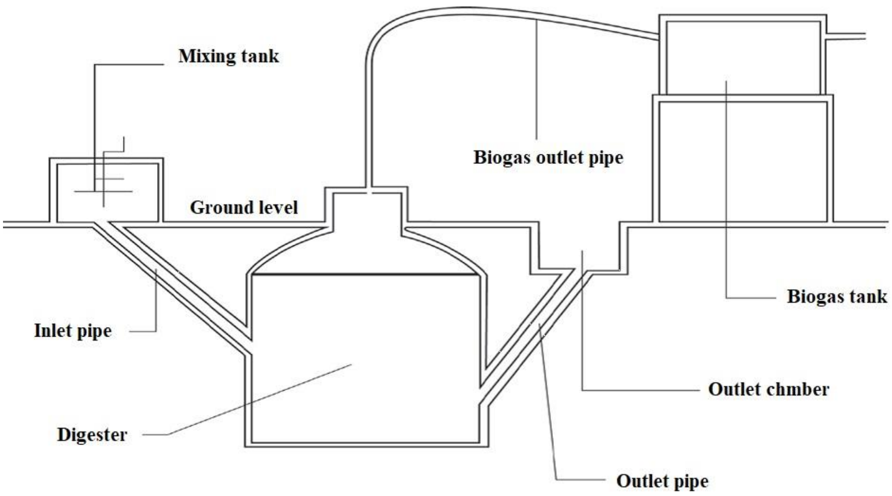

Figure (1) Zahed biogas station– Tartus Governorate - Syria, Source: (Hasan et al., 2019)

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 m³), 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 (10m3) 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 $1,095m^3$ per year), according to its price, which is based on the single price of biogas of 0.6 USD per m3 (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 m3 of methane for manure-based biogas production, and 0.11 USD to 0.50 USD per m3 of methane for industrial waste-based biogas production (IRENA, 2017), 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 been widely deployed yet (Hasan et al., 2019). For more, see table (2), where retrieved information was cross-referenced with publicly available information from the internet.

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 sponser	Cow manure, kitchen waste	Cooking
7	Ibtaa biogas	20	2001	Indian	1	Private sponser	Cow manure	Cooking

	station in Daraa							
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

Source: Almikdad., 2015; Abdo et al., 2015; Al Afif and Amon., 2008; Al-Mohamad., 2001; Hasan et al., 2020; Hasson et al., 2019; Jafar and Awad., 2021

3.1 Potential of organic waste suitable for biogas production

The population of the coastal area (Latakia and Tartus) reached 2,44,4000 people in 2019. The area of cultivated land is 226,000 hectares. Note that a cow produces 16 kg of manure daily, which may be up to 20 kg (Almikdad, 2015). This area 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 m3 per day. As the average daily waste per person is estimated at 0.5 kg, the amount of day-to-day waste generated is 1,222 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 Figure 2, which helps future planning invest in biogas units.

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

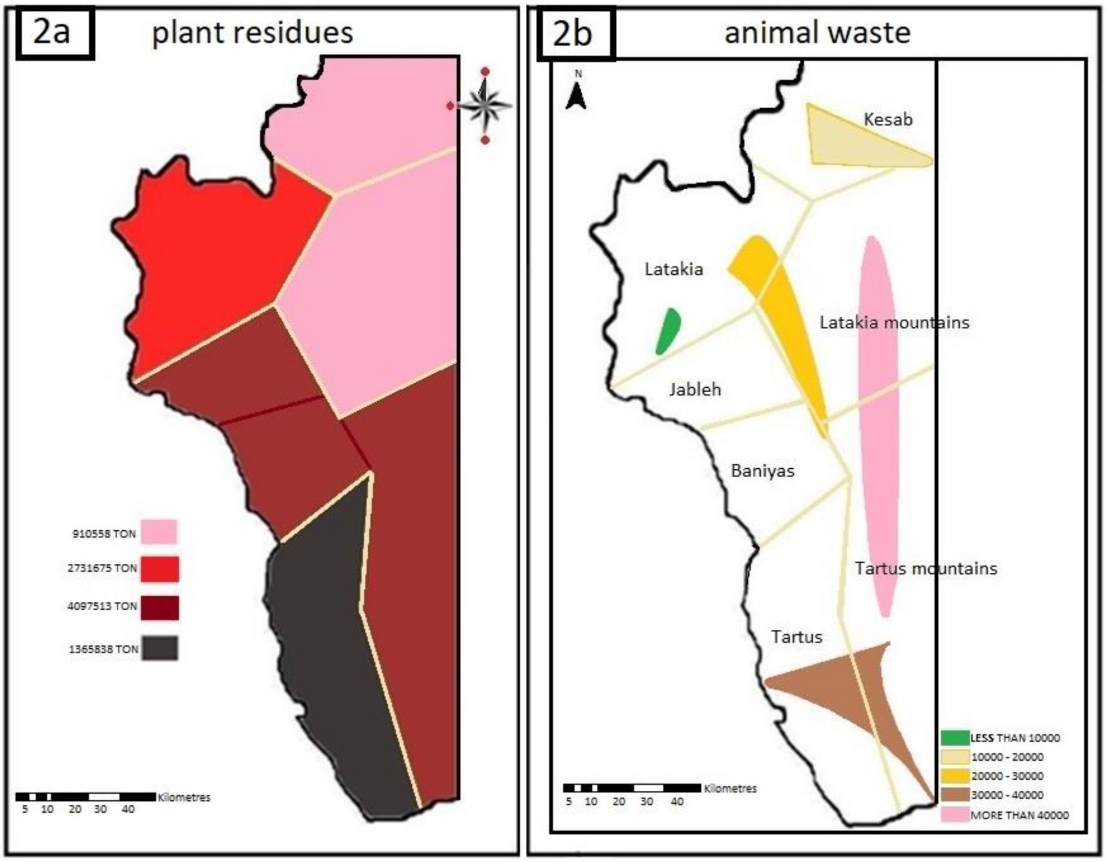

Figure (2) GIS maps showing the distribution of (2a) plant residues figure and (2b) animal waste figure (tons per year) in the Syrian coast where Google Maps was used for the coastal area. Data were entered into the GIS software to determine the distribution of agricultural and animal waste.

We note from figure 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 figure 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 10m3):

3.2.1.1 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. (2020) to 69.35% and about 70% of the total cost in the Biogas Development Guide published by the United Nations (1984) and 35-40% in a GTZ project Information and Advisory Service on Appropriate Technology (ISAT) report (1999). The cost of constructing a 10m3 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. (2020) in Bangladesh, the total cost of 10m3 biogas unit was 821 USD, while in Egypt, the total investment cost of 6m3 biogas unit was 1151.31 EUR (Samer et al., 2020). 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. (2020) 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.
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. (2021) 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.

3.2.1.2 Revenues

The household production unit outputs of biogas and fertilizer are represented at a rate of 3m³ biogas/day, where the fermentation of 1m3 of waste gives 0.3m3 of biogas. According to Bagi et al. (2007), biogas production was measured in biogas units in Tartus by the water displacement method. The biogas output is equivalent to 1095m³ 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 m3 of biogas contains a thermal energy equivalent to 0.6 litres of kerosene (Shrestha, 2001), and if the free price of a litre of kerosene is 0.11 USD/ 1m3 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 1,000 square meters). 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. (2020) 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 (UNHCR, 2019); 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. (2019), 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 et al. (2017); Chen and Liu (2017) and Qin and Bluemling (2013) agree that the government also plays a vital role in biogas technology development.

3.2.1.3 Financial index calculation:

Figures 3 and 4 shows 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 equation 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. (2020), 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 2,416 USD (equation (5)).

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 equation

(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 et al. (2014) at 36.97%.

The Payback Period (PBP) of the biogas unit using equation (6) is 2.9 years. This means that the 10m3 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 et al. (2020) 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. (2005) (5.7 years), Walla and Schneeberger. (2005) (7.5 and 11 years), Patmanomai et al. (2009) (4.11 years), Lungkhimba et al. (2010) (4.81, 7.57, and 7.20 years) Dereli et al. (2012) (7.2 years), Sahu et al. (2013), (6.27 years), Scano et al. (2014) (5.4 and 7.25 years), Agostini et al. (2016), (6 and 7 years), Al-Maghalseh. (2018), (8 years), and Imeni et al. (2019) (<10 years). A short payback period was emphasized to be very valuable from the standpoint of the profitability analysis by the United Nations (1984) and Werner et al. (1989).

Through the previous data, SRR (equation 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%, surpasses 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.

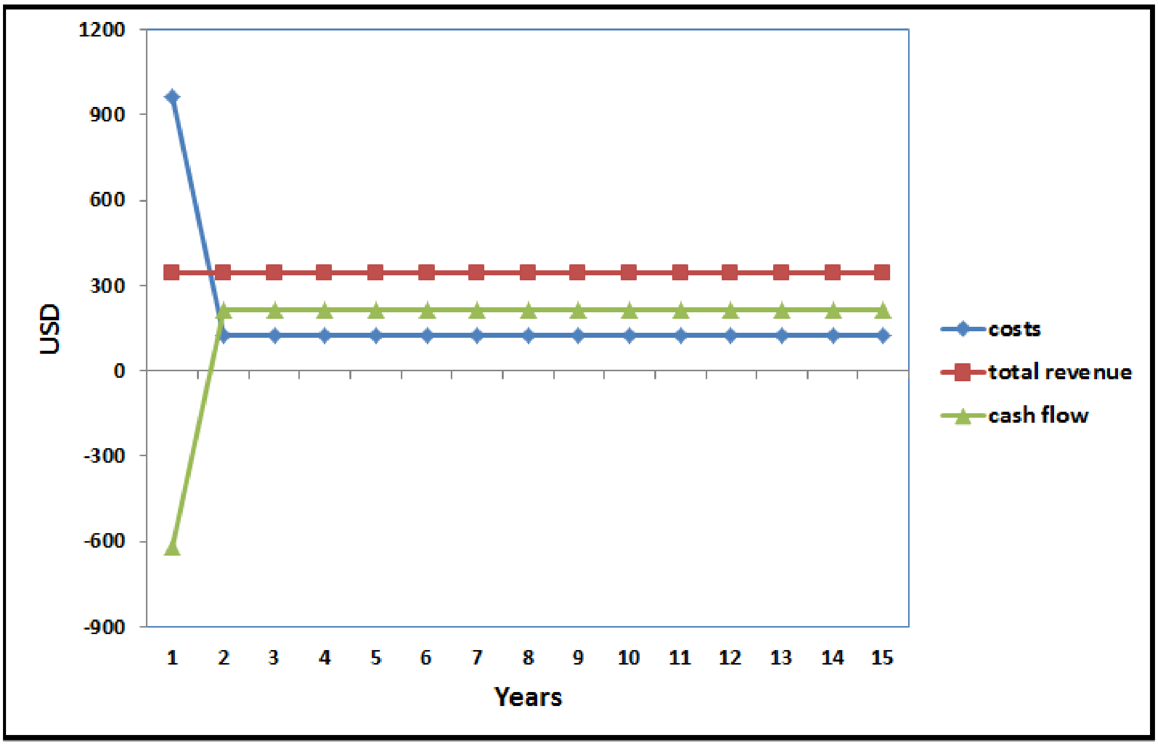

Figure (3) Total costs, revenues and cash flows of a biogas unit that uses animal waste without discounting factors

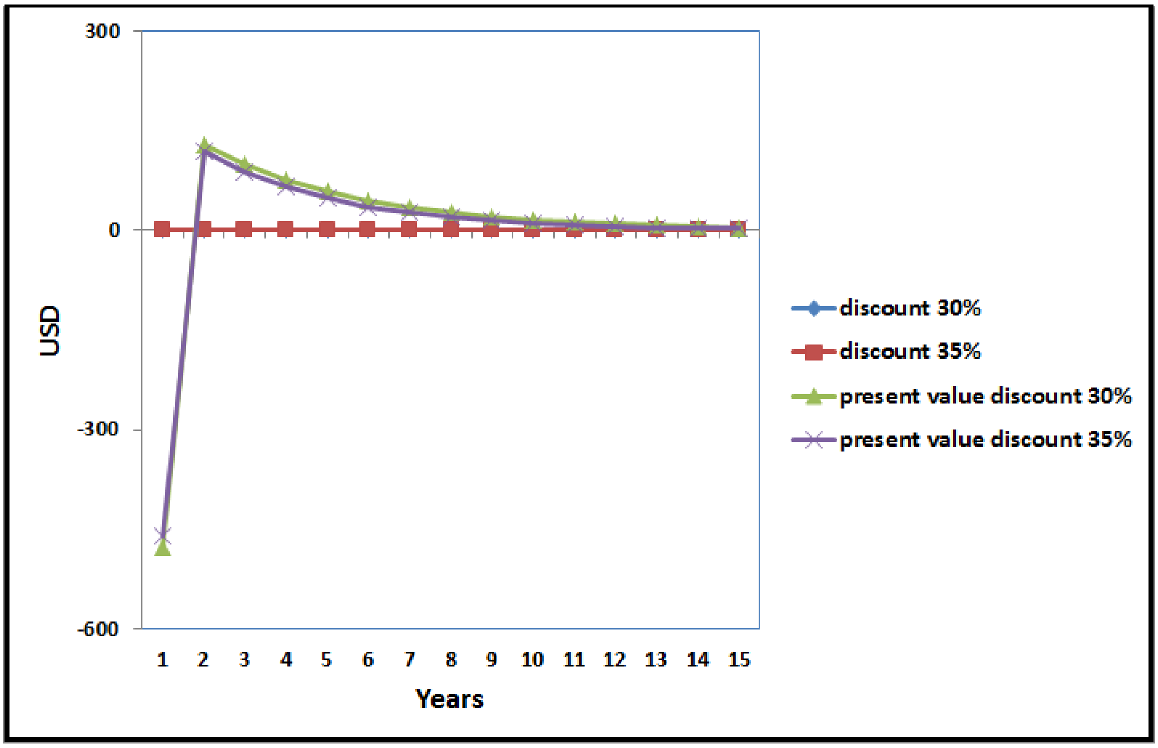

Figure (4) Analysis of the expected economic return using animal waste discount factors over 15 years. Note: Since numbers between 0 and 1 are on top of each other, as well as in hundreds on top of each other, the lines in the figure lay partially on top of each other.

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 (equation 7).

3.2.1.4 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 equation 2 equal 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 equation 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 equation 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 m3 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. (2020) in Bangladesh, where it was found that biogas units remain economically stable even in the worst conditions.

Table (4) Analysis of the economic return of the 10 m3 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

3.2.2 Analysis of the feasibility of small biogas units that use plant residues only (size of 10m3)

3.2.2.1 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.

3.2.2.2 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.

3.2.2.3Financial index calculation

Economic analysis was made using discount factors of 50% and 60% (using equation 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 3,466 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 (equation 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 (equation 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 (equation 3) is 33.4%.

3.2.2.4. 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 2,104.07 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 (equation 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 (equation 6) is 4.02 years, while in a study by Zhang and Xu (2020), the recovery period is 5.34 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 4.02 years.

The simple rate of return SRR on invested capital (equation 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 1,428 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 Internal Rate of Return by using equation 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 (equation 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 (equation 3) is 19.56%.

The results 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.

Table (5) Analysis of the economic return of the 10 m3 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

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. (2020), 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.

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. (2020) 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.

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6. CRediT authorship contribution Statement

Ghaith Hasan: Methodology, Verification, Investigation, Data collection, Formal analysis, Writing - original draft, Writing – review & editing, Visualization.

Jana Mazancova: Validation, Data curation, Writing - review & editing, Project administration.

Jan Banout: Writing - review & editing.

Raed Jafar: Investigation, Data collection, Writing - review & editing.

Hynek Roubík: Conceptualization, Methodology, Validation, Formal analysis, Resources, Data curation, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition.

7. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Chapter 2. - Assessment of Individual Acceptance of Biogas Technology by Syrian Farmers - evidence from Coastal, Central and Southern regions

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Abstract

The need for reliable and renewable energy sources in Syria is increasing in light of the war and the strong embargo. Many energy sectors were destroyed and suffered from poor investment, maintenances, and modernization. Organic waste management methods are often ineffective regarding health, environmental, and economic sustainability. Therefore, the current situation opens the interest in biogas technology to solve the potential energy crisis. This paper aims to study the acceptance of biogas technology as a waste technology of agricultural and animal wealth to support energy production among small farmers in Syria; data were collected from 255 households in different Syrian regions through a corresponding form and then compared using path analysis for the results of the survey. The model was built as knowledge and administrative and financial factors affect the orientation towards using and accepting technology. It was concluded that there is good knowledge among the Syrian rural community about biogas technology and its costs despite its lack of application on the ground, which makes it a raw environment for investment. On the other hand, there are concerns among the rural community about the inability to maintain the biogas unit and the lack of training in this area, which is an obstacle to the application of technology; also, the majority of the sample will use biogas technology if the initial cost of its construction is compensated within one or two to five years, and they confirmed that it is an environmentally friendly technique. The knowledge of biogas technology and both management and financial aspects affects the trends towards use and thus the acceptance of technology, since the extent of knowledge of biogas technology with its factors of benefit and resulting measures strongly the orientation towards use and therefore acceptance of the technology, as the management aspects of its public and private factors measure and strongly the orientation towards use and thus acceptance of the technology. The study recommends that investment in the Syrian environment be an environment with sufficient knowledge of technology and the need to facilitate the granting of funding for investment in biogas technology, tax reduction, and the establishment of support and training centers for this technology.

Keywords: Renewable Energy; Anaerobic Digestion; Organic Waste; Developing Countries; Biogas Technology.

1. Introduction

There is growing demand for energy in developing countries and the inability of renewable energy sources, including natural gas and crude oil, to meet the world's energy needs. In addition to the adverse environmental, health, and social impacts associated with the use of traditional fossil fuels, there has been a growing interest in the search for a cleaner alternative source of energy globally that can contribute to economic growth and reduce the consequences of greenhouse gases (Abdoli et al., 2020) (Scott et al., 2022) (Shahbaz et al., 2022) (Dong et al., 2020) (Dong et al., 2018). Many countries have taken several measures to adjust the energy system and find various alternative resources (Kumar et al., 2019; Chandrasekhar et al., 2020). However, many studies indicate that fossil fuels (oil and natural gas in particular) will continue to dominate in the short and medium term by up to about 80% of energy supplies globally due to the worldwide increased demand in sectors such as transportation and rapid urbanization (Chandel et al., 2013; Amulya, Venkateswar et al., 2014; Kumar et al., 2019; Chandrasekhar et al., 2020).

The implementation of renewable energy technologies has varied in the Arab world, as the Arab countries are generally divided into three sections, the first enjoys abundant oil resources, the second enjoys limited oil resources, and the scarcity of these resources characterizes the third. Despite the richness of Arab countries in renewable energy sources, including biomass, the experience of adopting alternative energy as a strategic solution to future energy problems remains limited. However, renewable energy projects have received attention from the Arabic national governments with the help of international cooperation, donors, and multi-lateral financing (Hanger et al., 2016). Despite the vast reserves of natural gas and oil in its territory, the clean energy participation rate has been set at 50% as one of the goals of the energy strategy in the Kingdom of Saudi Arabia and the United Arab Emirates by 2050 (Amran et al., 2020; Albattah and Attoye., 2021). The Abu Dhabi Biofuel initiative project launched: "Our journey towards sustainability.

Furthermore, the Tadweer Waste Management Center announced that the plant for converting used cooking oil into biodiesel would open at the end of

2020. By 2023, the center could convert waste to energy or jet fuels (Advanced BioFuels USA, 2020). While in Egypt, the target of 42% renewable energy percentage from the country's electricity production by 2035 is based on wind and solar energy (Renewable Energy Outlook: Egypt, (2020 - 2025)). More than the target set by the Syrian government of 30% of energy from renewable energy resources by 2030 (RCREEE, 2021). However, biogas production has made notable progress since the bioenergy project for sustainable rural development started in 2009 (EEAA et al., 2013). The project has made remarkable progress in developing and deploying biogas. During its three-year operation period, the project operated 960 biogas units of different sizes in 18 Egyptian governorates (ERINA, 2018). Twenty companies were established to provide bioenergy services and spread in various villages of Egypt to provide services to more than 1000 families (ERINA, 2018). Iraq has abundant fossil fuel sources; however, research projects have been established to produce biofuels that are still being studied (Star et al., 2016). In Morocco, renewable energy projects have been found, primarily from waste fish oil (Kara et al., 2018).

Additionally, several projects have been carried out in Libya, including producing biofuels using the anaerobic decomposition of cattle waste, but they have not started operating yet (Emara et al., 2016). In Sudan, ethanol is produced from the Kanana laboratory, established as the country's first project to produce ethanol (Hamad et al., 2017). In Palestine, unused agricultural waste could be converted to biodiesel and replace 5% of the production of imported diesel; also, the biogas from animal waste has the potential to meet the needs of 20% of the rural population (Abu Hamed et al., 2012).

Given the current situation in Syria, ten years after the start of the devastating war, in 2019, 70% of power stations and fuel supply lines have stopped serving (Center for Strategic and International Studies, 2021), the adoption and application of biogas production technology can constitute an important tributary to the energy sector in Syria.

Regarding the legislation and policies related to deploying and using renewable energies in Syria, the National Center for Energy Research has been established by Law No. / 8 of 2003, affiliated with the Ministry of Electricity. The center is responsible for conducting studies, scientific and applied research, and implementing pilot projects that help set and adopt policies related to renewable energy sources. (UNESCWA, 2019) (NERC, 2022).

Several legislations have been issued regulating the use of renewable energies, including:

1. The executive instructions of Energy Conservation Law No. //3 of 22/2/2009, which includes the dissemination of the use of renewable energy with its various applications, and the adoption of the latest technologies and equipment used in renewable energy applications such as solar water heating, photovoltaic cells, wind turbines, and biogas units. (UNESCWA, 2019).

2. Electricity Law No. 32 of 2010 related to the general policy of the electricity sector and encouraging the use of renewable energies in various fields and the localization of their industries, and allowing the local, Arab, and foreign private sectors to invest in this field according to encouraging rules and conditions

3. Law 17 of 2013 established a home solar heater support fund at the Ministry of Electricity (NERC, 2022).

4. Law No. (23) of 2021 establishing a fund to support the use of renewable energies and raise energy efficiency. One of its most important goals is to raise awareness among citizens of the importance of renewable energies and spread the culture of its use and its role in the sustainability of energy resources (SOME, 2021).

However, since 2011 due to the country's crisis, biogas production has been limited to individual initiatives by a few biogas production units on private farms (Hasan et al., 2019). As part of the project to support the production of biogas and fertilizers from biogas facilities, the World Food and Health Organization has established 60 rural households in five governorates (OCHA, 2017). Another 120 small-scale biogas units have been installed in Idlib, northern Syria, as part of the global communities' project (Global Communities report, 2018). Renewable energy technologies are not limited to reducing the harmful environmental impacts of fossil fuels. Still, it also contributes to the process of fossil fuels and economic development (Stigka et al., 2014). Biogas is renewable energy and a byproduct of biomass. It is produced through micro-bacterial digestion processes under anaerobic conditions from various organic materials from animal, agricultural, industrial, and domestic waste (Teferra and Wubu, 2018). Biogas production from small-scale biogas plants manages organic waste. It offers environmental improvement and solutions for the disposal of organic waste and can be used for cooking, electricity production, and lighting with little maintenance. The fertilizer obtained from the biogas plant has a higher nutritional value than ordinary farmyard manure (Roubík et al., 2017). However, applying biogas technology within the scope of small-scale biogas plants faces economic, social-technical, and other difficulties in Syria (Ghanem and Ibrahim, 2014).

The social acceptance of renewable energy technologies is essential in implementing and achieving renewable energy goals. The term NIMBY (not in my backyard) has appeared in many papers on the principles of accepting renewable energies (van der Horst, 2007) (Wüstenhagen et al., 2007). E.g. Dumont et al. (2021) Lovrak et al. (2022) Mazzanti et al. (2021) Bertsch et al. (2016) explained that the relationship is often direct between development projects such as the adoption of renewable energy projects in a region and the opposition of the local population to such projects if the projects close to their homes, despite their belief in its usefulness. On the other hand, Wolsink et al. (2007) Soland et al. (2013) Kortsch et al. (2015) Zemo et al. (2019) showed that the opposition of the local population to renewable energy projects such as the adoption of solar, wind or biogas technologies could not be explained through the concept of NIMBY. Many factors affect the residents' acceptance of such projects, such as the balance between benefits and costs and other personal, social, psychological, and cultural factors. The gap between the high social acceptance of renewable energy technology and the local rejection and opposition to the application of technology was discussed in what is known as the social gap (Bell et al., 2007) (Wüstenhagen et al., 2007). The acceptance or rejection of the adoption of renewable energy in societies is related to the local feelings of individuals related to customs, traditions, and cultural beliefs (Yaqoot et al., 2016).

This research aims to determine the level of knowledge of Syrian rural residents about biogas, the extent of acceptance of this technology, the society's approach to biogas and the resulting organic fertilizer, and the accompanying management and financial aspects. The importance of this research also comes from the lack of such research in Syria.

2. Model and hypotheses

In-depth socially comprehensive studies are needed to know and clarify the links between future renewable energy systems and between social sciences and human needs (Sovacool et al., 2015). A systematic literature review conducted by Apfel et al. (2021) showed that the quantitative approaches, focusing on resources and energy models, dominate the research agendas on renewable energies in the Global South and that the local conditions of the dissemination of technology affect the technological maturity of the adoption of renewable energies. Energy transitions are related to many interconnected regional scales to contribute to the transition process (Truffer et al., 2015). A study by Köhler et al. (2019) showed that the sustainability transition faces challenges such as climate risks, environmental, social problems, and the phase-out of unsustainable technologies. The adoption of renewable energy is an important factor of the transition. Fastenrath and Braun. (2018) discussed the importance of societal recognition of sustainability for adopting economic and technological solutions and suggested integrating learning paths and the role of actors in sustainability transition research processes.

Innovative technology systems and updated models play a key role in the transition to decarbonize economy (Diaz et al., 2019; Lüdeke et al., 2019). Corsini et al. (2019) stressed the importance of the participation of community members as a prerequisite for achieving sustainable development. A study conducted by (Dobers, 2019) showed the importance of place and space in society's acceptance of biogas technology in Germany, despite the great government support that the biogas sector receives in Germany, ranking it third after wind and solar energy. The benefits of biogas technology and its production costs and the community's confidence in the management of biogas facilities have affected the acceptance of the technology in Switzerland (Soland, et al., 2013). A study made by (O'connor et al., 2021) showed that there is an inverse relationship between the lack of information and the acceptance of BG technology; while the majority of the possible BG adapters preferred a self-owned plant ownership structure, 58% of the scanned group showed interest in a cooperative scheme. A study by (Frantál and Prousek, 2016) focused on the individual motivations of farmers to adopt renewable energy production activities in the Czech Republic, showing that the main characteristic between farmers is a discrepancy between their behavior towards renewable energies and attitudes. Chodkowska et al. (2019) conducted a significant level of awareness of biogas technology among farmers in Poland and the Czech Republic. Biogas plant owners played a major role in spreading knowledge about biogas technology through local events.

Zemo et al. (2019) conducted research in Denmark on the effect of the proximity of biogas facilities to homes and its reflection on property prices and, thus, its direct impact on technology acceptance. His results showed an inverse relationship between the price of homes and their proximity to large biogas units. A study by Bourdin et al. (2019) stressed the importance of local authorities in France in promoting the deployment of biogas projects and making efforts to reconcile the stakeholders. Schumacher and Schultmann. (2017) research showed the importance of the geographical location of the biogas production unit in its acceptance by individuals due to their fear of emitted odors.

Therefore, this article focuses on the farmer's final decision (driven by endogenous and exogenous factors) to adopt biogas energy production in Syria as a path to the transition to sustainability and an essential source of power that is missing due to the ongoing conflict and unstable situation. The structural equation model was applied to determine the acceptance of biogas technology (BT) at the individual (farmer) level. The model in Emmann, et al. (2013) inspired the conceptual framework and modified it for Syrian conditions. There are five constructs in the present model (Fig. 1): (1) favorable environment (incl. externalities) for biogas technology (policy incl. information campaign and subsidies; technical support; training received; the existence of neighbor BT; energy resources availability), (2) knowledge about biogas technology, (3) attitude towards biogas technology (optimism in benefits; psychology resilience), (4) personal traits towards innovations (self-estimation), and (5) personal innovativeness (socio-demo characteristics; willingness in investment).

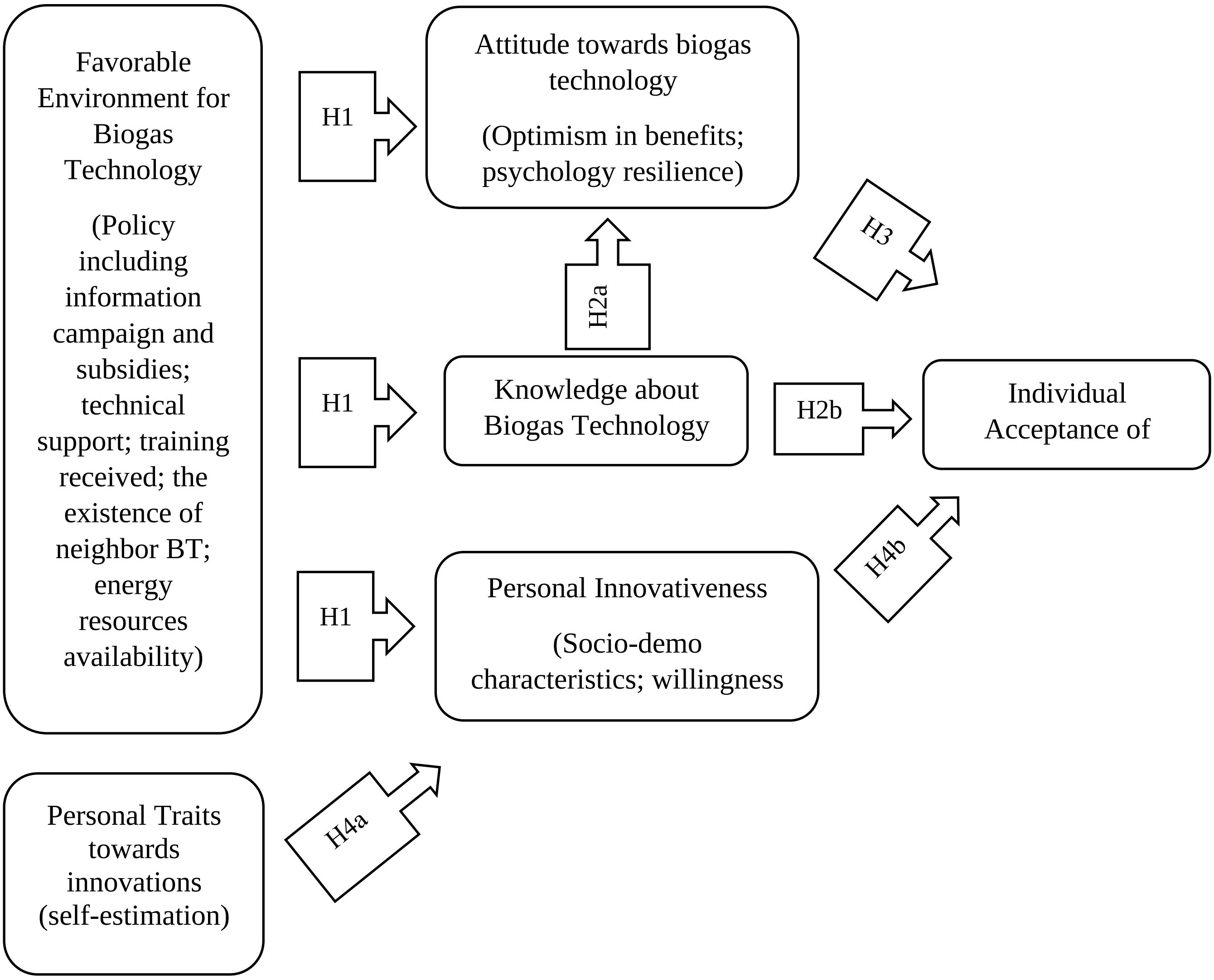


Figure. 1. Conceptual framework

Considering the mentioned factors in the above model, the following hypotheses were tested:

Hypothesis 1: Favourable environment influences a farmer's attitude towards BT, their level of knowledge about BT, and personal innovativeness.

Governmental Supportive policies for biogas production and the promotion and information campaign and subsidies as driving factors and influence the attitude toward biogas techno (Zafar et al., 2006) (Chen et al., 2012)(Suwanasri et al., 2015)(Rupf et al., 2015) (Mittal et al., 2018)(Kabir et al., 2013).

Hypothesis 2a: Level of knowledge about BT influences attitude towards BT.

Hypothesis 2b: Level of knowledge about BT influences individual acceptance of BT.

Hypothesis 3: Attitude towards BT influences individual acceptance of BT.

Hypothesis 4a: Personal Traits towards innovations influences Personal Innovativeness.

The financial factor plays an important role in the process of adopting and installing a biogas plant, Subsidies can be in loans or affordable access to credit (Rupf et al., 2016) (Zhao et al., 2016).

Hypothesis 4b: Personal Innovativeness influences individual acceptance of BT.

3. Methods and data

The study was conducted from March 2019 to January 2020, using a standardized questionnaire to determine biogas technology (BT) acceptance at the individual level (farmer). The survey covered about 56% of Syrian territory represented by seven provinces (Latakia, Tartus, Homs, Hama, Damascus, Sweida, and Daraa), which were not under security restrictions (Fig. 2).

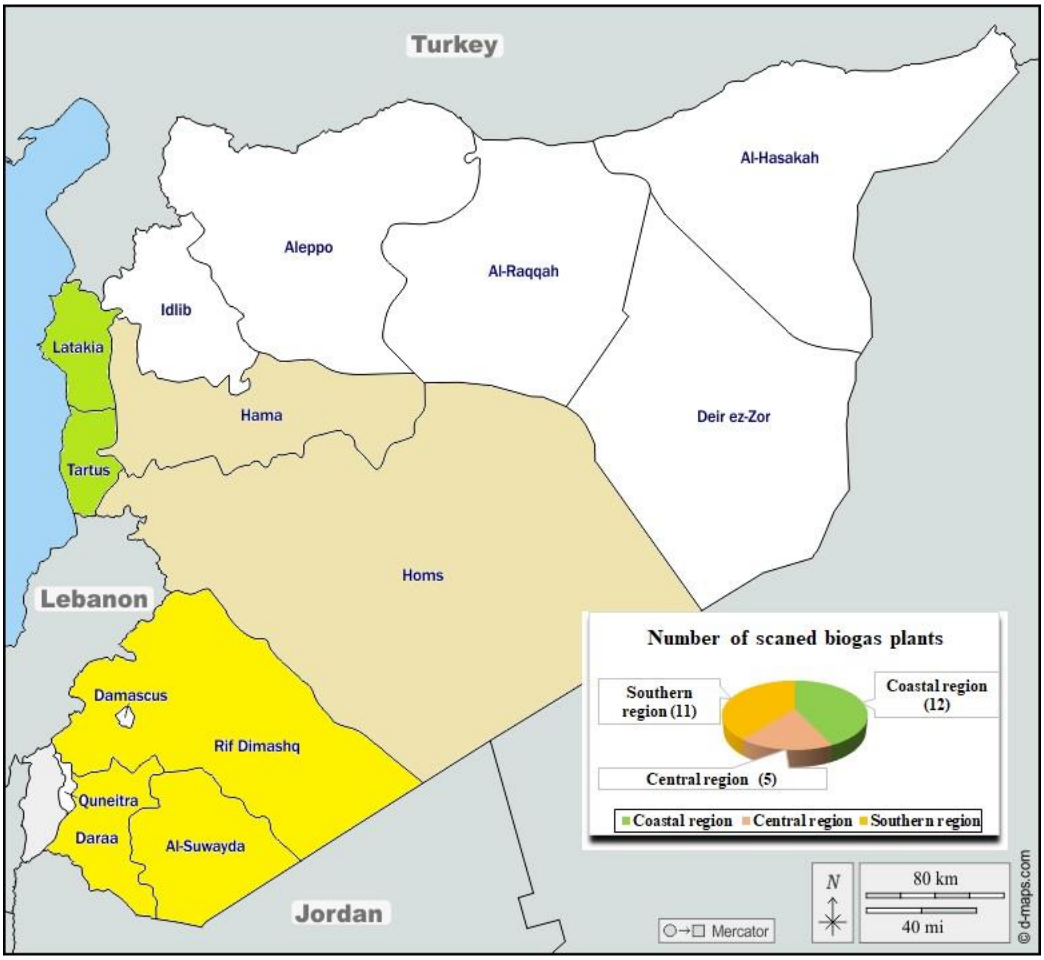


Figure. 2. Map of target study areas (Syria).

The target group involved 300 farms by using stratified random sampling from three geographical areas that were safe at the time of sampling in 2019 to find out the extent of the difference in the answers of Syrian farmers and shed light on their understanding of biogas technology. With a response rate of 85%, 255 farmers were considered for the study, distributed in 84 farms in the Coastal region, 69 farms in the Central Region, and 102 farms in the Southern region. The questionnaire included six parts (Table 1) reflecting the aim of the study. The collected data were coded using the Microsoft Excel program to store and process the collected data. To measure construct variability, we use Cronbach alpha; the validation of responses by Cronbach alpha coefficient exceeded 60% for all the questionnaire chapters. The Kolmogorov-Smirnov test was used to compare the sample with a reference probability distribution; the natural distribution of the questionnaire terms was tested using the KS test, and the distribution was normal (p-value>0.05).

Table 1. Questions for each component.

Component/Questions	Min.	Max.	Answers in percentage
Favorable Environment			
I am aware of governmental policy supporting biogas technology.	0	1	33.3%
I have experienced any information campaign about biogas technology.	0	1	11.8%
I can apply for subsidy for biogas technology.	0	1	
I know where to get information support in case of interest in biogas technology.	0	1	56.9%
I know where to get technical support in case of biogas technology failure.	0	1	18.8%
I have ever received training on biogas technology.	0	1	9.4%
My neighbors use biogas technology.	0	1	6.7%
Biogas technology is locally available.	-2	2	59.98%
Other energy sources are expensive for me.	-2	2	73.80%
Attitude toward biogas technology			
Biogas technology is a suitable alternative to my previously/currently used energy source.	-2	2	79.69%
Biogas technology brings me extra income.	-2	2	79.14%
Biogas technology can harm the environment I live in.	-2	2	43.53%
I do not like to use energy from dung for my cooking.	-2	2	53.33%
Knowledge about biogas technology			
Biogas technology reduces the volume of final organic waste.	-2	2	81.57%
I consider that the initial costs of biogas technology are high.	-2	2	78.54%
The organic waste decomposition through biogas technology produces liquid and solid materials.	-2	2	69.65%
Organic waste decomposition through biogas technology produces fertilizer for plants.	-2	2	78.51%
Biogas technology usage has positive effects on the environment.	-2	2	81.18%
I prefer to connect the toilet to biogas technology.	-2	2	51.37%
Personal Innovativeness			
I am willing to invest in biogas technology.	-2	2	75.06%
What is the minimum you would invest?	20,000 (SP)	2,000,000 (SP)	218,095.24 (SP)
What is the maximum you would invest?	50,000 (SP)	5,000,000 (SP)	501,861.47(SP)

I am able to collect dung regularly.	-2	2	60.71%
Personal trait			
I am interested in new innovations.	-2	2	85.02%
Individual acceptance			
Do you run your own biogas plant?	0	1	10.98%
I am able to stock dung.	-2	2	62.12%

Min.=minimum; Max.=maximum. Scales: −2=totally disagree to 2=totally agree. Scales: 0=no, 1=yes.

4. Data Analyses

The collected data were statistically analyzed after editing and categorizing the collected data through Microsoft Excel program. SPSS V20 Statistical Package for Social Sciences Program and AMOS statistical software were used.

Variance analysis ANOVA was used to measure the significance of the differences between averages. Furthermore, Path analysis was used, which is a form of multi-statistical regression that was applied to evaluate causal models by examining the relationships between the dependent variable and the two or more independent variables (Gao et al., 2022) (Lleras, 2005). Using this method, one can estimate the size and importance of causal links between variables.

5. Results and discussion

5.1. Characteristics of respondents

Basic demographic characteristics are shown in Table 2. In addition to the results, it was also observed that 53.38% use some animal waste as fertilizer for crops, and 78.95% of the research sample does not ferment animal waste for biogas. In comparison, 50.38% dump animal waste in containers and waste 85.71% prefer to leave it in place, and the average distance between the house and the nearest location to dispose of waste is 59.65 meters.

Table 2. Descriptive statistics for sample research (N=255)

variables		values
gender	male	164(64.3%)
	female	91(35.7%)
Age $mean \pm sd$		39.3 ± 11.4
Family size $mean \pm sd$		5 ± 1
Job as a primary source of income	Agricultural	184(72.2%)
	Commercial	13(5.1%)
	Government	28(10.9%)
	private	18(7%)
	Agricultural and private	12(4.7%)
Type of educational level	Uneducated	35(13.7%)
	Primary	15(5.9%)
	preparatory	34(13.4%)

	secondary	66(25.9%)
	university	105(41.7%)
Average income	Less than 25000	4(1.6%)
	25000-50000	57(22.3%)
	50000-100000	115(45.1%)
	More than 100000	79(31%)
Percentage of farm income from total household income $mean\% \pm sd$		45.9 ± 21.1
Farm space $mean \pm sd$		10.5 ± 5.4
Presence of a biogas unit	yes	28(11%)
	no	227(89%)
Owning animals	yes	113(44.3%)
	no	142(55.7%)

A high percentage prefers to burn household waste up to 57.3%, 67.1% prefer to be disposed of in public containers, 55.3% prefer to feed organic waste to animals, 87.5% do not prefer to ferment organic household waste for biogas and/or compost. In comparison, 92.5% of the sample members prefer to dump it in a nearby land.

As well as, 90.2% of the research sample deals with wastewater by draining it into the sewage system, which is the same that it does not discharge in an absorbing hole and that more than 96% do not discharge it through an open channel or use it to irrigate crops. In addition, 54.5% do not deal with agricultural waste by burning them on the farm or burning some of them 43.5%, 53.7% prefer to use it as animal food, 92.2% prefer to leave it on the ground or its borders, 58.8% use it for energy, and 94.1% prefer to collect straw in the form of molds, while 84.7% prefer to use it for fertilizer or biogas.

5.2. Analysis of responses to questionnaire statements

5.2.1 Knowledge about biogas

Of total 255 farmers, 62.4% had prior knowledge about biogas. A high percentage of 255 farmers (56.6%) got knowledge via the Internet. 57.6% of 255 farmers believed that biogas results from the decomposition of organic waste. However, this finding is different when comparing the knowledge of biogas in Syria with South Africa. A study by Muhiiwa et al. (2017) showed that 64% of the respondents had no knowledge about biogas, its nature, and its application.

That the sample answers were within the approval (3.4-4.19) (According to the Fifth Likert Scale) that biogas technology reduces the final volume of waste as well as there is the approval that the initial cost of establishing a biogas unit is high and there is an agreement that the analysis of organic waste produces fertilizer and approval rates exceeding 69% of 255 farmers, on the impact of biogas on the environment, were the answers within the high approval (4.2-5) and by 84.08%, which is an indication that the majority of the total sample of 255 farmers consider that the use of biogas technology It has positive effects on the environment.

5.2.2 Acceptance of the technique

The respondents of the sample members agreed (3.4-4.19) that the majority of the sample members are willing to buy a biogas unit and use it in their home or farm, that biogas technology will benefit their family, that the majority of the members of the sample do not mind separating organic waste from the rest of the household waste, and that the majority of the sample members if they acquire a biogas unit, fear that they will not be able to maintain it in the event of a malfunction, as well as lack of expertise to follow up on the work of the unit and maintain it in proportions by more than 70% of the sample.

Between 57% and 61% of the farmers responded that there are alternatives better than biogas technology for treating organic waste, and running a biogas unit in the house or farm will require a lot of time and effort. This can be compared with Zimbabwe where research conducted by Matsvange et al. (2016) showed the importance of the cost of biogas units in the willingness to adopt the technology.

It was also noted from the survey results that the majority of the respondents would use biogas technology if the initial cost of its construction was compensated within one year or 2-5 years and by 36.1% and 48.6%, respectively. The average minimum investment desired by the sample members was 218,095.24 S.P, and the average upper limit was 501861.47 S.P.

The sample answers were rejected (1.8-2.59) by 43.53% that biogas technology could harm the environment in which they lived, while there was approval (3.4-4.19) by 79.69% of the sample of 255 farmers considered biogas technology as a suitable alternative to the energy source currently in use, neutrality and ratios is ranging from 53 to 62% about the desire to use dung energy for cooking. There is a neutrality that other alternatives to organic waste management are better than gas technology, vital and able to collect and store dung regularly.

On the other hand, the majority of the respondents are denied knowledge of the government policy that supports biogas technology and 66.7% of the sample of 255 farmers, and there is a denial to the majority of the members of the sample about their participation in media campaigns on biogas technology and by 88.2% of the sample of 255 farmers are known to the majority of the sample members about where to obtain the necessary information in case of interest in biogas technology and 56.9% of the sample of 255 farmers and there is a denial to the majority of the sample members about their knowledge of the place of Obtain technical support in case of failure of biogas technology, training in biogas technology or the use of this technology by neighbors at 81.2%, 90.6%, and 93.3% respectively from the sample of 255 farmers, This research finding is in agreement with the research conducted in Uganda by Lwiza et al. (2017) which showed that the governmental and non-governmental organizations should the acceptability and usability of the technology and offer appropriate information and training to minimize malfunctioning of the technology. Similar results from a study in Bali in Indonesia by Silaen et al. (2019) showed the importance of providing government subsidies or facilitation lending by banks to help farmers afford the cost of investment in biogas technologies.

Finally, there is neutrality (2.6-3.39) and between 50 and 58% of the sample of 255 farmers that biogas technology is available locally, and there was approval (3.4-4.19) and by 73 80% of the sample of 255 farmers that other energy sources are expensive for them, and there is high interest (4.2-5) and 85.02% of the sample of 255 farmers with new innovations.

5.2.3 Trends toward using biogas

More than 78% of the sample of 255 farmers agreed to use biogas fertilizer in their garden or farm, and it is desirable at the home level, which is economically and environmentally feasible.

5.2.4 Management Aspects

The high percentage considers biogas technology management a collective process and exceeds 67% of the sample of 255 farmers.

The sample responses were neutral (2.6-3.39), and between 50 and 66% of the sample of 255 farmers, so there is neutrality among the majority of the sample members about the use of biogas technology at home and only at home and in managing the use of biogas technology. Through a private company, the responses of the sample members to the phrases (3-5-6) were within the approval (3.4-4.19) and by more than 70% of the sample of 255 farmers. Therefore, there is an approval that the management of biogas technology is collective as there is agreement that the direction of the use of biogas technology is preferable to be through the government or its representative locally or through a joint-stock company.

5.2.5 Financial Aspects

The responses indicated that the household income from using biogas technology was unknown, and 89% of the sample of 255 farmers.

The sample answers are neutral (2.6-3.39) by 63.37% of the 255 farmers that the proceeds of biogas technology should be distributed equally to the villagers, while there was approval (3.4-4.19). More than 74% of the sample of 255 farmers that the returns of biogas technology would be distributed to participants in the technology according to the participation ratios, as well as the government contributing to the cost of biogas construction.

Finally, the majority of the sample considers that the best measures to restore the cost of biogas technology are to produce and sell gas collectively by 32.5% of the sample of 255 farmers as well as by setting fees or reducing taxes by 19 to 20% and by less than 12% for other options.

Many studies have looked at the acceptance of biogas technology, where a study (Putra et al., 2017) has shown the effects of the adoption of biogas technology among agricultural households that the utilization of biogas technology has not been optimally performed at the family level, which may partially explain the slow rate of use of biogas technology among farmers. While in a study by Kabir et al. (2013) showed the factors of acceptance of technology represented by education, income level, number of animals, and the number of animals. The study showed that raising the level of education, supporting women, improving the level of income, and increasing the number of animals are strategies that are likely to increase the adoption of biogas plants, as the environmental, economic, social, and technological benefits were an essential factor in motivating families toward the installation of biogas. A study by Shallo et al. (2020) indicated that households adopting biogas and non-biogas are very different as adoptive households have a significant average level of education, the number of animals, household income, the size of agricultural land, and the number of trees planted, and access to electronic media has had a significantly positive impact on the adoption of biogas technology. On the other hand, distance to water sources and access to electricity has a negative effect on the adoption of biogas technology. Another study by Lwiza et al. (2017) examined the determinants of non-acceptance of biogas technology. It showed that the increase in family size, the number of animals, and the age of the head of the household reduce the likelihood of biogas technology. Other factors that contributed to the lack of dependence are the lack of preservation of animal residues necessary for the supply of raw materials, the decrease in family work, and the inability of families to repair biogas after it is disrupted.

Table 3. Normal distribution test (K-S)

Factors	Correlation coefficient	Cronbach's alpha	KS Value test	Normality test	Result
Knowledge about Biogas Technology	0.891	0.658	0.765	0.972	Normal
Individual Acceptance of Biogas Technology	0.803	0.661	0.777	0.85	Normal
The subscriber's approach to the use of biogas and the resulting organic fertilizer	0.885	0.688	0.904	0.319	Normal
Administrative aspects	0.873	0.676	0.831	0.339	Normal
Financial aspects	0.854	0.601	0.846	0.302	Normal

Kolmogorov-Smirnov (K-S) has been used to find out the nature of the responses to each of the research chapters distributed. Table (3) shows a summary of the results of the normal distribution test (K-S) for the results of the hypotheses. If the value of (Alpha) is statistically significant more than (5%), this indicates that the data follows the normal distribution. The normal distribution of data was found for all the research chapters.

5.3 Test hypotheses

5.3.1 The results of the first hypothesis test

Variance analysis (ANOVA) was used for variables (studied area - educational level - average monthly household income) and Student test for variables (sex-housing - presence of a biogas unit) and explain the results in the following Table (4).

Table 4. ANOVA and Student test results

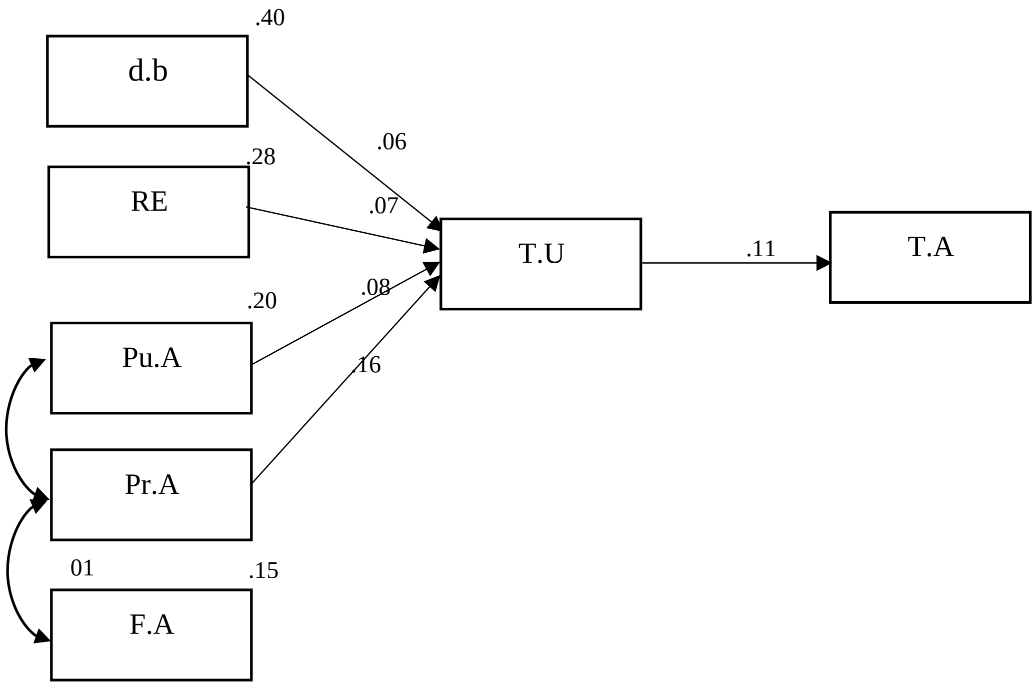
variables	Demographic variables	statistic	Sig
Knowledge	studied area	F=3.748	0.025*
	sex	T=0.821	0.412n.s
	housing	T=0.543	0.588n.s
	educational level	F=2.140	0.076n.s
	income	F=0.749	0.524n.s
	biogas unit	T=-2.21	0.028*
Acceptance	studied area	F=0.020	0.980n.s
	sex	T=0.091	0.927n.s
	housing	T=-1.33	0.186n.s
	educational level	F=1.823	0.125n.s
	income	F=0.517	0.671n.s
	biogas unit	T=-1.29	0.253n.s
Trends toward using	the studied area	F=0.023	0.977n.s
	sex	T=0.490	0.625n.s
	housing	T=1.07	0.286n.s
	educational level	F=0.803	0.524n.s
	income	F=0.915	0.434n.s
	biogas unit	T=-1.37	0.253n.s
Management	studied area	F=1.123	0.327n.s
	sex	T=-1.37	0.253n.s
	housing	T=-1.22	0.224n.s
	educational level	F=2.175	0.072n.s
	income	F=1.638	0.181n.s
	biogas unit	T=-1.12	0.264n.s
Financial	studied area	F=0.147	0.863n.s
	sex	T=0.989	0.324n.s
	housing	T=-0.121	0.904n.s
	educational level	F=3.887	0.004**
	income	F=1.193	0.313n.s
	biogas unit	T=-0.771	0.442n.s

And for binary variables, the chi-square test was used, and it was non-significant for all (p-value>0.05).

From Table (4), there were statistically significant differences (sig<00.05) in the knowledge of biogas according to the area studied, as well as by the presence of a biogas unit, and therefore there is an unequal knowledge of biogas in the community, It was also noted from the table(4) that there are statistically significant differences (sig<00.05) in the knowledge of biogas unit where it was found that the extent of knowledge of those who own the biogas unit is higher by 5.29%. The presence of statistically significant differences (sig<0.05) in financial aspects by educational level, and therefore, it can be said that the orientation of members of society towards the use of biogas according to financial aspects is unequal according to their level of education.

3.3.2 Test results for the second and third hypotheses:

Before the test, we entered the variables before naming the factors to verify an actual relationship by conducting a path analysis, figure (3), and the morale of a relationship between the variables studied was confirmed.



d.b: The desired benefit
T.U: Trends towards using biogas
RE: The resulting
Pu. A: Public administration
Pr. A: Private administration
F.A: Financial aspects
T.A: Technology acceptance

Goodness of fit indices
Chi-square: Cmin= 9.429
d.f= 6
sig= 0.151
Cmin/d.f= 1.572
Comparative fit index: CFI= 0.902
Tucker-Lewis: TLI= 0.836
RMSEA= 0.047

Figure. 3. Path analysis using the original form criteria

It was noted that the value of the Comparative Fit Index (CFI=0.902). It's more than 0.9, so the model measures what it's set for, and Table (5) shows the Baseline Comparisons**.**

Table 5. Baseline Comparisons

Model	NFI Delta1	RFI rho1	IFI Delta2	TLI rho2	CFI
Default model	.790	.649	.912	.836	.902
Saturated model	1.000		1.000		1.000
Independence model	.000	.000	.000	.000	.000

The significance level is 0.151, which is greater than 0.05. This means there is no difference between the assumed model and the data.

All correlations are less than 0.9, and this indicates the validity of the differentiation where:

-The difference between the management and financial aspects is 16%.

-The difference between the management aspects and the trend towards biogas technology is 20%.

-The difference between the extent of knowledge and the trend towards biogas technology is 15%.

-The difference between acceptance of the technology and the trend towards biogas technology is 23%.

RMSEA (Root mean square error of approximation) value is 0.047, less than 0.08. This means that the model is acceptable and measures what was set for it.

The model is acceptable when the value of the index is less than 0.08, and here we note its value of 0.047 and the model measures what was set for it.

- **The impact of the extent of knowledge about biogas on the use-oriented approach**

The following figure is the AMOS statistical software outputs. This analysis aims to know whether each factor influences, in its terms, the tendency toward using the technology

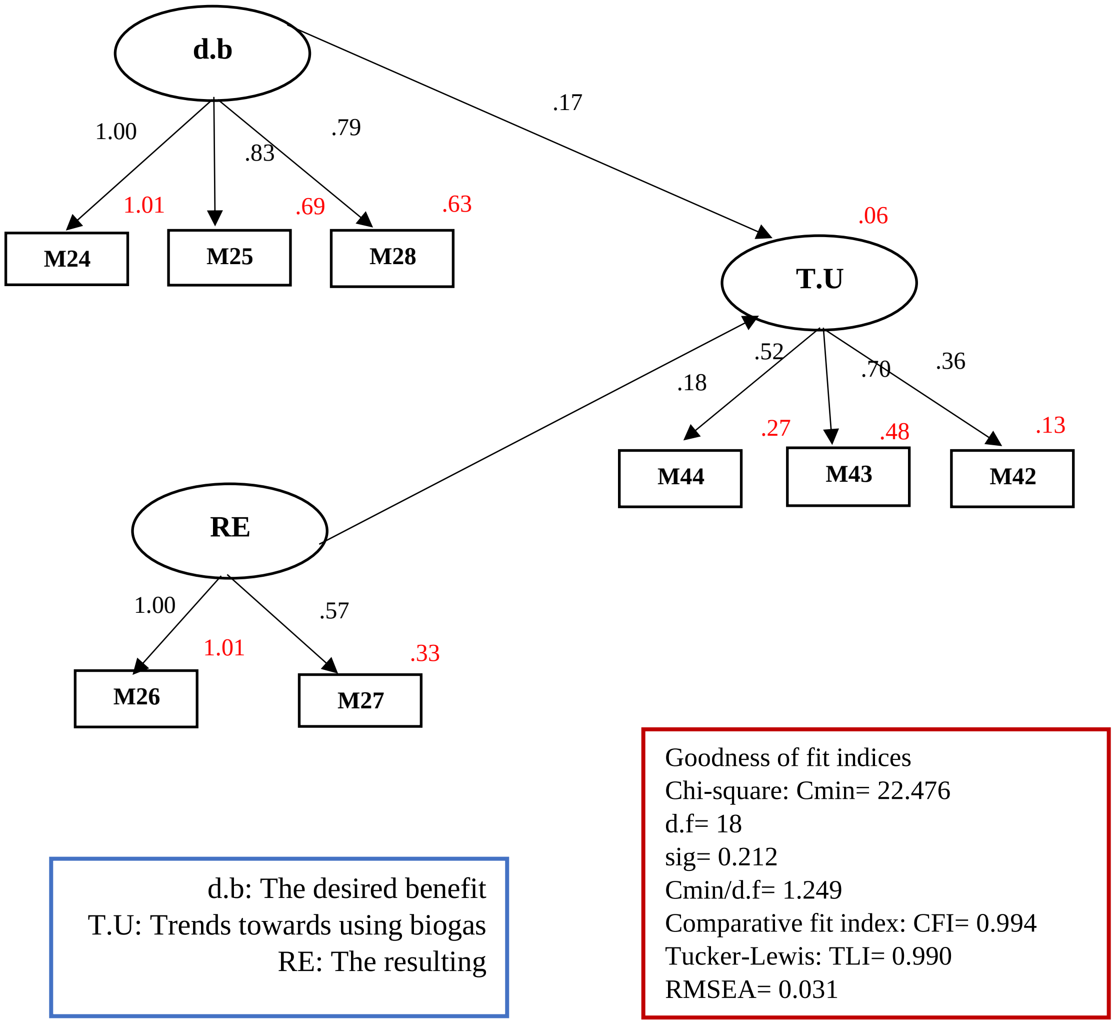


Figure. 4. The SEM results of the impact of the extent of knowledge about biogas on the use-oriented approach.

Table 6. shows the quality indicators. Hence, the extent of knowledge of biogas technology measures the strength and direction of use.

Looking at the links, we define the strongest terms that relate to the extent of knowledge of biogas technology and which led to the tendency to use it:

1. Decomposition of organic waste produces fertilizer via biogas technology, liquid and solid waste, where the link has reached a near-perfect value.

2. The decomposition of organic waste produces fertilizer for the plant, amounting to 0.83.

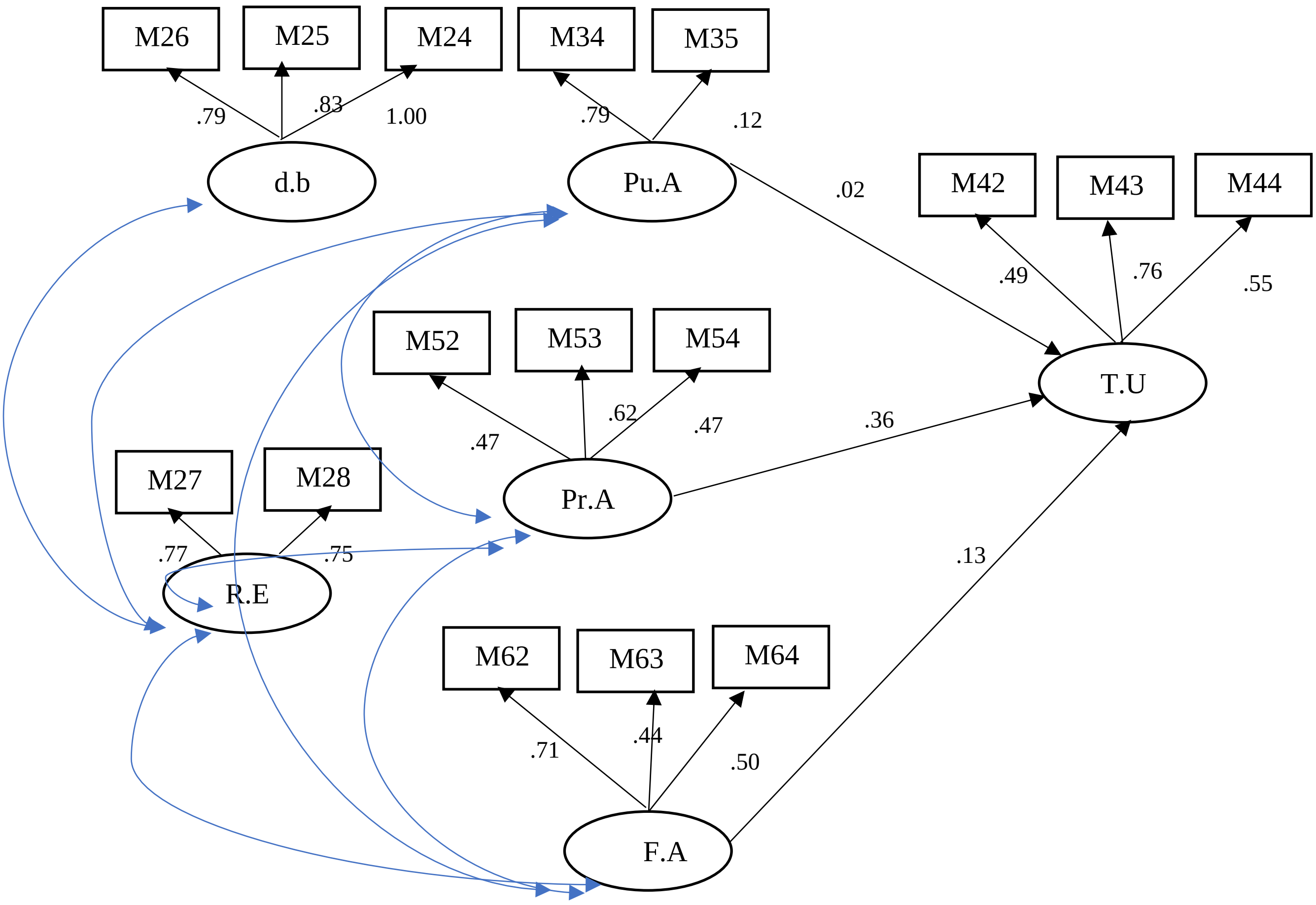
3. biogas technology positively affects the environment as the link has reached a near-perfect value.

Table 6. The goodness of fit indices

Indices	Value	Quality indicator	Verification
Sig	0.212	More than 0.05	Verified
Cmin/d.f	1.249	Less than 5	Verified
Comparative fit index: CFI	0.994	More than 0.9	Verified
Tucker-Lewis: TLI	0.990	More than 0.9	Verified
RMSEA	0.031	Less than 0.08	Verified

- The impact of financial and management aspects on the tendency toward using the technology

The following figure is the AMOS statistical software outputs. This analysis aims to know whether each factor influences, in its terms, the tendency towards using biogas technology, indicating the quality indicators of the model:



d.b: The desired benefit
T.U: Trends towards using biogas
RE: The resulting
Pu. A: Public administration
Pr. A: Private administration
F.A: Financial aspects
T.A: Technology acceptance

Goodness of fit indices
Chi-square: Cmin= 164.912
d.f= 91
sig= 0
Cmin/d.f= 1.812
Comparative fit index: CFI= 0.925
Tucker-Lewis: TLI= 0.901
RMSEA= 0.057

Figure. 5. The SEM results of the impact of financial and management aspects on the tendency towards using the technology.

Table (7) shows the quality indicators. Therefore, the degree of knowledge of biogas technology measures the strength and direction of use. Looking at the links, we define the strongest terms that relate to the extent of knowledge of biogas technology and which led to the tendency to use it:

1. I recommend that the use of biogas technology be managed by a private company where the link is 0.79.

2. If the management of biogas technology was collective, I would like to participate in a management committee in this regard, amounting to 0.62.

3. I recommend that the proceeds from the biogas technology be distributed equally to the village residents, where the link is 0.71.

Table 7. The goodness of fit indices

The indicator	the value	Quality requirement	Verification
Square morale kai	0	More than 0.05	Insufficient
Standard Kay	1.182	Less than 5	Sufficient
Comparative matching index	0.925	More than 0.9	Sufficient
The Tucker-Lewis Index	0.901	More than 0.9	Sufficient
Ramsey pointer	0.057	Less than 0.08	Sufficient

6. Conclusions and recommendations

1. There is good knowledge among the Syrian rural community about biogas technology and its costs despite its lack of application on the ground, which makes it a natural environment for investment, as there is a willingness of the majority of the sample members to buy a biogas unit and use it in their home or farm as well as the use of the fertilizer resulting. This knowledge continues to vary from area to area and according to educational level.

2. There are concerns among the rural community about the inability to maintain the biogas unit and the lack of training in this area, which is an obstacle to the application of technology.

3. The majority of the sample will use biogas technology if the initial cost of its construction is compensated within one or two to five years, and they confirmed that it is an environmentally friendly technique.

4. The majority of the sample is not clear on government policies for biogas technology or about the existence of technical support for this technology.

5. Respondents want to manage the technology collectively, through a private company, or through the government and do not want to manage it personally.

6. The sample wishes financial support for establishing a biogas unit associated with tax reduction.

7. The extent of knowledge of biogas technology and both administrative and financial aspects affect the orientation towards use and thus the acceptance of technology since the extent of knowledge of biogas technology with its factors

of benefit and resulting measures strongly affects the orientation towards use and therefore acceptance of the technology, as the management aspects of its public and private factors measure and strongly the orientation towards use and thus acceptance of the technology.

This study recommends that investment in the Syrian environment be an environment with sufficient knowledge of technology and the need to facilitate the granting of funding for investment in biogas technology, tax reduction, and the establishment of support and training centers for this technology. 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 and can play an important role both for further researchers and practitioners.

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8. CRediT authorship contribution Statement

Ghaith Hasan: Methodology, Verification, Investigation, Data collection, Formal analysis, Writing - original draft, Writing – review & editing, Visualization.

Jana Mazancová: Conceptualization, Methodology, Validation, Formal analysis, Resources, Data curation, Writing - original draft, Writing - review & editing, Supervision, Project administration.

Hynek Roubík: Conceptualization, Methodology, Validation, Formal analysis, Resources, Data curation, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition.

9. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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Chapter 3. - Assessment of the incubating environment for investment in biogas technology in Syria by using AHP and SWOT

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Abstract

In light of the massive energy supply shortage due to the Syrian war since 2011, renewable energy adoption has a high potential to cover the actual energy demand. Hence, this study aims to shed light on the factors that affect investment in biogas technology. With the scarcity of research on alternative energies in Syria, this paper focused on the characteristics of the Syrian environment toward biogas technology adoption. The results show that Syrian society accepts and desires to adopt new technologies, representing an optimal strategy to stimulate biogas technology use and the need to spread awareness about its benefits. The SWOT model was applied to identify strengths, weaknesses, opportunities, and threats facing biogas technology adoption. The Analytical Hierarchy Process (AHP) model was applied to set priorities and make better decisions related to the knowledge of biogas, acceptance of biogas technology, desire for and common approach for its use, the resulting organic fertilizer, and administrative and financial aspects. The work concludes that the southern region was at the forefront in the areas studied in terms of weights of biogas technology investment criteria, subsequently, the central and later the coastal regions. By presenting a systematic and comprehensive approach, this study represents a roadmap to assist decision-makers in inking decisions related to adopting and deploying biogas technology on a larger scale and contributes to developing a criterion for selecting biogas sites in Syria.

Keywords: Biogas technology, Analytic hierarchy process, SWOT analysis, Biogas adoption, Developing Countries.

Introduction

The reality of the Syrian war that has been ongoing since 2011 has cast a shadow over the energy sector. Northeastern Syria contains more than 80% of the country's energy sources; its exit from the control of the Syrian state, in addition to the sabotage and destruction of electric power plants and gas and oil fields during the war, are among the primary reasons that led to the current energy shortage (Li et al., 2022, Cheung et al., 2020, World Bank, 2022, Petrov L, 2022, EUI, 2021, SANA, 2022, Hatahet and Shaar, 2021). Furthermore, direct and indirect losses in the oil sector, which amounted to about 100.5 billion USD between 2011 and 2022, caused a severe shortage of various oil derivatives, as 60% of the energy infrastructure was destroyed (SANA, 2022; Petrov L, 2022).

Globally, countries are increasingly interested in renewable energy use contributing to greenhouse gas emissions reduction, climate change mitigation, circular economy development, and sustainable energy utilization (D'Adamo et al., 2019, Yazan et al., 2018, Falcone et al., 2018). Syria, in addition, also constitutes its application as a way to solve the problem of acute shortage of energy sources due to the heavy ongoing conflict (CFR, 2021, UN, 2017).

When comparing alternative energy projects in Syria with Arab oil countries whose economy is mainly dependent on oil, the share of alternative energy on the total energy supply did not exceed 1% (30 megawatts) in Syria in 2019 (IRENA, 2021), while UAE production in 2022 amounted to 2.6 GW of alternative energy, especially solar. Saudi Arabia produces 0.78 GW, while Egypt, which hosted the UN Climate Change Conference (COP27) in 2022, even 3.5 GW. Although, in Syria 1.7 GW were produced from alternative energy sources (Behrsin et al., 2022) in 2021; to achieve the 2030 goals to add 2 GW more (1.50 GW wind power, 0.25 GW biomass-based power, 0.25 GW photovoltaic power) (Krepl et al., 2020), it is necessary to highlight the importance of biogas energy in countries that suffer from war effects, such as Syria's case, explore strengths and opportunities and exploit them, and work to overcome obstacles and threats facing the adoption of this technology.

In view of the facts mentioned, it is noticeable that there is a real gap between the declared goals and the results achieved in Syria. There is a dearth of literature related to bioenergy systems adoption in developing countries that are witnessing exceptional circumstances such as civil wars (Yemen, Iraq, Lybia, Lebanon, Syria) (Krepl et al., 2020). The SWOT analyzing of biogas technology adoption factors contributes to defining its importance in the achievements of the declared goals.

Previous studies have proven the suitability of various renewable energy resources (solar, wind, biomass, hydropower, tidal, wave and geothermal energy) in the Middle East (Tumenand Caliskan, 2022; Shawon et al., 2013, Alshami and Hussein, 2021; Noorollahi et al., 2019 Salah et al., 2022). The current conditions encouraged local communities to search for alternative solutions to the energy problem. This has been reflected in the spread of home-scale solar energy use for those who can obtain it despite its high price compared to the purchasing power of the individual (Elistratov and Ramadan, 2018, Al Halabi et al., 2021). But surprisingly, biogas production has not received attention despite its high potential in terms of available feedstock, reducing dependence on natural gas and timber and contributing to the high need for sustainable energy in the Syrian countryside (Hasan et al., 2022, Jafar and Awad, 2021).

Historically, the Syrian experience with biogas technology is limited, despite the favorable conditions of sufficient feedstock availability and the moderate climate of the region. Studies (Jafar and Awad, 2021; Abdo et al., 2015) attribute the restricted dissemination primarily to economic, technical and social challenges. Since the 1990s, several small-scale biogas plants have been established by the Ministry of Agriculture and Agrarian Reform, the Arab Center for Studies of Dry Areas and Dry Lands (ACSAD), and the National Center for Energy Research. Therefore, Alafif et al. (2008) and Almikdad et al. (2015) showed that biogas production is a technical solution that is economically and environmentally viable; it allows the use of organic, animal, and plant waste, sewage, and industrial waste, and also has additional economic value in the resulting organic fertilizer; it also allows investment of the energy produced in rural communities. A study by Al-Mohamad, A. (2001) showed that the presence of low-cost energy sources that covered the demand in Syria and the high implementation costs of renewable energy projects were among the rationales for the modest application of such projects. Since the onset of the conflict in 2011, international organizations such as FAO and Global Communities have helped to install small-scale biogas plants in poor rural areas (OCHA, 2017, Global Communities, 2018) demonstrating the tendency to adopt alternative energy to fill the energy shortage caused by the war. This is considered the best option due to the availability of ideal conditions for its adoption in the post-war period.

This paper explores the current strengths, weaknesses, opportunities, and threats of the economic environment for biogas technology dissemination in Syria. In addition, it analyzes the common approach and criteria for selecting biogas unit locations. It also defines the best areas to establish biogas units among other regions studied in Syria. Table (1) illustrates the methods previously applied and their intersection with this study.

Table 1. Overview of studies that employ the SWOT-AHP approach.

Number	Method	Intersection with our study	Country	Reference
1.	SWOT AHP	Measuring biogas and biofertilizer production	Nigeria	(Audu et al., 2020)
2.	SWOT	Considering biogas production as a sustainable development tool	EU	(Pawlita et al., 2020)
3.	SWOT	Analyzing prospects and challenges of large-scale biogas technology	Bangladesh	(Saha et al., 2022)
4.	SWOT	Projecting biogas sector development	Latvia	(Bumbiere et al., 2021)
5.	SWOT	Empowering biogas as renewable energy for sustainable energy evolution	Pakistan	(Kamran et al., 2020)
6.	AHP	Analyzing the barriers impeding rural domestic biogas plants diffusion	Rwanda	(Mukeshimana, et al., 2021)
7.	AHP	Assessing biogas production from industrial liquid wastes	Indonesia	(Nasution et al., 2020)
8.	AHP	Analyzing impact factors of biogas technology implementation in rural areas	India	(Yadav et al., 2022)
9.	SWOT AHP	Measuring prospects of biogas technology and its contribution to sustainable energy supply	Austria	(Brudermann et al., 2015)
10.	SWOT AHP	Testing the biomethane and biogas contribution to electricity production	Spain	(Gonzalez et al., 2020)
11.	MCDA AHP	Locating biogas power plants in energy-poor areas	Thailand	(Nantasaksiri et al., 2021)
12.	AHP	Determining the factors affecting the generation of biogas from solid waste	Brazil	(Ruoso et al., 2022)
13.	MCDA AHP	Determining the obstacles and factors affecting the selection of sites for the construction of biogas units	Portugal	(Silva et al., 2014)
14.	MCDA AHP	Analyzing the best site and size of biogas plants	Turkey	(Yalcinkaya et al., 2020)
15.	Reflexive thematic analysis	Identifying factors and logic for biogas plants location	Sweden	(Feiz et al., 2022)

2. Methodology

Primary data collection was carried out through a questionnaire survey among farmers. A standardized paper-based questionnaire was distributed on 300 farms between March 2019 and January 2020. The response rate of 85% (255 farms) covers the Coastal (84 farms), the Central (69 farms), and the Southern (102) regions of Syria. The questionnaire was comprised of five principal chapters covering the following: (i) respondent's knowledge of biogas (incl. biogas production processes, biogas technology and its costs); (ii) the biogas technology respondent's real and potential acceptance level; (iii) the respondent's approach to the use of both biogas and digestate (organic fertilizer); (iv) the attitude of the respondent toward the management of the biogas unit (individual vs. collective, private vs. governmental); and (v) the knowledge and attitude of the respondent about the financial aspects of biogas technology (costs and expected profits).

The collected data were computerized in Microsoft Excel and analyzed in SPSS V20 Statistical Package for Social Sciences Program. Two analytical methods were employed, such as SWOT and AHP.

The methodological approach aimed at reducing potential bias in responses by quota sampling the target groups in seven provinces (Latakia, Tartus, Homs, Hama, Damascus, Sweida and Daraa).

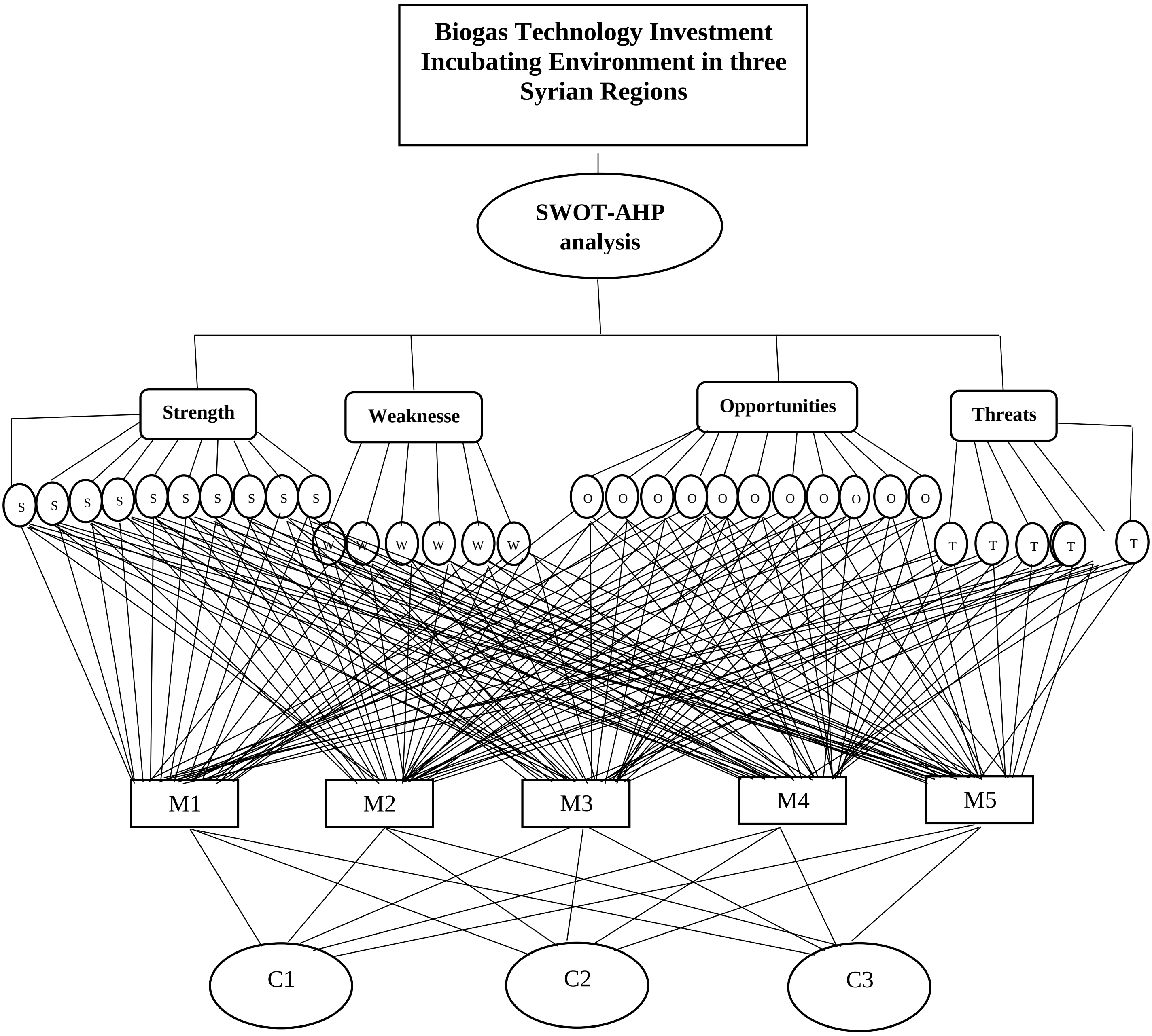

Figure 1. Hierarchical SWOT-AHP model

2.1. SWOT Analysis

To specify effective strategies for the implementation of biogas technology in Syria, take advantage, empower and work on weak points, and avoid threats, SWOT analysis was used to analyze areas of strength, weakness, opportunity, and threats (Olabi et al., 2022, Longsheng et al., 2022). SWOT analysis is used to obtain a comprehensive view of the study area by analyzing the current and future environment. At the same time, it provides a planning tool for dealing with the changing environment (Pyzalska et al., 2020; Paschalidou et al., 2016; Ng, 2021). In this research, SWOT analysis is used to monitor, evaluate, and disseminate information on the internal and external environment. This leads to an effective strategy that should enhance the strengths and opportunities in the environment studied and reduce the impact of weaknesses and threats.

As a qualitative analysis, SWOT analysis does not deliver precision in terms of the relative importance of relevant factors (Brudermann et al., 2015). Therefore, Analytic Hierarchy Process AHP was employed, which is based on a comparison and weighting of SWOT factors through pairwise comparisons, to find out the most relevant factors within the group (Kurttila et al., 2000).

2.2. Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a hierarchical analysis procedural technique widely used for making various types of complex decision in many sectors (Burak et al., 2022; Pathak et al., 2022), introduced by Thomas L Saaty in the 1970s (Saaty, 1977). It has attracted many researchers due to its mathematical properties and the ease of obtaining the data required to use it (Ilbahar et al., 2022). This process is known as the theory of constructing indicators using marital comparisons that adopt the opinion of experts and decision-makers within the limits of a specific scale. It can help the decision-maker to set priorities and make better decisions by transformation the goal into a hierarchical series of criteria arranged in a horizontal and vertical matrix. Within the matrix, each criterion is compared separately in double comparison (Mastrocinque et al., 2020). The method relies on determination of the relative importance of a specific set of criteria and alternatives to a predetermined goal, considering the criteria and sub-criteria. The AHP attempts to introduce analytical thinking into decision-making based on different principals shown below:

1. Composing an order of decision problems.

2. Prioritizing while using Satty's numerical scale (Table 2) to weight sub-criteria, criteria, and other alternatives. The weighing procedure was carried out in the Expert Choice Program (Ishizaka and Labib, 2009; Bagheri et al., 2021).

Table 2. Satty scale summary of the nine-point ratio based on (Mukeshimana et al., 2021; Nilsson et al., 2016).

Name of points	Equal Importance	Weak Importance	Strong Importance	Very strong Importance	Strongest Importance
Description	More than one criterion contributes at the same level to the objective	One criterion is slightly different from the other.	One criterion is essentially different from another	One criterion is different from another	one criterion is different over another
Importance intensity	1	3	5	7	9

Note: Average values are used when compromise is needed between the previous values, such as 2 - 4 - 6 - 8

3. Creating a pairwise matrix by summing the outputs of Satty's scale in one pairwise matrix for each level (Sedghiyan et al., 2021, Gottfried et al., 2018).

$$X = \begin{bmatrix} 1 & A1/A2 & . & . & . & . & A1/An \\ A2/A1 & 1 & & & & & \\ A3/A1 & & 1 & & & & \\ . & & & 1 & & & \\ . & & & & 1 & & \\ . & & & & & 1 & \\ An/A1 & An/A2 & . & . & . & . & 1 \end{bmatrix}$$

Where Ai (i=1,2,…,n) represents the weight of each factor from the SWOT analysis table.

4. Creating the consistency ratio using the normalized eigenvector for each matrix λmax (Yadav et al.,2022).

$$\mathbf{Xw} = \boldsymbol{\lambda}\mathbf{max\ w}$$

X denotes the value of preference vectors. W can be calculated by determining the eigenvector of A and its corresponding to its eigenvalue.

5. Calculating the index of consistency CI:

$$CI = {\lambda\max - n}/{n - 1}$$

6. Calculating the ratio of consistency CR by comparing the value of the index of consistency CI with that of the index of randomization RI:

$$CR = {CI}/{RI}$$

where (RI) is the Random Index that relates to the matrix structure table 3. When the CR is ≤ 10%, the matrix consistency is acceptable; otherwise, evaluation should be made again of pairwise comparisons in the matrix (Gottfried et al., 2018). RI is essential in the consistency of the comparison matrix used in the decision-making process (Shyamprasad et al., 2020; Rao et al., 1998; Wedley, 1993). After the above levels, we multiply each element by its corresponding criteria (Saaty, 2008).

Table 3. Random index values (Saaty, 2008).

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

3. Results and Discussion

3.1. SWOT Analysis

Based on the questionnaire, the answers were specified on the 5-point Likert Scale (1) Strongly disagree; (2) Disagree; (3) Neither agree nor disagree; (4) Agree; (5) Strongly agree). To identify the SWOT factors and measure the agreement of each statement by calculating the mean score for each SWOT factor code. Table (4) illustrates the strengths of adopting biogas technology in Syria.

Table 4. Strength points formulation for the adoption of biogas technology in Syria

	Factor Code	Description	Mean score (5-point Likert Scale)*
Strengths	S1.	Attention to innovations	4.25
	S2.	Biogas technology reduces final waste volume	4.08
	S3.	Being prepared for separation of organic waste (kitchen and garden waste) from the rest of the household waste	4.08
	S4.	Showing desire to use digestate resulting from biogas technology in the home or farm garden	3.93
	S5.	The degradation of organic waste results in a plant fertilizer	3.93
	S6.	Being prepared for purchase a biogas unit and use it at home or on the farm	3.75
	S7.	Other energy sources are expensive	3.69
	S8.	The use of biogas is recommended at the home level	3.65
	S9.	The decomposition of organic waste produces fertilizer through biogas technology, liquid and solid waste.	3.48
	S10.	Support the use of biogas technology at home and with home management only	3.33
	S11.	Knowing where to obtain the necessary information in case of interest in biogas technology	3.14
	S12.	The ability to store manure	3.11
	S13.	The ability to collect dung regularly	3.04
	S14.	Receive training in biogas technology	2.19
The total average			**3.54**

*1 – lowest, 5 - highest

The total average response of the respondents to the strength dimension was 3.54, which is greater than 3 (which is the neutral scale in the Likert scale analysis). At the level of the paragraphs, paragraph (8) had an average point of 4.25 which is higher than 3, while paragraph (6) was the only Paragraph lower than 3, with an average of 2.19. These results confirm that most of the sampled individuals emphasized the most important strengths enjoyed by the Syrian environment around biogas technology.

Given the content of the factors description, the most important strengths of the Syrian environment in biogas technology are the interest of Syrian farmers in modern technology, their willingness to deal with organic waste, their interest in the results of that process, and their desire to use it on a large scale. The results are consistent with the strengths of the Ugandan environment in terms of the interest of farmers in biogas as a clean and reliable energy that contributes to the effective management of organic waste (Okello et at., 2014). Table 5 shows an assessment of the weakness dimension.

Table 5. Weaknesses points formulation for the adoption of biogas technology in Syria

	Factor Code	**Description**	**Mean score (5-point Likert Scale)***
Weaknesses	W1.	The initial construction cost of a biogas unit is high.	3.79
	W2.	There exist other alternatives better than biogas technology for organic waste treatment.	3.07
	W3.	Running a biogas plant at home or on the farm will require much time and effort.	3.02
	W4.	Digestate is the low quality of fertilizer.	2.87
	W5.	Energy produced from manure is not recommended for cooking	2.67
	W6.	Other alternatives to organic waste management are better than biogas technology.	2.66
The total average			**3.02**

*1 – lowest, 5 - highest

The total average response of the respondents to the weakness dimension reached 3.02, slightly greater than 3. At the same time, for the paragraphs, paragraph (1) had the highest average of 3.79, while paragraph (5) was the lowest paragraph with an average of 2.67. In general, these results confirm that most of the individuals in the sample confirmed the most critical weaknesses that Syrian farmers face in adapting biogas technology.

Given the content of the description of the factors, the most important weaknesses that the Syrian environment suffers from biogas technology are cost, belief in the existence of better alternatives, time and effort required, and concerns about digestate and cooking on organic waste. The results of the analysis of weaknesses share with the environment in Bangladesh in terms of the initial cost of establishing biogas units (Saha et al., 2022) and in terms of the effectiveness of biogas technology to treat organic wastes (Iqbal et al., 2014).

Table 6 shows an analysis of the opportunities dimension in the SWOT variable:

Table 6. Formulation of opportunities points for the adoption of biogas technology in Syria

	Factor Code	Description	Mean score (5-point Likert Scale)*
Opportunities	O1.	Environmental impacts of biogas technology	4.20
	O2.	The use of biogas is feasible economically and environmentally	4.06
	O3.	Biogas technology is a suitable alternative to the energy source currently used	3.98
	O4.	The financial benefit of technology to the family	3.96
	O5.	The desire to collectively participate in the Biogas Management Committee	3.91
	O6.	The desire for the biogas technology revenues to be distributed to the technology participants according to the participation rates	3.74
	O7.	The desire to manage biogas technology through the government or its representative locally.	3.70
	O8.	The desire to manage the use of biogas technology through a joint stock company.	3.51
	O9.	The desire for the revenue from biogas technology to be distributed equally to the villagers	3.17
	O10.	Biogas technology is locally available	2.95
	O11.	The desire to manage the use of biogas technology through a private company	2.53
The total average			**3.61**

*1 – lowest, 5 - highest

The average response of the respondents to the opportunities dimension was 3.61, which is greater than 3. In general, most of the paragraphs were higher than the neutral point of the Likert scale. These results identify the most critical opportunities in applying biogas technology in the areas studied.

Given the content of the description of the factors, the most important opportunity that should be taken care of is the awareness of the studied environment of the positive effects of technology on the environment, their knowledge of its economic feasibility as an essential and alternative source of traditional energy and its significant material effects, and the incubator's desire to participate in the management of the technology. The importance of the agricultural sector as a backbone of the Syrian economy (Aw-Hassan et al., 2014), with the presence of thousands of farm engineers and extension units in every township of the countryside which explains opportunities.

Table 7 shows an analysis of the dimension of the threat in the SWOT variable:

Table 7. Threats points formulation for the adoption of biogas technology in Syria

	Factor Code	Description	Mean score (5-point Likert Scale) *
Threats	T1.	Taxes	4.16
	T2.	Call for the governmental subsidies for biogas unit construction	3.98
	T3.	Fees	3.92
	T4.	Fear of inability to maintain and repair a biogas unit	3.64
	T5.	Fear of lacking expertise in biogas unit's operation and maintenance	3.58
	T6.	Biogas technology can harm the environment in which I live	2.18
The total average			**3.59**

*1 – lowest, 5 - highest

As shown in table 6, the respondents' average response to the threat dimension was 3.59. Generally, most of the paragraphs were higher than 3; These results identify the most critical threats facing applying biogas technology in the areas studied.

Given the content of the factors description, the most critical threats that must be addressed are tax deductions, fees for establishing biogas, maintenance and lack of experience in dealing with technical difficulties. Similar threat dimensions in Brazil regarding the adopting biogas in the southern part of Brazil related to the specific regulation regarding renewable energy support (Sacco et al., 2022). The SWOT matrix (Table 8) comprises only the first five scored statements in of internal (strengths and weaknesses) and external (opportunities and threats) factors.

Table 8. The SWOT Matrix

	Positive factors	Negative factors	
S	S1. Attention to innovations. S2. Preparation for separation of organic waste from other household waste. S3. Biogas technology reduces the final waste volume. S4. The decomposition of organic waste produces fertilizer. S5. The desire to use biogas technology fertilizer in the home or the garden.	W1. High initial construction cost of a biogas unit. W2. Existence of better alternatives than biogas technology for organic waste treatment. W3. Biogas technology is time and labor demanding. W4. Digestate is low quality fertilizer. W5. It is not recommended to use the energy produced from manure for cooking.	W
O	O1. Environmental impacts of biogas technology. O2. Economic and environmental feasibility of biogas use. O3. Biogas technology is a suitable alternative to the current energy source. O4. Accentuation of existing differences in family income and property ownership. O5. Desire to participate collectively in the Biogas Management Committee.	T1. Taxes. T2. Low involvement of the government in covering the biogas unit construction cost T3. Fees. T4. Fear of inability to maintain and repair a biogas unit T5. Fear of lacking expertise in biogas unit's operation and maintenance	T

Our findings are in line with the study by Gottfried et al. (2018) on the material benefit of technology for household families and the desire for collective participation in the biogas management committee, and the strengths in terms of interest in innovations, as well as weaknesses over a long time, to invest in this technology, and in terms of opportunities through financial benefit and threats through high construction costs.

However, a study by Mukeshimana et al. (2021) showed that seven independent strategies have the most substantial ability to affect the entire renewable energy sector. Then, four strategies have the most significant driving force, such are increasing investment in renewable energy, providing incentives and policy support, creating favorable conditions for private investment and strengthening institutional management. This is consistent with our findings.

A study by Obrecht et al. (2011) proves that biogas technology reduces the final waste volume, and the decomposition products of the organic waste constitute fertilizer for plants and the desire to use the fertilizer produced by biogas technology.

Schaper et al. (2007) in their study demonstrated how a SWOT analysis of the most important factors shaped recommendations for farmers and extension services. This study aligns with ours in many ways, including the willingness for organic waste separation from the rest of home waste. Biogas technology reduces the final volume of trash and opportunities. These include the positive environmental impacts of biogas technology, the perception of biogas technology as an appropriate alternative to the currently used energy source, the financial benefit of the technology to the family, and the desire for collective participation in the biogas management committee.

Martin (2015) used the SWOT analysis to understand the gap between potential and the perspectives of biogas producers to understand the factors influencing biogas expansion in Sweden. The factors involved the availability and competition (consistent with our study in terms of threats), handling of digesters (consistent with our study in terms of threats), regulations, market incentives and support biogas production (consistent with our study in terms of opportunities).

3.2 Analyzing alternatives using Analytic Hierarchy Process

The AHP was used to scale experts' assessment of SWOT analysis results to determine the most important criteria to be focused on in the process of biogas technology adoption and the central region that gained the highest importance among other alternative criteria to specify the best areas to invest in biogas technology (Table 9). As a result, three areas were chosen to establish a biogas unit; we define these as follows:

1. Southern Region: Damascus (105 km^2), Damascus countryside (18,032 km^2), Daraa (3,730 km^2), and As-Suwayda (5,550 km^2); the sample of 102 surveyed farms (40% of the total sample).

2. Central Region: Hama (8,883 km^2) and Homs (42,223 km^2); the sample of 69 surveyed farms (27% of the total sample).

3. Coastal region: Lattakia (2,297 km^2) and Tartous (1,892 km^2). the sample of 84 surveyed farms (33% of the total sample).

Table 9. The average of the corresponding criteria for studied regions

The standard	Southern Region Response weight	Central Region Response weight	Coastal Region Response weight
The level of the respondent's knowledge on biogas technology (M1)	4.04	4.00	3.87
The degree of biogas technology acceptance and potential use (M2)	3.98	3.95	3.91
The respondent's approach to the use of biogas and digestate (M3)	4.13	4.06	3.98
Administrative aspects (M4)	4.12	4.02	3.85
Financial aspects (M5)	4.11	4.01	3.83
The average response rate of each region %	81.53	80	77.76

*1 – lowest, 5 - highest

The criteria with the highest weight among each region is the approach to the use of biogas and digestate. The average response rate of the Southern region was 81.5%, while the average response rate of the Central Region was 80%. The average response rate of the Coastal region was 77.8% (Figure 1).

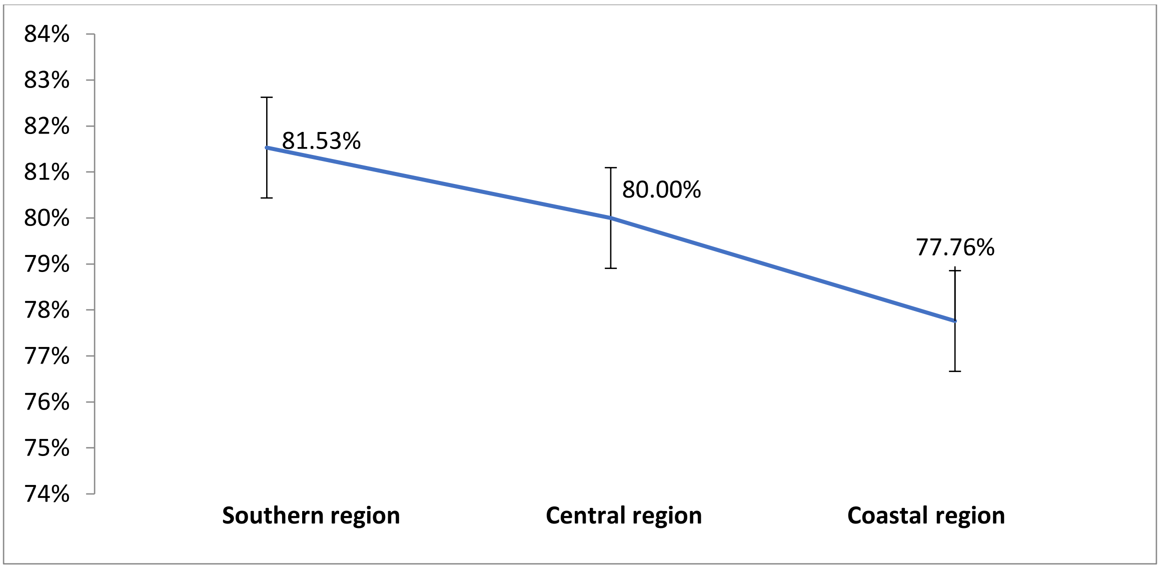

Figure 2. Alternative weights of the regions studied.

Table 10. Matrix of binary comparisons of the main criteria that affect the adoption of biogas technology

	M1	M2	M3	M4	M5	Weight
M1	1	2	0.14	0.2	0.5	0.07
M2	0.5	1	0.11	0.14	0.33	0.04
M3	7	9	1	2	3	0.46
M4	5	7	0.5	1	0.5	0.23
M5	2	3	0.33	2	1	0.20

CR = 0.07

Table 10 show expert criteria, of which the highest ranked was the standard M3 (the approach for the use of biogas and digestate) at 46 % of importance, followed by standard M4 (Administrative aspects) at 23%. Standard M5 (Financial aspects) at 20% and then the criterion M1 (the respondent's knowledge about biogas) at 7% and finally M4 (the respondent's acceptance and potential use of biogas) at 4.3%. The consistency ratio CR is 7% which is acceptable (not more than 10%). Whereas, for example in Rwanda, the hierarchy of criteria in terms of importance is as follows: financial, institutional, technical and socio-cultural barriers (Mukeshimana et al., 2021). In rural India (Yadav et al., 2022), the AHP analysis revealed the highest importance of economic dimension, then market, high installation cost, high competition from available fuel for free, capital subsidy, and the lack of easy loans.

The expert choice program was applied to demonstrate the alternatives (figure 2).

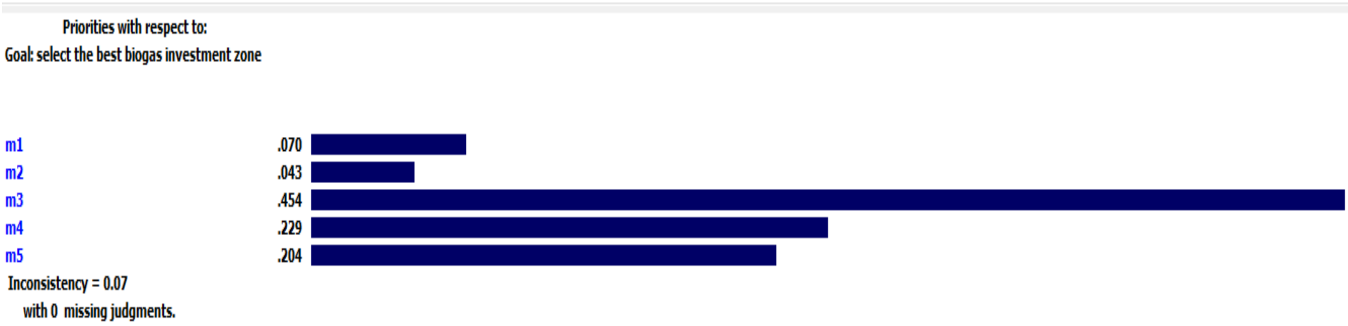

Figure 3. The marital comparisons of the main criteria that affect biogas technology adoption.

Table 11. Matrix of binary comparisons of alternative regions to establish biogas units

	Southern	Central	Coastal	Weight
Southern	1	2	3	0.55
Central	0.5	1	1.5	0.27
Coastal	0.33	0.67	1	0.18

CR = 0.0

Results of binary comparisons matrix show that the most suitable region for investments in biogas technology is the southern region with 54.5%, followed by central (27.3%) and coastal (18.2%). The CR equals to 0 shows complete stability in decision-making. Given that the primary feedstock is animal manure, the result of the investigation is consistent with the reality in terms of the concentration of livestock numbers and the amount of organic waste in Syria (CBS, 2019).

The expert choice program was used to select the best region to invest in biogas technology (figure 3).

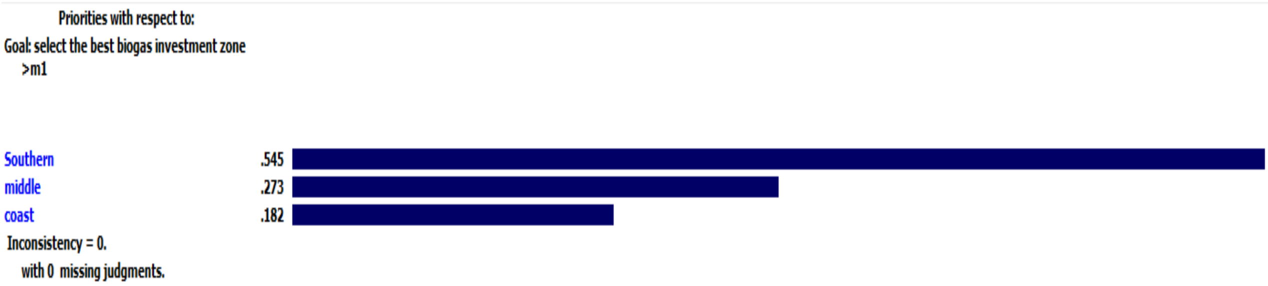

Figure 4. The marital comparisons of alternative regions to establish biogas units.

The use of AHP in determining and evaluating the geographical suitability of biogas production at industrial level was used by Zhang et al. (2022) in China by dividing the 31 areas under study into three principal categories based on the following four criteria: societal and economic conditions, resources and environmental pressures. Results showed that the level of development achieved the highest importance among other alternative criteria. As similarly approached by Falcone and Sica (2019) in Italy, where the authors concluded that it is it also essential to involve the implementation of a green agenda at both national and international levels when considering successful societal transitions in the field of green energy sector. This is even more pressing issue in the post-COVID-19 era (Giganti and Falcone, 2022; Roubík et al., 2022). The study by Akther et al. (2018) used that environmental, social, safety and economic factors to analyze the criteria influencing the selection of a suitable location for the establishment of large-scale biogas units for the treatment of municipal waste in Bangladesh. However, AHP employed by De Jesus et al. (2021) to identify the appropriate areas to establish biogas units in southern Brazil used only geographical criteria (nearness to roads, proximity to pipes, proximity to organic waste suppliers).

4. Conclusions and recommendations

SWOT-AHP analysis is conducive to providing the dimensions and factors that affect the investment in biogas technology and location selection in the Coastal, Central, and Southern regions of Syria. Exploiting opportunities based on available strengths will be the optimal strategy. The acceptance of biogas technology by Syrian society and the intention to use it will create awareness of its material and moral benefits, which will eventually lead to an increase in private investments in biogas plants. Furthermore, the interest of the community in innovations is one of the most critical strengths of adopting biogas technology. However, the positive impacts on environment and microeconomy are the main opportunities. On the contrary, the most outstanding weaknesses that hinder the application of biogas technology are the high costs, while the most critical threats are taxes and fees that can affect farmers' decision to establish biogas plants. Therefore, calls for governmental support on tax exemption and loan facilitation for farmers to adopt renewable energy projects are crucial in post-conflict times. The SWOT analysis results have been categorized into five main criteria; the approach to use biogas for energy and digestate as fertilizer were best among the criteria in the study of the location of a biogas unit, followed by the respondent's acceptance and intended use of biogas technology, which was essential in making a decision toward investment in biogas technology.

According to the weight of alternative criteria for each region, the region with the highest percentage of alternative criteria is the southern region.

The study highlights the need to provide a clear strategy from the relevant authorities in the field of biomass-based energy and the need for awareness programs to support the spread of biogas technology in rural areas as an ideal solution to produce energy from organic waste.

The main limitation of this study is that it does not take into account the northern and eastern parts of Syria due to the unstable situation there at the time of the search.

We suggest expanding the search for the best sites for the establishment of biogas units using geographic information systems (GIS) as an effective research methodology. The study focused on determining the criteria that affect biogas investment and the best areas to invest in this type of renewable energy. The expansion of research related to other types of sustainable energy can play an important role in improving the energy situation, especially in the post-war period.

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6. CRediT authorship contribution Statement

Ghaith Hasan: Methodology, Verification, Investigation, Data collection, Formal analysis, Writing - original draft, Writing – review & editing, Visualization.

Jana Mazancová: Methodology, Validation, Formal analysis, Resources, Data curation, Writing - original draft, Writing - review & editing, Supervision, Project administration.

Hynek Roubík: Conceptualization, Methodology, Resources, Data curation, Writing - original draft, Writing - review & editing, Supervision, Project administration, Funding acquisition.

7. Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

8. Data availability statement

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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Discussion

The social and economic assessment of small-scale biogas plants in developing countries is an important area of study within sustainable development. This topic is of academic interest due to its potential to address energy poverty, improve living conditions, and promote sustainable economic growth in developing nations.

From a social perspective, the assessment examines the level of knowledge of rural residents about biogas, the extent of acceptance of this technology, and the society's approach to biogas and the resulting organic fertilizer.

Regarding the economic dimension, the assessment evaluates small-scale biogas plants' financial viability and economic benefits. This involves analyzing the cost-effectiveness of biogas production, assessing the potential for income generation through biogas and by-products, and examining the overall economic impact on local economies .

Considering the contextual factors influencing the social and economic assessment of small-scale biogas plants in developing countries is essential. Understanding these contextual factors is crucial for designing effective policies, programs, and interventions to promote the widespread adoption and successful implementation of small-scale biogas plants.

Through this research, an attempt was made to shed light on biogas technology and investigate the possibility of its application from an economic and social point of view, as the Syrian Arab Republic is considered new in the exploitation of renewable energies.

Among the renewable energy sources, biogas technology was chosen based on its importance as an alternative, environmentally friendly, cheap, and necessary energy in light of the scarcity of energy sources as a result of the ongoing war in Syria since 2011, in addition to the increasing factors of environmental pollution.

The ongoing energy crisis that the country has been experiencing for years is still ongoing and requires serious thinking about new methods and methods for the Syrian environment to mitigate the shortage, especially in light of the constant effort to secure the necessary energy. The search for new sources of renewable energy in Syria that support the main sources of primary energy has become a top priority in the lives of people to keep up with the growing need for this energy, especially in the current stage with all its challenges imposed by the war and subsequent sanctions and economic blockade.

It is possible to benefit from the large quantities of solid household waste in the production of biogas through the anaerobic digestion process and to benefit from the resulting methane gas in energy production, in addition to improving the solids for the soil, which can be used to increase the performance of soils poor in organic matter.

What distinguishes biogas most is that it is renewable (inexhaustible), unlike oil, for example, and is available, cheap, can be broken down biologically, and less dangerous to the environment than coal or oil.

Due to the conditions that prevailed during the investigation due to the ongoing armed conflict in Syria, the study focused on the coastal, central and southern regions. The thesis is designed in the form of three scientific articles (Figure 7).

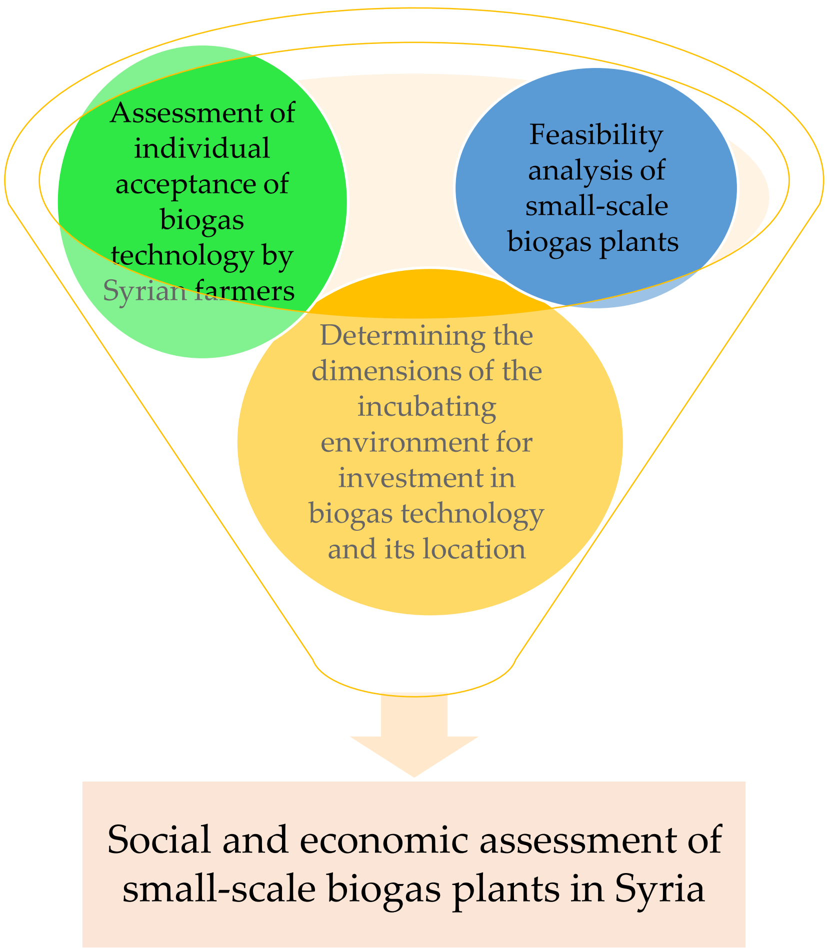

Figure 7: The applied approach to cover the assessment of biogas technology from a social and economic point of view in Syria.

In the first article (Chapter 1), a techno-economic analysis of biogas production was carried out in rural Syrian areas (the Syrian coast) to establish biogas plants. The feasibility provided showed whether biogas technology produced from small-scale plants could be considered a solution to energy problems resulting from a lack of resources. In light of a large amount of organic waste, there is quite a high potential for processing plant and animal residues for biogas. The applicated financial ratios showed how small-scale biogas plants which use co-digestion of manure or agricultural crop residues can be profitable in the worst scenarios (higher costs and lower revenues).

The study discusses the findings of a feasibility analysis conducted on small biogas plants that utilize animal waste as the primary feedstock. The research encompasses various aspects such as costs, revenues, financial indices, and sensitivity analysis, providing valuable insights into the viability of such plants.

Regarding costs, it is estimated that the total construction expenses for a $10m^3$ biogas unit amount to 859 USD. Among these costs, civil construction constitutes approximately 56% of the total, while tank construction represents 31%. Additionally, the operational requirements over a 15-year lifespan are projected to cost around 115 USD, and the annual depreciation of fixed capital is estimated at 19 USD. In terms of revenues, the biogas production resulting from the utilization of animal waste is estimated to yield $3m^3$ per day, equivalent to $1095m^3$ per year. The biogas value generated by the unit is estimated to be approximately 77 USD per year.

Moreover, the biogas fertilizer produced is valued at around 265 USD annually. Consequently, the combined value of biogas and biogas fertilizer output is approximately 342 USD per year. The average annual net return is projected to be around 217 USD.

The financial indices calculated in the analysis include the internal rate of return (IRR) at 34%, which is similar to a study by Gonzalez et al. (2021) at 36.97%.

The payback period (PBP) at 2.9 years, and the simple rate of return (SRR) at 25.26%. Furthermore, the total current value of cash flow, discounted at a rate of 30%, is estimated to be approximately 64 USD. The findings align with Khoshgoftar et al. (2020) study, which found a payback period of less than 3 years. Comparatively, the payback period for the current community-type fixed-dome biogas digester project is lower than those reported by Goodrich et al. (2002) (5.7 years), Walla and Schneeberger (2005) (7.5 and 11 years), Patmanomai et al. (2009) (4.11 years), Lungkhimba et al. (2010) (4.81, 7.57, and 7.20 years).

A sensitivity analysis evaluates the project's profitability under different assumptions. Even when considering a 20% increase in costs and a 20% reduction in revenues, the project remains financially viable. The current cash flow value throughout the project's lifespan ranges from 25 USD (using a 10% discount rate) to 153 USD (using a 15% discount rate).

In general, the findings indicate that the production of biogas from animal waste can be a feasible and profitable project from a financial point of view.

The same feasibility analysis was carried out to compare the previous results of small-scale biogas plants that use co-digestion of manure with small-scale biogas plants that use agricultural crop residues. The study evaluates the costs, revenues, financial indices, and sensitivity of such plants. Regarding costs, replacing manure with agricultural crop residues, such as rice straw and other crops, amounts to approximately 21 kg/day of residues at 0.25 USD per day. This translates to an estimated 91 USD per year for crop residues. The total input for the unit amounts to 111 USD per year, while the estimated total output is 342 USD, resulting in an average net annual return of 231 USD.

Regarding revenues, if a farmer owns 4 Dunums of land and cultivates it twice a year, saving 3.5 tons of crop residues annually, operating the biogas unit for approximately 166 days would be sufficient. The farmer would then purchase additional waste to meet the unit's daily needs for the remaining 199 days, amounting to 35 USD. In this scenario, the total input value is 55 USD per year, and the average annual net return amounts to 287 USD per year, exceeding the return achieved using animal waste.

The financial index calculation shows promising results. The internal rate of return (IRR) is 52.2%, higher than the 34% achieved using animal waste. The payback period (PBP) of the biogas unit is 1.9 years, indicating a relatively quick return on investment. The simple rate of return (SRR) on invested capital is 33.4%.

Sensitivity analysis is conducted to assess the project's profitability under changed assumptions. Assuming a 20% increase in costs and a 20% reduction in revenues, the project remains profitable. The estimated net cash flow during the project's lifespan ranges from 2,104.07 USD to 3,466 USD, depending on the discount rate applied.

The analysis emphasizes the significance of government support and financial institutions in providing loans and technical assistance to promote the establishment of biogas plants. In particular, the project demonstrates a positive net return and there is potential for even higher returns if government support and market conditions improve.

The findings suggest that the production of biogas from plant residues is a feasible and profitable project from an economic perspective. It can significantly contribute to solving the energy problem in rural Syria and reduce the reliance on petroleum hydrocarbons. The analysis also emphasizes the importance of using agricultural resources in Syria, particularly plant residues, and highlights the potential for significant energy production and the generation of biogas fertilizers.

The economic benefits of generating energy from agricultural and animal waste in Syria are substantial. The use of crop residues can produce approximately 0.88 billion m^3 of biogas per year, which can meet the energy needs of thousands of households and benefit millions of people. Furthermore, the production of biogas fertilizer can bring significant economic value, estimated at 102.459 USD million annually. The findings suggest that biogas production from plant residues should be prioritized in Syria, considering the country's agricultural resources.

However, the research did not address the economic feasibility of biogas plants of different sizes.

In the second article (Chapter 2), the individual acceptance of biogas technology by Syrian farmers was evaluated.

The findings reveal several characteristics and trends related to the behaviors and attitudes of the respondents toward biogas technology and waste management.

Regarding the characteristics of the respondents, it was found that 53.38% use animal waste as fertilizer for crops, while 78.95% do not ferment animal waste for biogas. Furthermore, 50.38% of the respondents dump animal waste in containers, while 85.71% prefer to leave it in place. The average distance between the house and the nearest place to dispose of waste is 59.65 meters. Regarding household waste, 57.3% prefer to burn it, and 67.1% prefer to dispose of it in public containers. Furthermore, 55.3% of the respondents prefer to feed organic waste to animals, and 87.5% do not prefer to ferment organic household waste for biogas or compost.

Regarding wastewater management, 90.2% of the respondents drain wastewater into the sewage system. Regarding agricultural waste, 54.5% do not burn it on the farm and 53.7% prefer to use it as animal food. Furthermore, 92.2% prefer to leave agricultural waste on the ground or its borders, while 58.8% use it for energy. Regarding straw, 94.1% prefer to collect it, and 84.7% prefer to use a straw for fertilizer or biogas.

Analysis of responses to questionnaire statements revealed that 62.4% of farmers had prior knowledge about biogas, and 56.6% gained knowledge through the Internet. Furthermore, 57.6% believed that biogas is the result of the decomposition of organic waste. Most of the respondents agreed that biogas technology reduces waste volume and has positive effects on the environment. They also expressed willingness to buy a biogas unit, believing that it would benefit their family. However, concerns were raised about maintenance, expertise, and support for the biogas unit. Some respondents believed that there are better alternatives for organic waste management than biogas technology. The desired minimum investment for biogas technology was 218,095.24 S.P, and the desired maximum was 501,861.47 S.P. Additionally, a majority agreed to use biogas fertilizer in their garden or farm, and many respondents considered biogas technology management as a collective process. There was uncertainty about the financial aspects and distribution of income from biogas technology.

Biogas at the household level was considered economically and environmentally feasible. Regarding management aspects, a high percentage of respondents considered biogas technology management as a collective process. However, there needed to be more certainty among the respondents about using biogas technology only at home, and many agreed that the management of biogas technology should be through the government or a joint-stock company.

Regarding the financial aspects, 89% of the respondents did not know the household income from biogas technology.

The research also mentions the test hypotheses conducted. Variance analysis and chi-square tests revealed significant differences in knowledge and acceptance of biogas on the basis of the studied area, the presence of a biogas unit, and educational level. The path analysis confirmed the relationships between the variables studied. It was found that the extent of knowledge about biogas technology influenced the tendency toward certain behaviors.

Several studies have examined the acceptance of biogas technology. Putra et al. (2017) found suboptimal utilization of biogas technology at the family level, which contributes to the slow adoption among farmers. Kabir et al. (2013) identified education, income level, number of animals, and women's support as factors influencing acceptance. Adopting households showed higher education levels, animal numbers, income, agricultural land size, tree planting, and access to electronic media, positively affecting biogas adoption. On the contrary, proximity to water sources and electricity access negatively impacted adoption. Non-acceptance factors included larger family size, higher animal numbers, older household heads, inadequate preservation of animal residues, reduced family labor, and the inability to repair disrupted biogas systems (Lwiza et al., 2017).

In the third chapter, an in-depth SWOT AHP analysis focused on determining the criteria that affect biogas investment and the best areas to invest in this type of renewable energy. The perceived strengths of the Syrian environment in biogas technology that can be leveraged, appear to be the interest of Syrian farmers in modern technology, their willingness to deal with organic waste, their interest in the results of that process, and their desire to use it on a large scale.

On the contrary, cost, belief in better alternatives, time and effort required, and concerns about digestate and cooking on organic waste are perceived as the main weaknesses.

Therefore, calls for governmental support on loan facilitation for farmers to adopt renewable energy projects are crucial in post-conflict times.

In the category of opportunities, the highest priorities are seen to be the awareness of the studied environment of the positive effects of technology on the environment, their knowledge of its economic feasibility as an essential and alternative source of traditional energy, and its significant material effects, and the incubator's desire to participate in the management of the technology.

The most critical threats that must be addressed are tax deductions, fees for establishing biogas, maintenance, and lack of experience dealing with technical difficulties.

The findings align with Gottfried et al. (2018) study on the material benefits and collective participation in the biogas management committee. We also observed strengths in innovation, weaknesses in long-term investment commitment, and opportunities for financial benefits alongside threats of high construction costs.

Mukeshimana et al. (2021) study identified strategies impacting the renewable energy sector, such as increased investment, policy support, favorable conditions for private investment, and strengthened institutional management.

The Analytic Hierarchy Process (AHP) showed that the main criteria that affect adopting biogas technology are the approach for using biogas and digestate, followed by administrative and financial aspects. The southern region is the most suitable region for investments in biogas technology, with 54.5%, followed by central (27.3%) and coastal (18.2%).

Zhang et al. (2022) used the AHP method to evaluate the geographical suitability of industrial biogas production in China. They categorized the 31 study areas based on societal and economic conditions, resources, and environmental pressures. The study highlighted the significance of development level, among other criteria. Similarly, Falcone and Sica (2019) stressed the need for a green agenda at national and international levels to facilitate societal transitions in the green energy sector, especially in the post-COVID-19 era (Roubík et al., 2022).

In contrast, De Jesus et al. (2021) employed the AHP method to identify suitable areas for biogas unit establishment in southern Brazil, focusing primarily on geographical factors like proximity to roads, pipes, and organic waste suppliers.

The objectives of the thesis were covered, as this research represents a road map that helps to apply biogas technology in a stricken country seeking to recover from the effects of the civil war.

Conclusion

This thesis provides an in-depth analysis of biogas technology in Syria from social and economic points of view.

Choosing Syria as the country under study posed a significant challenge in light of the circumstances of the country. On the one hand, this research presents a roadmap for applying biogas technology as one of the most important renewable energy sources that the country desperately needs, especially in light of the current energy situation in the country and the importance of adopting it in the reconstruction phase.

However, it is considered one of the original research projects on biogas in Syria.

The high potential for processing plant and animal residues for biogas production from both animal and crop residues. The economic indicators of the use of small-scale biogas plants, such as the cost-benefit ratio, the average rate of return, the simple rate of return, the internal rate of return, net cash flow, and the payback period, have achieved attractive ratios compared to other countries, which calls for the attention of these projects.

The study found that the use of crop residues in the production of biogas achieved higher economic rates compared to the use of animal waste. Furthermore, the biogas project would still be profitable under the worst circumstances, even with higher costs and lower revenues.

Despite its lack of application, the good knowledge among the Syrian rural community about biogas technology and its costs makes it a raw environment for investment. Most farmers showed a willingness to buy a biogas unit and use it. This interest in adopting biogas technology varies from area to area and according to educational level.

The inability to maintain biogas units and the lack of experience in this area were among the concerns of the rural community. The initial cost was among the critical indicators of the adoption of biogas technology; the majority of the respondents will use biogas technology if the initial cost of its construction is compensated within one to two to five years, which was proven to be a fact from the feasibility analysis that was made. There is a lack of clarity regarding government policies and technical support for biogas technology.

In light of Syria's severe ongoing economic reality, such as poverty, unemployment, inflation, and low energy, farmers want financial support for establishing a biogas unit associated with tax reduction.

The results showed a positive relationship between the acceptance of biogas technology and the knowledge of biogas technology and its administrative and financial aspects.

The attention to innovations, the interest in using biogas technology to reduce waste volume, and the desire among farmers to use the fertilizer resulting from biogas plants were among the most important strengths. The main weaknesses of the application of biogas technology are the high costs and concerns about the time and effort required to operate a biogas unit. However, the environmental and economic impacts of biogas have emerged as the main opportunities. In contrast, the most outstanding threats were taxes, concerns about government support, fees, and maintenance.

The AHP analysis applied in three main regions (Coastal, central and southern regions) showed that the approach to using biogas and the resulting organic fertilizer is the best among the criteria in the study of the location of a biogas unit production.

By determining the weight of alternative criteria of each region, the region with the highest percentage of alternative criteria is the southern region, followed by the central region and the coastal region.

This study recommends increasing the sufficient knowledge of biogas technology and the need to facilitate the grant of funding for investment in biogas technology, tax reduction, government support in terms of subsidies or other project activities, and establishing support and training centers for this technology.

Therefore, calls for governmental support on tax exemption and loan facilitation for farmers to adopt renewable energy projects are crucial in the post-conflict period. There is a great need for the relevant authorities to provide a clear strategy in using biomass as a source of energy and awareness programs to support the spread of biogas technology in rural areas as a solution to produce energy from organic waste.

The study assessed small-scale biogas plants in Syria; therefore, it is recommended to study the impact of producing biogas from different plants of different sizes.

The findings of this research contribute to the recovery post-conflict after the conflict of the energy sector in Syria with the help of renewable energy resources generated in the agricultural industry and can play an essential role for future researchers and practitioners.

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Appendix

Czech University of Life Sciences Prague
Faculty of Tropical AgriSciences

Questionnaire

The main aim of this questionnaire is to find out the extent to which the Syrian community is aware of the biogas technology, its acceptance and willingness to use biogas technology for domestic use. Also, collect data about the applicable waste management methods used by household in rural areas in Syria; observe the level of knowledge about biogas.

The questionnaire consists of open, closed, semi-closed and evaluation questions with multiple answers and the concerned authorities approved it. $\chi 2$ test and analysis of variance test will be used to process the data.

The questionnaire is targeting farmers (livestock farmers and Crop farmers) (N= 227) and biogas plants owners (N=28). The copies of the questionnaire are in Arabic language and will be distributed and gathered through field visits and with the assistance of agricultural extension units distributed in rural areas. In addition to personal interviews with the local experts. All the questions will be explained to the farmers in order to remove any misunderstanding. The content of the questionnaire is based on similar researches that have been made and applied in developing with taking into consideration the Syrian situation.

All questionnaires will be edited and coded, the data will be entered into computer by using a Microsoft excel software template which will be prepared to satisfy the requirements to prevent the duplication during the data entry. In addition, to insure that the collected data will transfer to another format for data analysis using the Statistical package for social sciences (SPSS) program.

The collected information will be kept strictly confidential and will be used for scientific research purposes only, so please fill in the requested information honestly and objectively.

Thank you for your cooperation.

Specialist supervisor: Ing. Hynek Roubik, Ph.D.

Supervisor: doc. Ing. Jan Banout, Ph.D.

Researcher: Ing. Ghaith Hasan Date: 27/06/2019

Table 1: General data:

City: \ village name					
Sex	1. male		2. female		
age					
Household members number					
Type of residence	1. separated		2. apartment		
Type of job	1. agricultural	2. commercial	3. governmental		4. special
Educational level	1. uneducated	2. primary	3. preparatory	4. high school	5. university
Average monthly Household income (in Syrian pounds)	1. less than 25000	2. (25000-5000)	3. (50000-100000)		4. More than 100000
Share of off/farm income on total income (in %)					
Home garden availability	1. yes		2. no		
Type of home garden	1. flowers	2. vegetables	3. fruitful trees		4. Decoratio n Plants
Raising animals around the house	1. yes		2. no		
Farm size (ha)					
Land size holding (ha)					
Do you run your own biogas plant?	1. yes		2. no		

If your last answer was yes, please fill the following table:

type	number
Poultry and rabbits	
Birds	
Sheep	
Cows	
Others: (specify) …………………	

- Cleaning the animal farm:

a. Once everyday
b. 2 to 4 days
c. 5 to 7 days
d. More than 7 days

Methods of dealing with animal waste: (Highlight the option that applies):

	method	All	Mostly	Some	Nothing
A-	Selling to fertilizer factories				
B-	Use it as fertilizer for my crops				
C-	Brewing it for Biogas production				
D-	Throw it in the trash				
E-	Leave it at its place				

Distance between my house and the nearest place to get rid of household waste is … meters almost.

Methods of dealing with household waste: (Highlight the option that applies):

	method	All	Mostly	Some	Nothing
A-	rubbish burning				

B-	Disposal in public containers				
C-	Feeding organic waste to animals				
D-	Brewing household waste for biogas or biomass				
E-	Throw it in a nearby land				
F-	Others: (specify) ………………				

Methods of dealing with sewage: (Highlight the option that applies):

	method	All	Mostly	Some	Nothing
A-	Discharged into the sewerage network				
B-	Drain in the absorbent hole				
C-	Drawn through an open channel				
D-	Used to irrigate crops				

If you work in the agricultural sector, fill the following table please:

Type of Agriculture		Area (m^2)	Type of irrigation			
			Drip irrigation	Spray irrigation	Channel irrigation (traditional methods)	Rainfed agriculture (with rainwater)
Plastic greenhouses						
	Trees					

Open air agricultur e	**Vegetable s**					
	crops					

Methods of dealing with agricultural waste: (Highlight the option that applies):

	method	**All**	**Mostly**	**Some**	**Nothing**
A-	**Burned at the farm**				
B-	**Used as food for animals**				
C-	**Left on the ground or around the farm**				
D-	**Burned to get energy**				
E-	**Collect straw in the form of molds**				
F-	**Fermentation plant residues for composting or organic gas**				
G-	**Others: (specify) …...**				

Second chapter: The extent of the participant's knowledge about biogas

Have you heard about biogas before?				
1. yes	2. no			
If your answer was yes, from where you heard about biogas?				
1. School or collage	2. media	3. internet	4. seminars	5. others
What do you think biogas is produced from?				
1. Organic rubbish burning	2. Petrol	3. Decomposition of organic waste	4. I don't know	
I think that biogas technology reduces the volume of final waste.				
1. I totally agree	2. I agree	3. I don't know	4. I refuse	5. I totally refuse
I think that the initial cost to set up a unit vital gas is high.				

1. I totally agree	2. I agree	3. I don't know	4. I refuse	5. I totally refuse
I think that the organic waste decomposition through biogas technology produces liquid and solid materials.				
1. I totally agree	2. I agree	3. I don't know	4. I refuse	5. I totally refuse
I think that the organic waste decomposition through biogas technology produces fertilizer for plant				
1. I totally agree	2. I agree	3. I don't know	4. I refuse	5. I totally refuse
I think that the biogas technology usage has positive effects on the environment.				
1. I totally agree	2. I agree	3. I don't know	4. I refuse	5. I totally refuse

Third chapter: The extent to which the participant accepts the biogas technology and wishes to use it

I have a complete willingness to install biogas technology in my house or farm.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I have a complete willingness to install biogas technology on my farm.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I am willing to invest in biogas technology.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I will use the biogas technology if the cost of its initial construction is compensated during:				
1. One year	2. 2 to 5 years	3. More than 5 years		
What is the minimum you would invest? (in Syrian pounds)				

What is the maximum you would invest? (in Syrian pounds				
Biogas technology brings me extra income.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
Biogas technology can harm the environment I live in.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I do not like to use energy from dung for my cooking.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
Biogas technology is a suitable alternative to the previously/currently used energy source for me.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
Other alternatives for organic waste management are better than biogas technology.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I do not mind separating organic waste (waste of kitchen and garden) from another household waste.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I have concerns about the low quality of the output fertilizer from using the biogas technology.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I am able to collect dung regularly.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I am able to stock dung.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
In case I purchased a biogas unit, I am afraid that I will not be able to maintain them in the event of a malfunction.				

1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
In case I purchased a biogas unit, I am afraid that there is no suitable expertise to follow the work of the unit.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I am aware of governmental policy supporting biogas technology.				
Yes		No		
I can apply for subsidy for biogas technology.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I know where to get information support in case of interest in biogas technology.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I know where to get technical support in case of biogas technology failure.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I have ever received training on biogas technology.				
Yes		No		
My neighbors use biogas technology.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
Biogas technology is locally available.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
Other energy sources are expensive for me.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I am interested in new innovations.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree
I prefer to connect the toilet to biogas technology.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree

Forth chapter: Participant's orientation to use biogas and organic fertilizer output

I prefer to use the energy produced from biogas in:			
1. Supply of cooking gas	2. Generating electricity to run a device at home (fridge)	3. House warming	4. House lightning

I would like to use the output fertilizer in my home garden or in my farm:				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree

Biogas usage is favored at home level.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree

Biogas usage is economically and environmentally feasible.				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree

Fifth chapter: Administrative aspects

I think that administration of biogas technology is an operation:	
1. Individual	2. Collective

I support using biogas technology in house just under household management				
I totally agree	I agree	I don't know	I disagree	I totally disagree

If the administration of biogas technology was collective, I would like to participate in a management committee in this regard				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree

The administration of biogas usage should done by a private company				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree

The administration of biogas usage should be done by government				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree

The administration of biogas usage should be done by a shareholding company				
1. I totally agree	2. I agree	3. I don't know	4. I disagree	5. I totally disagree

Sixth chapter: Financial aspects

Do you know the amount of income from the usage of biogas technology?				
1. Yes		2. No		3. I don't know
I recommend that the profits of biogas technology be distributed equally to the villagers				
1. I totally agree	2. I agree	3. I don't know	4. I refuse	5. I totally refuse
I recommend that the proceeds of biogas technology be distributed equally to the participants in technology according to participation rates				
1. I totally agree	2. I agree	3. I don't know	4. I refuse	5. I totally refuse
I recommend that the government contribute to the cost of establishing biogas technology				
1. I totally agree	2. I agree	3. I don't know	4. I refuse	5. I totally refuse
What do you recommend for biogas technology cost recovery?				
1. Produce biogas and sell it collectively **2.** Add taxes to contribute in biogas technology to decrease waste and save the environment **3.** Low waste taxes for who participates in contribution of running biogas technology				

Thank you very much for participating

Curriculum vitae, publications and conference contributions

ING. GHAITH HASAN

Profile

An energetic, self-motivated and patient researcher pursuing a PhD in sustainable and renewable technologies. Expert in managing university courses, research, and projects that thrives in international environments. Experience in prioritizing tasks properly to maximize the teams' output and efficiency.

contact

Address: Prague Czech Republic

Tel: +420776505069

+963991858484

E-MAIL: hasan@ftz.czu.cz

ghaithhasan1@hotmail.com

LANGUAGES

Arabic: Mother tongue

English: C1

Czech: B1

Persian: B1

Education

Czech University of Life Sciences in Prague

Oct 2018 – present

- PhD Degree (Final semester) (Faculty of Tropical Agrisciences)

Title: Social and Economic Assessment of Small-Scale Biogas Plants in Syria.

Czech University of Life Sciences in Prague

Oct 2016 – June 2018

- **Master degree** (Faculty of Economics and Management)

Title: An Economic Analysis of the Impact of Ethanol Production on Food Prices in the United States of America.

Tishreen University in Syria

Oct 2007 – Oct 2012

- **Bachelor degree** (Faculty of Economics)

Published papers (WoS) and books

- 2022 Hasan, G., Mazancová, J., Banout, J.et al. Feasibility analysis of Small-scale biogas plants usage in the Syrian coast through agricultural crop residues and co-digestion of manure. Biomass Conv. Bioref. IF: 4,103.

https://doi.org/10.1007/s13399-021-02112-6.(IF-4.987)

- Hasan, G., Mazancová, J., Roubík, H. Assessment of individual acceptance of biogas technology by Syrian farmers - evidence from

PERSONAL TRAITS

Communication

Proficiency

Creativity

Patience

Confidence

Punctuality

Dedication

Organization

.

Coastal, Central and Southern regions. Submitted to Renewable Energy (2023) IF: 8.634.

- Hasan, G., Mazancová, J., Roubík, H. Assessment of the incubating environment for investment in biogas technology in Syria by using AHP and SWOT. Accepted in Environment, Development, and Sustainability (2023) IF: 4.080. https://doi.org/10.1007/s10668-023-03137-9

- Coauthor of operations research book for fourth year students in the Faculty of Science, Tishreen University, Syria. (Winter Semester Course 2022-2023).

Conference contributions

1. International Multidisciplinary Conference for Young Researchers in Ukraine

Nov 2021 (Reasons behind the low numbers of small-scale biogas plants, the case of Syria and Jordan)

2. Tropentag Conference held virtually

Sep 2020 (Using SWOT- AHP approach in determining the dimensions of the investment in biogas technology and its location in Syria).

3. Tropentag Conference in Germany

Sep 2019 (Biogas energy potential in Syria: Prospects and challenges).

4. ELLS Conference in Sweden

Nov 2019 (An Outlook of Biogas Energy Prospects and Challenges: The Case of Syria).

5. Multidisciplinary Conference for Young Researchers in Ukraine

Nov 2019 (An Economic Analysis of the Impact of Bioethanol Production on Food Prices in the United States of America).