Food and Agriculture Organization of the United Nations

GLOBAL BIOENERGY PARTNERSHIP
WORKING TOGETHER FOR SUSTAINABLE DEVELOPMENT

Working Group on Capacity Building

Activity Group 7 ‘Biogas’

Stocktaking Paper – Regional analysis of biogas value chains

Based on SWOT analysis

April 2020




BIOENERGY
Electricity Heat Transport

PARTNERS
Public
Private
Civil Society

STRATEGIC AREAS
Sustainable Development
Climate Change
Food and Energy Security

Required citation:

Miller C., Pereira Coronel L. C., Pirelli T. and Morese M. 2020. *Stocktaking Paper – Regional analysis of biogas value chains*. Rome, FAO.

Cover photos: FAO/Tiziana Pirelli; FAO/Maria Michela Morese, SuSanA Secretariat/CC BY; Ralph Muvhiiwa, Diane Hildebrandt, Ngonidzashe Chimwani, Lwazi Ngubevana, Tonderayi Matambo/CC BY.

EXECUTIVE SUMMARY

The stocktaking paper is based on the work of the GBEP Secretariat along with GBEP Partners and Observers during the GBEP Bioenergy Weeks (Ghana in 2017, Argentina in 2018 and Philippines in 2019). As such, its focus is on Africa, Latin America and the Caribbean (LAC), and Asia. It is to be used as a preliminary background document to guide the focus of the Activity Group 7 on Biogas (AG7) of the Working Group on Capacity Building (WGCB).

Biogas, produced through anaerobic digestion of organic matter, can provide flexible modern bioenergy services for power generation, transport, heating and cooling, and cooking. It can represent a more sustainable alternative to traditional biomass use or fossil fuels. Anaerobic digestion is an established technology but its uptake in some developing countries has been slow. It is necessary to understand the main factors that affect the success of biogas in order for policies and projects to be developed to deliver sustainable renewable energy. The paper analyses the factors that contribute to the success of biogas operations or projects in different regions of the world. The analysis is carried out using SWOT analysis; this approach seeks to identify the strengths, weaknesses, opportunities and threats of a particular business model through discussions with relevant stakeholders.

The results of this study show that although there are differences between regions in terms of the most relevant strengths, weaknesses, opportunities and threats, there are also common factors across regions. Although anaerobic digestion is valuable for providing modern energy services, the most important positive factors for the success of biogas value chains appear to be the co-benefits, in terms of, for example, use of residue and waste streams as feedstock, substitution of traditional biomass or fossil fuel energy, improved waste disposal/sanitation, reduced contamination of surrounding soils and water, reduction in lifecycle GHG emissions, and the use of digestate as fertiliser. Key negative factors instead focus on the high cost of initial investment in biogas systems, lack of knowledge of the population surrounding construction and maintenance, and the need to adapt technology to local circumstances. Robust, dedicated policies that valorise the co-benefits of biogas are suggested, as well as training programmes on the construction and maintenance of anaerobic digesters.

ACKNOWLEDGEMENTS

This report represents a contribution to the scope of work of the Global Bioenergy Partnership (GBEP) Activity Group 7 “Biogas” of the Working Group on Capacity Building (WGCB). It was developed by Constance Miller, Luis Carlos Pereira Coronel and Tiziana Pirelli of the GBEP Secretariat, under the overall supervision of Maria Michela Morese, GBEP Executive Secretary, and with the valuable contribution of the AG7 co-chairs, Bah F. M. Saho (ECREEE/ECOWAS) and Pham Quang Ha (Viet Nam).

GBEP would like to express its appreciation to all the experts that actively and generously contributed to the development of this report through the surveys, interviews and focus groups.

CONTENTS

LIST OF ACRONYMS

AD	Anaerobic digester
AHP	Analytical hierarchy process
ASEAN	Association of Southeast Asian Nations
CDM	Clean Development Mechanism
CO_2eq	Carbon dioxide equivalent
FAO	Food and Agriculture Organization of the United Nations
GEF	Global Environment Facility
GHG	Greenhouse gas
IADB	Inter-American Development Bank
IBRD	International Bank for Reconstruction and Development
IEA	International Energy Agency
LAC	Latin America and the Caribbean
LPG	Liquid Petroleum Gas
MINEM	Ministry of Energy and Mines (*Ministerio de Energía y Minería*)
NDC	Nationally Determined Contributions
OFMSW	Organic fraction of municipal solid waste
SDG	Sustainable Development Goals
UNDP	United Nations Development Programme

1. INTRODUCTION TO BIOGAS

1.1. Biogas for sustainable development

At a time when global problems such as poverty, hunger, lack of energy access, climate change and biodiversity loss are compounding, it is key to identify holistic development strategies that are able to have positive impacts across all dimensions of sustainability. Modern bioenergy, the use of biomass to provide modern energy services (FAO, 2011, p.209), is recognised by international organisations, such as the IEA, as an integral part of the energy mix for a low carbon future, and is expected to expand in the next 5 years, with 30 percent of the growth in renewable consumption until 2023 expected to come from the bioenergy sector (IEA, 2018).

Biogas is one such modern bioenergy, which is produced through the anaerobic digestion of organic matter. It is primarily composed of methane, carbon dioxide and hydrogen sulphide. It is produced from a process known as anaerobic digestion, which is the degradation of organic compounds to simple substances by microorganisms that release gas (Mao *et al*., 2015; Abdeshahian *et al*., 2016). With the rising demand for renewable energy and environmental protection, anaerobic digestion has attracted considerable attention within the scientific community over the last few decades (Mao *et al*., 2015; Kulkarni & Ghanegaonkar, 2018). Anaerobic digestion is a renewable energy technology that can be utilised at many scales, from household to industrial level. At small scales, biogas is directly combusted in stoves for cooking and heating, whereas at larger scales, it can be either upgraded for use in the national gas grid or as a transport fuel, or it can be combusted to produce power. Biogas can be produced from a variety of feedstocks, ranging from human and animal waste, and agro-industrial residues to dedicated crops.

Biogas is recognised as a renewable energy technology that provides modern energy services, such as modern cooking facilities, electricity and transport fuel. Biogas technology typically uses 'wastes' as feedstock and can therefore also contribute to the circular economy. As such, it can support the achievement of the SDGs under Agenda 2030, especially SDG7 on affordable and clean energy (UN, 2019). As highlighted by Fagerström *et al*. (2019), anaerobic digestion is 'multifunctional' and therefore has the opportunity to promote other sustainable development objectives, including:

- **SDG 1 No poverty** – e.g. through livelihood improvements arising from the availability of modern energy services, increased numbers of jobs, and through the use and/or sale of digestate;
- **SDG 11 Sustainable cities and communities** – e.g. through the treatment of wastes and reduction in household air pollution;
- **SDG 13 Climate action** – e.g. through reductions in methane emissions from untreated wastes, and the replacement of fossil fuels; and
- **SDG 15 Life on Land** – e.g. through reductions in water and soil contamination in surrounding ecosystems, among others.

1.2. Benefits of biogas

One of the advantages of biogas is its flexibility to be used at a variety of scales. Biogas at large scale can be produced from agricultural and agro-industrial residues and effluents, the organic component of municipal solid waste, as well as human and livestock waste. At this scale, biogas is often used to produce heat and power, thus contributing to energy self-sufficiency for industrial activities, and providing opportunities for a new source of income derived from sale of electricity to the grid (where available), and sale of co-products such as digestate that can be used as an organic fertiliser or as components of soilless substrates.

At this scale, biogas can have multiple economic, social and environmental benefits. The production of biogas can lead to new product streams that increase revenue (e.g. through the sale of digestate), and can reduce costs of power and for disposal of wastes, thus increasing profit (see Gebrezgabher *et al*., 2010 for an example from The Netherlands). Power produced can also be sold to the electricity grid. It also has environmental benefits, as proper treatment of wastes and residues reduces soil and water pollution (Börjesson & Berglund, 2007). Furthermore, use of anaerobic digestion has huge GHG mitigation potential through: CO_2 emission reductions from fossil fuel substitution; CH_4 emission reductions from decomposition of animal/human wastes and agroindustry residues; and N_2O emission reductions from biological oxidation of ammonia and reduced demand for synthetic fertiliser (Bond & Templeton, 2011; Piacentini and Vega, 2017).

Biogas in rural households and small farms may supply the modern energy services required for sustainable development, whilst also transferring other benefits. Its establishment may increase the income of households by creating new job opportunities, and reduce the time spent for collecting firewood and the need for purchase of other fuels, such as LPG or charcoal (e.g. Bedi, Sparrow & Tasciotti, 2017). The digestate produced as a by-product of the biogas system can also be used as organic fertiliser, thus also promoting soil fertility, increasing crop yields and ultimately improving livelihoods (e.g. Bezzi, Maggioni & Pieroni, 2016). Furthermore, it can transfer significant health benefits through management of human and animal waste, improved sanitation and smokeless cooking (e.g. Lewis *et al*., 2016).

1.3. Barriers to uptake

Although biogas can have large benefits at multiple scales, there are barriers to its uptake. Previous studies note ignorance of the benefits of biogas as a significant obstacle (Muvhiiwa *et al*., 2017), thus making it difficult to overcome the social unacceptability of the system. Both at small and large scale, installation of biogas systems can be expensive and there is the need for an enabling environment and regulatory framework that supports biogas installation through financial incentives (Austin and Morris, 2012; Muvhiiwa *et al*., 2017). A further challenge identified at both large and small scale is the affordability and reliability of feedstock. In some cases, agricultural systems may need to be modified to make collection of feedstock for biogas viable; this is the case where extensive livestock systems make collection of manure challenging (Werner *et al*., 1989). Development of capacity to construct and maintain biogas plants is also imperative. It has been noted, especially for small-scale plants, that lack of human capacity can undermine the environmental and economic benefits of biogas systems (e.g. Viet Nam, Thu *et al*., 2012).

1.4. Policy Framework

The regulatory framework in a country can have a large impact on the uptake of biogas technology. Both positive incentives and regulations can be used to promote biogas.

As identified by several researchers (e.g. Garwood, 2010; Vasco-Correa *et al*., 2018), there is the opportunity to promote biogas through stricter environmental regulations on the treatment of wastes. Indeed, Aso *et al*. (2018) note that anaerobic digestion can accommodate tight restrictions on environmental regulations (p.223).

Some authors have noted that positive incentives are required to make biogas viable, for example, ‘green tags, preferential taxes, ease rural credits’ (Alemán-Nava *et al*., 2015, p.11). Indeed, in countries where the positive externalities are not accounted for using subsidies, installation of anaerobic digesters (ADs) may not be economically attractive (e.g. Chile – INDAP & GORE, 2016, p.81). Instead, some countries provide incentives for renewable energy technologies through tax exemptions on imports of equipment related to biogas (and other renewable energy) installation, for example the Renewable Energy Development Act of the Dominican Republic (Global Methane Initiative, 2014).

It is also possible that the policy framework and market environment have negative effects on biogas uptake. For example, subsidies for fossil fuels have been identified as a disincentive to investment in biogas and bioenergy in general; for example, subsidies for LPG in Ecuador limit investments in small-scale ADs (Garwood, 2010), and subsidies for fossil fuels in Bolivia reduce pressure on firms to invest in biogas or other renewable options (Lönnqvist *et al*., 2018, p.495). There can also be 'predatory or inhibitory competition' between renewable energy strategies in certain cases that can limit uptake of biogas. For example, in Colombia, palm oil mills and ethanol-sugarcane distilleries do not have the option to produce electricity surplus for the grid from biogas, and it has been suggested that this is to protect hydropower participation in the electricity mix (Alemán-Nava *et al*., 2015, p.15). On the opposite end of the spectrum, Brazil uses a smart-grid concept to incorporate small electricity sources into the grid (Alemán-Nava *et al*., 2015).

Given the environmental benefits of biogas technology, international funding opportunities may also be available to incentivise uptake. One example of this is the CDM under the Paris Agreement.

1.5. Regional analysis

Given the differences in climate, political structures, cultural perception, and human and institutional capacity, the uptake and success of biogas between regions has been varied. This research aims to identify the most important strengths, weaknesses, opportunities and threats (SWOT analysis) to biogas business models in each regional context at a variety of scales. Brudermann *et al*. (2015) have used a SWOT analysis approach to examine the prospects of agricultural biogas plants at the national level. However, as the authors are aware, there has been no such analysis of perceptions of biogas at the regional level. The scope of this study is to understand the most relevant factors that affect the success of biogas business models and their future prospects for growth.

1.5.1. Africa

Lack of modern energy services is a serious barrier to development in Africa, where 80 percent of the population still rely on the traditional use of biomass for cooking (Stecher *et al*., 2013). This has significant negative social, environmental and economic consequences for many households. A non-exhaustive list of these consequences includes deforestation and forest degradation due to unsustainable use of forest resources, unpaid work for households in collecting solid biomass, and health and environmental effects from indoor and outdoor air pollution, among others. For instance, a study by Tumwesige *et al*. (2017) in sub-Saharan Africa shows that full conversion from solid biofuels (i.e. firewood and charcoal) to biogas for cooking reduces the levels of airborne emissions of fine particulate matter (PM2.5) to within the levels suggested by the World Health Organisation (WHO) guidelines.

Although biogas can have many benefits, studies of biogas technology application in Africa have shown it to have varied success due to a number of barriers. Although in other developing countries biogas at small scale can be a suitable and successful opportunity for producing modern bioenergy (FAO, 2018), cases of successful stories of small-scale biogas plants in Africa are more limited. Cost-benefit analysis of small-scale biogas in Ethiopia has demonstrated that there are financial benefits for rural households from the use of biogas technology but that success of biogas programmes depends on the effective use of slurry as fertiliser and on the price of the replaced energy source (Gwavuya *et al*., 2012). As part of a financial and economic analysis of the milk value chain in Kenya, Tanzania and Tunisia, FAO found that biogas is attractive in some cases, for example for biogaspowered domestic milk chiller, but not attractive in other cases, such as biogas for power generation (Flammini *et al*., 2018).

1.5.2. Latin America and the Caribbean

Household level biogas

In LAC, tubular ADs are favoured at household level due to their low cost and ease of construction. According to available evidence, biogas at household level has a remarkable climate change mitigation potential, with it being estimated that 316 million tonnes CO_2eq could be mitigated annually in Latin America alone (Garfí *et al*., 2016). It could also: reduce indoor air pollution from open fires; improve crop yields and reduce the need for chemical fertilizer; reduce the amount of time collecting firewood; and reduce the amount of OFMSW going to landfill (Muñoz *et al*., 2018; Lansing *et al*., 2018).

Studies have shown that tubular ADs can help rural families save up to 50 USD per month in propane fuel costs from a switch to biogas (e.g. Colombia – Castro *et al*., 2017). However, it is important to note that climatic factors are extremely important for the success of biogas projects at this scale, as low temperatures inhibit biogas production. Garfí *et al*. (2016) found that in high altitudes where temperatures are lower, only 60 percent of the cooking fuel needs of the household could be met through biogas, compared with over 100 percent in tropical regions (p.606).

At household scale, the greatest barriers identified to uptake of biogas by previous authors were the high initial investment costs (Garfí *et al*., 2016), lack of knowledge and expertise in biogas maintenance due to absence of institutional support, and inexpensive alternative fuels (Garwood, 2010).

Biogas for productive and industrial use

At larger scale, biogas is used in both urban and rural settings to produce heat and power for self-consumption and injection into the electricity grid. Biogas can also be upgraded to biomethane for injection into the national gas grid or as a transport fuel.

As already mentioned, use of anaerobic digestion has dramatic GHG mitigation potential. Other environmental benefits include the treatment of wastes, thus reducing soil and water contamination. There are also social and economic benefits, including job creation, improved working conditions and incomes, provision of clean and reliable energy, and reduced fuel costs for industries (Guttiérez-Castro *et al*., 2015).

There are, however, also barriers. Feedstock availability is an important factor: some feedstocks may be seasonal (e.g. coffee sector) or have a market price (e.g. molasses in the sugar sector) (SNV, 2011), whilst some feedstocks may be difficult to collect (e.g. manure due to extensive cattle management practices). Moreover, the low development of the sector and associated value chain in many countries means that there is scarce reliable data on project costs, lack of human capital, no market for by-products, high initial investment costs, and difficulty in adapting imported technologies to the local circumstances (Martiniello, 2017).

1.5.3. Asia

Major economic and population growth have been taking place in many Asian countries during the last decades. In fact, India is expected to become the most populous country by 2030 (Mohan *et al.,* 2006). In terms of economic growth, ASEAN's economy is currently ranked as the seventh largest economy in the world, and is projected to rank as the fourth largest economy by 2050 (Pappalardo, 2019). Furthermore, China is currently home to the world's second-largest economy and is expected to replace the United States as the world's largest economy by 2030 (World Bank, 2013).This impressive growth creates regional energy and environmental sustainability challenges, as in South

East Asia alone energy consumption is expected to double by 2040 (Pappalardo, 2019), while the amount of municipal solid waste (MSW) produced is also expected to increase (Mani, 2020).

Despite Asia's rapid modernization, a substantial portion of the region's population lives without access to basic, reliable energy services. In fact, 107 million ASEAN citizens still lack access to electricity (Ggnanasagaran, 2018). Therefore, modern energy technologies are needed to improve access to energetic resources for those people and provide additional health and livelihood benefits (FAO, 2012).

As a solution to these challenges, the diversification of regional energy supply through investment in renewable energies might be beneficial for a sustainable economic development, and also help to manage MSW (Mani, 2020).

In this context, biogas may represent an opportunity not only for energy production but also for waste valorisation and mitigation of GHG emissions. Especially considering that Asia accounts for most of the world's livestock population, and the animal waste produced annually constitutes a major source of methane and other GHGs. The potential to reduce CO_2 emissions through the implementation of ADs could be as significant as 1 billion tonnes per year in South East Asia alone (Ggnanasagaran, 2018).

Studies of biogas application have shown numerous cases of successful stories of small and large plants in Asia. China alone accounts for more than 90 percent of biogas installations globally, with about 43 million household digesters being counted in 2014. It was estimated that biogas used in China cut annual carbon dioxide emissions in 2014 by 61 million tonnes (IRENA, 2017). The most common type of technology used for anaerobic treatment is the upflow anaerobic sludge blanket (UASB) (Deng *et al.*, 2017). They have also developed many types of commercialized or half-commercialized prefabricated biogas digesters (PBDs), which are categorized into three: glass fibre-reinforced plastic digesters, plastic soft digesters and plastic hard digesters. By 2013, China already had 100 PBD manufacturers (at least one manufacturer in each province), and many countries in South East Asia, such as Myanmar, Viet Nam, Bangladesh, and Cambodia were importing PBDs from China (Cheng *et al.*, 2013).

Some Asian countries such as India, China and Viet Nam currently offer subsidies for the construction of ADs, in order to encourage their use (IRENA, 2017), while other countries are applying a Feed-In-Tariff, namely Indonesia, Malaysia and Thailand (ACE and CREEI, 2018). In Viet Nam these policies to promote low-cost technology based on flexible digesters have supported biogas uptake, and by the year 2015 more than 465 000 biogas plants had been installed in the country (IRENA, 2017; FAO, 2018).

2. METHODOLOGY

2.1. SWOT Analysis

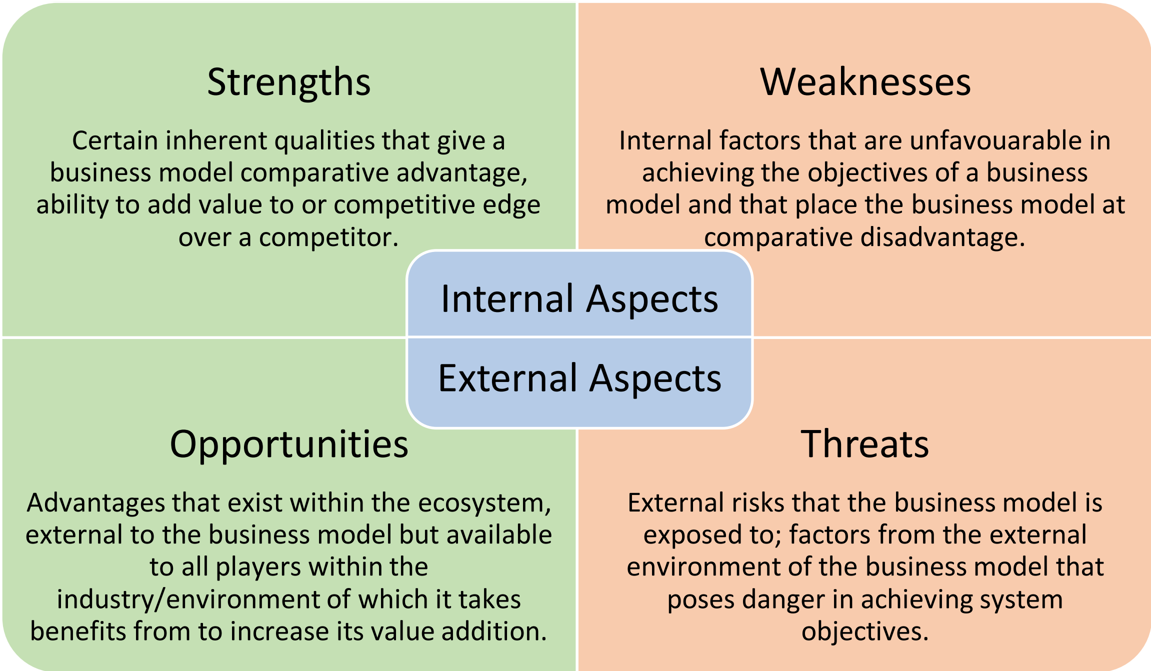

Figure 1 – Outline of the factors within a SWOT analysis. Source: adapted from Team FME (2013)

SWOT Analysis is a technique used to identify the Strengths, Weaknesses, Opportunities and Threats of a particular business model (Figure 1). It takes into account the positive and negative components of both the internal aspects (Strengths and Weaknesses) and the external aspects (Opportunities and Threats) of a business model. The internal aspects are those which can be in some way controlled within the system, whereas the external aspects are those which are exogenous and therefore cannot be controlled for within the system.

2.2. Africa

For Africa, biogas value chains were divided into small and large scale. The two scales of business model for biogas were dealt with separately in acknowledgement of the fact that they have different positive and negative factors.

2.2.1. The ECOWAS/GBEP Bioenergy Week 2017

Given the potential benefits of biogas in Africa and the need for developing supporting policy, biogas was one of the focuses of the ECOWAS/GBEP Bioenergy Week 2017 held in Accra (Ghana), from 22 to 24 June 2017. The event brought together over 90 participants from Africa, the Americas, Southeast Asia and Europe (*Table 1*); the participants included scientists and government officials, as well as representatives from the private sector and civil society organizations. Within Session II "Sustainable value chains for food and energy security", a focus group on "The Biogas option in Africa" was conducted with the aim to discuss the potential for biogas in Africa at both small and large scales.

Africa	Rest of World	International/Regional Organisations
•Algeria •Benin •Burkina Faso •Cabo Verde •Côte D'Ivoire •Egypt •Ethiopia •Gambia •Ghana •Guinea •Guinea Bissau •Liberia •Mali •Niger •Nigeria •Senegal •Sierra Leone •Togo	•Brazil •Germany •Japan •UK •USA	•EBID •EREEEE •FAO •IRENA •UNDP

Table 1 – List of countries represented at the ECOWAS/GBEP Bioenergy Week 2017

2.2.2. SWOT analysis of large-scale biogas business models

To carry out the SWOT analysis of large-scale biogas business models, potential strengths, weaknesses, opportunities and threats (from here on out to be referred to as 'factors') were identified from the literature. All factors were grouped to allow for easier recognition (the groups by category of the SWOT, along with all factors can be seen in Annex 1). An online survey was prepared and sent to selected stakeholders who had been invited to attend the ECOWAS/GBEP Bioenergy Week 2017. For each category of the SWOT, the respondents were asked to select (from a possible list) *all* relevant factors for large-scale biogas business models in Africa already identified, and to propose any additional important factors that were not already listed (*Figure 2*). The survey consisted of four sections (one for each category of the SWOT), with between 17 and 23 factors to consider for each section. It was administered to selected stakeholders with expert knowledge of large-scale biogas in Africa to determine which of the factors were the most important for the success of the large-scale biogas business models.

The results of the survey were presented at the ECOWAS/GBEP Bioenergy Week 2017 (Accra, Ghana, 22-24 June 2017) for validation by relevant stakeholders.

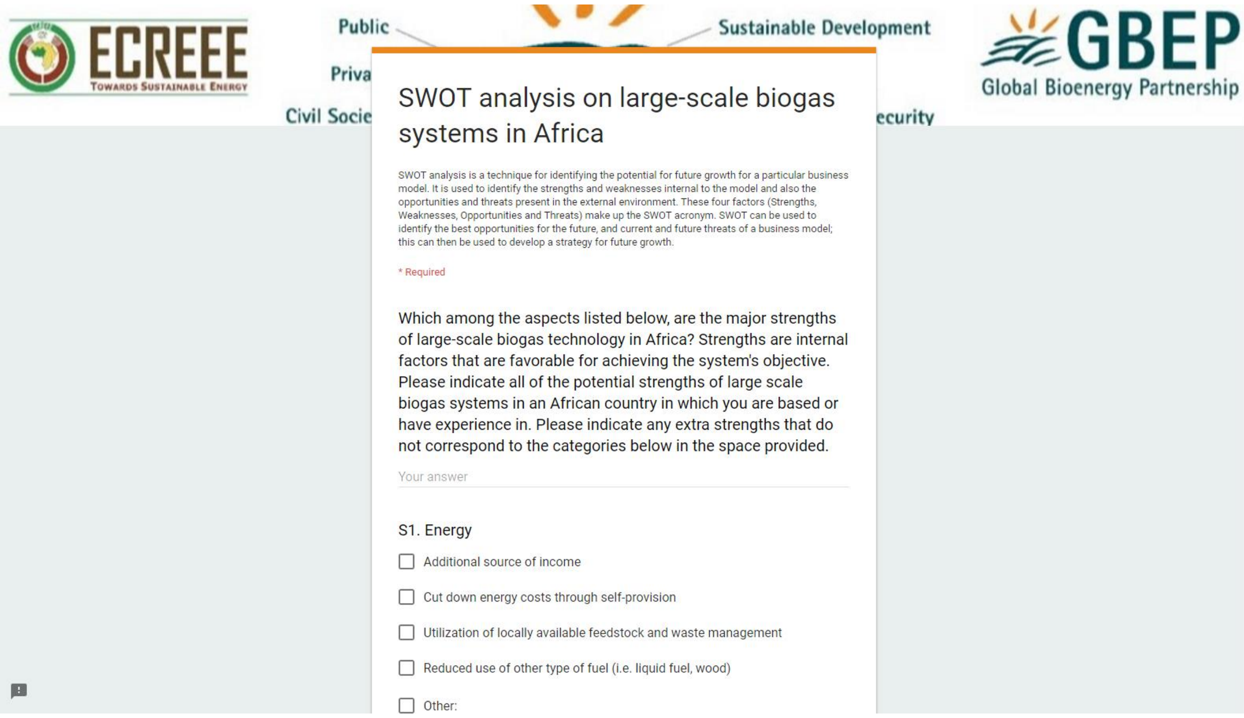

Figure 2 – Example of survey administered for large-scale biogas SWOT analysis

2.2.3. Small-scale biogas value chains

Focus groups

A focus group was carried out during Session 2 of the ECOWAS/GBEP Bioenergy Week (Accra, Ghana, 22-24 June 2017). Two groups (of 8 people per group) were assigned to each category of the SWOT. These groups were given time to brainstorm the relevant factors, and then the resulting lists were brought back to plenary for discussion. This produced a list of relevant factors for each category, which were edited to remove duplicates and similar factors and produce a final list of factors to be used for implementing the second phase of the SWOT analysis with the aim to rank the factors identified within each category.

Online survey

As noted by Brudermann *et al*. (2015), SWOT analysis provides only a qualitative analysis of relevant factors, and does not provide information on their relative importance. Therefore, a further online survey was sent to all participants of the Bioenergy Week in order to rank the factors using an Analytical Hierarchy Process (AHP) based on pairwise comparisons, similarly to the methodology described by Brudermann *et al*. 2015. Respondents were asked to compare the importance of each of the six factors previously identified as relevant for each category of the SWOT. Where there are N factors, the number of pairwise comparisons equals:

$$\frac{N(N-1)}{2}$$

This amounted to 15 comparisons for each SWOT category. Therefore, the survey was divided into two parts (external and internal aspects) and administered to two different groups to reduce respondent fatigue and therefore improve validity of results. These groups were chosen randomly from the full list of participants to the Bioenergy Week.

The respondents were asked to compare factors on a seven-point scale from 1 to 7. For example, when comparing factors F_i and F_j, a score of 1 would indicate that F_i was extremely more important than F_j, a score of 4 would indicate that the factors were equal in importance, and a score of 7 would indicate that F_j was extremely more important that F_i. After data collection was completed, this scale was then converted to a nine-point scale, as required by the AHP method developed by Saaty (1986). The priorities and rankings of the factors was then calculated using the online software from Goepel (2018).

2.3. Latin America and the Caribbean

For the LAC region, biogas systems were divided into two types, to account for differences in scale: household ADs and ADs for productive and industrial use. Other distinctions are sometimes used to divide biogas systems, for example He *et al*. (2013) distinguish between centralised and decentralised systems in rural China. However, the concepts of household ADs and ADs for productive and industrial use seem to be more prevalent in the literature, and better describe the scenarios in LAC. For the purposes of this study, we consider household ADs to be small-scale systems that are used by households or small, subsistence farms to produce biogas for cooking and heating in the household itself. We consider ADs for productive and industrial use as being typically larger-scale biogas systems used by commercial operations (both farms and industry) where the biogas produced is either used for energy in the productive activities, distributed via gas pipelines or used to produce electricity (both for own consumption and injection into the grid.

2.3.1. Interviews

Online interviews were used to collect qualitative data on the perspectives of experts in LAC on the factors that affect the success of biogas value chains in the region. The interviews were carried out either over Skype or using Adobe Connect software, and were between 30 and 60 minutes in duration. They were conducted in either Spanish or English, depending on the language preferences of the interviewee.

A generic purposive approach was used when sampling the participants (Bryman, 2016, p.410-412). Participants were 'biogas stakeholders': people with close ties or interest in biogas in the region, including selected experts from research institutions, government ministries, civil society and private sector. Effort was made to have a range of participants across different institutions/sectors and countries.

Thirteen interviews were conducted in total; *Table 2* provides information on the country of expertise and the sector of employment of the interviewees. The interviews covered perspectives from seven different countries, along with regional perspectives. The private and public sector were represented, as well as civil society, research institutions and international organisations.

Number	Country	Sector of employment
1	Brazil	Private sector
2	Chile	Public sector
3	Regional	Civil society
4	Jamaica	Public sector
5	Costa Rica	Private sector
6	Guatemala	Private sector
7	Chile	Public sector
8	Chile	Public sector
9	Argentina	Private sector/research institution
10	Paraguay	Public sector
11	Regional	International organization
12	Brazil	Research institution
13	Regional	Civil society

Table 2 – Country and sector of employment of interviewees

The questions in the interviews consisted of the perceptions of participants on the key factors that affect the success of biogas systems at household level, and for productive and industrial uses in LAC. The interviews were semi-structured in order to allow for flexibility in responses whilst still covering key questions and themes.

The interviews were recorded and transcribed to allow for full attention during the interview. The transcripts were then coded following the approach of Strauss and Corbin whereby: open coding occurs first, yielding concepts that can be turned into categories; followed by axial coding to determine connections between categories; and finally selective coding to frame the 'storyline' of the analytical account (Bryman, 2016, p.574). The codes primarily represent the SWOT factors to be employed in a SWOT analysis. However, other interesting or salient comments were also identified, e.g. specific national policies or projects.

The consolidated codes were used to produce a list of factors for the SWOT analysis for both biogas at household, and productive and industrial use scale. This list was placed in order of 'relevance' (where relevance is represented by the number of interviewees who identified the factor in their interview).

2.3.2. Online survey

The online survey was used to collect primary data for the case study on Argentina. It built on the factors of the SWOT for productive and industrial biogas identified through the interviews, with the aim to determine which of the factors were most important in each SWOT category, i.e. to determine the relevant factor priority, and therefore rank the factors.

In order to rank the factors, the Analytical Hierarchy Process (AHP) was used, based on pairwise comparisons of the factors. Given the exponential increase in pairwise comparisons as the number of factors increases, the six 'most relevant' factors were identified for each SWOT category. To overcome the potentially subjective nature of the choice of factors (as identified by Brudermann *et al*., 2015), the selection was based on the frequency of the coded responses provided during the interviews. Respondents to the survey were asked to make pairwise comparisons between the six SWOT factors in each category – comparing the importance of each of the factors.

There were a total of 15 pairwise comparisons for each SWOT category. Therefore, the survey was divided into two parts (external and internal aspects) and administered to two different groups to reduce respondent fatigue and therefore improve validity of results. The survey was administered in both English and Spanish.

The survey was administered to the participants of the GBEP Bioenergy Week 2018 held in Argentina in October 2018. The participants included over 200 representatives from government ministries, research institutions, civil society and private sector with experience in bioenergy. The two parts of the survey were sent to two different groups that were allocated randomly from the full list of participants to the Bioenergy Week, as well as the interviewees who responded to the first part of the research.

The respondents were asked to compare factors on a nine-point scale from 1 to 9, as required by the AHP method developed by Saaty (1986). For example, when comparing factors F_i and F_j, a score of 1 would indicate that F_i was extremely more important than F_j, a score of 5 would indicate that the factors were equal in importance, and a score of 9 would indicate that F_j was extremely more important that F_i. The average values from the expert opinions provided by the survey were used to calculate the relative priority of the factors in each SWOT category using the methodology provided by Goepel (2018).

Respondents to the survey were also asked two supplementary questions on policies, where they could provide open answers. These were:

- Please list the policies that you are aware of in your country/ies that facilitate the uptake of biogas at productive and industrial use scale (where more than one country, please specify).
- In your opinion, what extra policies are required to stimulate the development of biogas?

For the survey on Strengths and Weaknesses, there were 17 respondents, and for the survey on Opportunities and Threats, there were 22 respondents. Of these respondents, 13 and 18 respondents were from Argentina, respectively. Given the high percentage of respondents from Argentina (77 and 82 percent, respectively), it was decided to focus the results of the survey on the national situation in Argentina.

2.4. Asia

For the purposes of the regional analysis in Asia, biogas value chains were divided into two scales of business model: household-decentralized scale and large-centralized scale. These were dealt with separately in acknowledgement of the fact that they have different positive and negative factors. For the purposes of this study, household-decentralized level has been defined as small ADs with low biogas productivity, often designed for digestion of kitchen, animal and human excreta. Biogas production is used locally by families within their own properties. A typical household digester has a volume of 6-15 m^3 (Deng *et al.*, 2017). Centralized level has been defined as ADs that can treat large amounts of feedstocks (e.g. manure, palm oil waste, and other organic waste) produced by large-scale livestock and poultry farms, as well as industrial and organic waste streams (Song *et al.*, 2014). Energy (both as biogas or electricity) is either used by multiple households within an area or sold to the national grid.

2.4.1. Literature Review

Secondary data collection was primarily used: potential factors were identified from a literature review of 29 journal articles and reports. The factors were organised to eliminate duplications and allow for easier recognition. Then the factors were then classified into each scale based on the study context of each report.

The number of publications supporting a given factor was quantified in order to determine the most relevant factors by evaluating the frequency of each one. The frequency was calculated for each category (Strengths, Weakness, Opportunities and Threats) by determining the total number of sources of each factor (a), the total number of sources of each category (b), and then dividing a/b for each factor, were (b) represents the total number of sources of the category to which (a) belongs. This list was placed in order of 'relevance' (where relevance is represented by the higher frequency).

2.4.2. Interviews

Interviews were also conducted with experts in the region to validate the results of the literature review and identify any missing factors from the analysis. Four interviews were conducted with relevant experts with experience over multiple Asian countries. More information on the countries of expertise of each interviewee can be found in **Error! Reference source not found.**. The participants w ere 'biogas stakeholders': people with close ties or interest in biogas in the region, including selected experts from research institutions and private sector.

The interviews were conducted over Skype or through the submission of a survey. The duration of the interviews was between 30 and 60 minutes. The interviews covered different perspectives related to the field of expertise of each expert that participated.

Since all the interviews were anonymous, they are referenced as "Personal Communication" in this report.

Sector of employment	**Country of expertise**
Private Sector	Malaysia, Thailand and Indonesia.
Research Institution	Thailand
Private Sector	Thailand, Malaysia, Indonesia, Papua New Guinea, The Philippines, Australia, New Zealand, Brazil, Kenya.
Research Institution	Viet Nam and The Philippines

Table 3 - Country and sector of employment of interviewees

3. RESULTS AND DISCUSSION

3.1. Africa

3.1.1. Large-scale biogas value chains

There were ten respondents in total, from government ministries, research institutions, international organisations, private sector, non-governmental organisations and producer associations. They have experience from Ghana, Benin, Nigeria, Sierra Leone, Liberia, Togo, as well as wider experience in other countries in Africa. Factors that were deemed relevant by seven or more of the ten respondents have been identified as the most relevant and are summarized in Figure 3. The detailed results from the survey, with all potentially relevant factors divided by sub-category, can be found in Annex 2.

Strengths

- Reduced number of sanitation-related diseases and sicknesses due to poor waste management
- Reduces the use of other type of fuel (e.g. fossil fuel, wood) and the related environmental impacts
- Improved community sanitation
- Increase crop yield
- Cut down energy costs through self-provision
- Increase soil quality (soil organic matter content) and fight soil depletion
- Effective use of agro-industrial waste: easy and healthy waste disposal

Weaknesses

- Lack of technology know-how in plant management
- High cost for collecting and transporting the feedstock
- Low financial returns
- Limited financial access for initial investment
- High initial investment for plant setting
- Lack of know-how in digestate utilization
- Lack of know-how for plant maintenance
- High maintenance cost
- Lack of use for heat generated
- No regular feedstock supply (i.e. because of seasonality)
- Lack of data on feedstock availability, e.g. types, quantity available, seasons and locations

Opportunities

- Added value for existing business value chains
- Improve the livelihood of local population
- Existence of incentives for production of renewable energy
- Development of new enterprise for collecting and selling digestate to farmers as fertilizer substitute
- Building capacities
- Increased access to energy for local populations
- Socio-economic development
- Development of new enterprise for collecting, transporting and selling agro-industrial waste as feedstock. (Creation of consortium)
- Technicians for optimizing plant performance considering the locally available feedstock
- Skilled employees for checking plant performance
- Development of new training activities: teachers and educational experts

Threats

- Lack and/or inadequacy of means of transport for feedstock and by-product
- Availability and affordability of feedstock in the long term
- High cost of capital
- Low acceptance from local population
- Small scale agriculture is not adapted to large scale technology
- Competition with alternative uses of feedstock (e.g. fuel building material etc.)
- Possibility of accidental emissions of methane in the atmosphere
- Lack of understanding of technology among financial institutions
- Policy and administrative barriers
- Artificially low energy prices due to fossil fuel subsidies (e.g. coal)

Figure 3 – Overview of the most important factors in large-scale biogas business models, listed in order of the number of respondents who deemed them to be important factors.

For the strengths of large-scale biogas plants, it can be seen that the factors deemed most important span social, environmental and economic benefits. For instance, a social benefit that is particularly appreciated about large-scale biogas plants is that they improve sanitation and waste management, thus reducing disease burden. Environmentally, it was deemed important that they reduce the use of other types of fuel, increase soil quality (through application of digestate), reduce the need for chemical fertilisers, and provide a method of waste disposal for agro-industrial wastes and residues. Economically, factors that are most welcomed are that biogas systems can improve crop yields (through application of digestate) and thus improve farm income, and at this scale that they can reduce energy costs through self-provision of heat and power for agro-industrial processes.

There are many social and economic benefits (or opportunities) that exist outside of the biogas system that have been identified as important. One of the most acknowledged opportunities of large-scale biogas operations is that the local population benefit through access to modern energy services (where the plant generates power or heat that can be used in the surrounding area), increased job opportunities (for skilled and unskilled plant employees), and improvements of livelihoods through use of digestate as fertiliser. Furthermore, respondents thought that other influential opportunities were that: large-scale plants can create value for existing business value chains, where the production of energy can be used to reduce costs or increase revenue; they can create previously non-existent value chains for collection and transport of both the inputs (agro-industrial waste or other wastes/residues) and outputs (e.g. digestate) to the system; and where outside investment occurs, this can also bring with it capacity building and training.

The identified weaknesses of large-scale biogas can be divided into three main themes. The first theme is principally economic, and includes the potentially high cost of transporting feedstock, the high initial investment required, the high maintenance costs, and therefore the potentially low financial returns. This is exacerbated by the lack of financial access for the initial investment. These weaknesses could be overcome by ensuring that the plant is located close to sustainable feedstock sources (which reduces transport and feedstock costs) and that financial incentives are sought for the initial investment. The second theme is on lack of knowledge on feedstock supply, technology, plant maintenance and digestate use. The knowledge on feedstock availability could be overcome by thorough initial feasibility assessments, and technological know-how on plant maintenance and digestate use could be improved through capacity building and training.

The threats to the system also contain trends, although the external barriers to success identified in this study appear to be diverse compared with the other categories of the SWOT. One theme is that of feedstock; this includes the sustainability of feedstock in the long-term, competition for alternative uses of feedstock, and the difficulty with transporting feedstock (due to lack of adequate infrastructure). Policy and administrative barriers were also deemed highly relevant, one such policy barrier being fossil fuel subsidies that artificially lower energy prices and make biogas uncompetitive. Economic barriers were also identified, which include the high cost of capital and the lack of knowledge of the technology among financial institutions which could finance this high initial investment. Another threat is the social context; the African region is predominated by small-scale agriculture (Blein *et al*. 2013), which is not adapted to this large-scale technology. Furthermore, there can be low social acceptance from local populations. A final identified threat is the possibility of accidental methane emissions from the system if not correctly maintained or if the biogas cannot be store, and the use of flaring for surplus biogas (Flesch *et al*. 2011). Leakages of methane from the system could increase the lifecycle greenhouse gas emissions of the system and reduce its competitiveness with fossil fuel alternatives in terms of climate change mitigation potential.

3.1.2. Small-scale biogas value chains

The focus group during Session 2 of the ECOWAS/GBEP Bioenergy Week (Accra, Ghana, 22-24 June 2017) produced a list of factors deemed relevant in the African context for the success of biogas at the small scale (*Figure 4*).

Strengths

- Availability of feedstock (waste biomass, residues)
- Improve sanitation/health
- Reduce GHG emissions
- Save family time (e.g. in wood collection)
- Job creation
- Technology availability
- By-product as fertilizer
- Manpower availability
- Ease of transfer of technology know-how
- Poverty reduction
- Livelihood improvement

Weaknesses

- Availability of reliable feedstock
- Lack of technical knowledge and skills for operation and maintenance
- Lack of skills and knowledge in the construction of the biogas system (technical know-how)
- Cultural (un)acceptability
- High cost of construction
- Lack of financial resources
- Constant monitoring and evaluation

Opportunities

- The by-product can be used for commercial purposes
- The methane gas obtained can be used for cooking, heating and lighting for households
- There is availability of pre-finance
- No cost for dislodging
- Small space requirement
- Access to modern, clean cooking energy
- Reduce expenses on electricity bills
- Simple technology, thus easy to adopt and manage
- Poverty reduction
- Job creation
- Save family time (e.g. in wood collection)
- Reduce indoor air pollution
- Climate change mitigation
- Reduce deforestation
- By-products (digestate) increase agricultural production

Threats

- Comparative cost of other energy sources (e.g. LPG)
- Accessibility compared with other energy sources
- Social acceptability (due to culture/beliefs)
- Water requirements
- Lack of knowledge
- Availability of reliable feedstock
- Lack of skills/technological know-how (e.g. management of H_2S)
- High cost (initial capital requirements)
- Lack of knowledge on return on investment by investors and providers of capital
- Lack of bioenergy services
- Trade barriers on imports of biodigesters

Figure 4 – Factors of importance for small-scale biogas in the African context, as identified during the focus group at the ECOWAS/GBEP Bioenergy Week (Accra, Ghana, 22-24 June 2017)

Given that some of these factors were very similar or overlapping, the list was refined for further analysis and numbers were assigned to each factor (e.g. S1, S2, etc.) to facilitate identification during the subsequent online survey. The refined list of relevant factors was used as part of the ranking survey for AHP analysis. This analysis produced a ranking of the most important factors for each category of the SWOT (*Table 4*). The detailed methods of the AHP analysis for the factors of each category of the SWOT analysis, including priorities and consistency scores, can be seen in Annex 3.

Rank	Strengths	Weaknesses	Opportunities	Threats
1	S3: Access to modern, clean cooking energy.	W3: High initial capital requirements (high cost of construction)	O1: Commercial by-products	T5: Lack of knowledge on return on investment by investors and providers of capital (leading to lack of financial resources)
2	S2: Improve sanitation/health (through better waste management and reduced indoor air pollution).	W6: Cultural unacceptability	O4: Technology transfer and availability	T4: Uncertainty of feedstock availability in the long term
3	S1: Availability of feedstock and improved waste disposal.	W2: Lack of skills and knowledge in the construction of the biogas system (technical know-how)	O2: Availability of pre-finance	T1: Comparative cost of other energy sources (e.g. LPG)
4	S5: By-products (digestate) increase agricultural yields through use as fertilizer, increasing income.	W4: Lack of ability to identify financial resources (loans)	O5: Incentives for climate change mitigation	T3: Low water availability
5	S6: Ease of transfer of technology know-how	W1: Lack of technical knowledge and skills for operation and maintenance	O6: Incentives for forest stewardship	T2: Lack of knowledge and social non-acceptance (due to culture/beliefs)
6	S4: Save family time (e.g. in wood collection).	W5: Requirement for constant monitoring and evaluation	O3: No cost for dislodging	T6: Trade barriers on imports of biodigesters

Table 4 – Ranking of the factors for each category of the SWOT, based on the AHP analysis

The main strength of small-scale biogas, as identified by the study, is the ability to provide access to modern, clean cooking energy to households. Where grid access to power is unavailable (as is the case in much of the African continent, especially in rural areas), small-scale biogas plants provide an alternative to traditional biomass use for cooking and lighting, with the associated social, environmental and economic benefits that this entails. The second highest-ranked factor was the ability to use biogas production for waste management, thus improving sanitation and health. Where small-scale biogas plants use human or animal waste as the primary feedstock, this can be readily available and improve waste disposal.

The highest-ranked external opportunity was the ability of small-scale biogas plants to produce commercial by-products (i.e. digestate) that can be sold or used for own crop production, as fertiliser. As observed by Seadi *et al.* (2012), although this organic fertiliser can increase crop yields, its proper management and application is key to ensuring that these economic benefits are conveyed and to prevent environmental pollution. The benefits of technology transfer and the availability of the biogas technology at small-scale were also ranked highly as opportunities of the system. Both of these strengths require effective national policies that facilitate markets for biogas technologies and by-products, and reduce barriers to technology uptake.

In terms of internal weaknesses to the system, respondents ranked the high initial capital requirements of biogas systems to be the greatest challenge. To overcome this barrier, pre-financing is required. Mwirigi *et al.* (2014) note that external funds need to be mobilised in Sub-Saharan African in order to overcome initial construction costs of biogas plants, and that Clean Development Mechanisms and joint procurement through disseminator associations could present options for this. Another weakness ranked highly by respondents was the cultural unacceptability of biogas produced from human or animal waste, due to lack of information about the cleanliness of the system and associated odours. In this case, education campaigns are required in order to improve knowledge on the benefits of biogas and remove stigma surrounding its use at household level.

The highest-ranked external threat is the lack of knowledge on return on investment which leads to lack of financial resources for biogas plant construction. This is strongly linked with the highest-ranked weakness (above) of the high initial capital requirements. Together these two barriers limit the uptake of the technology in Africa compared with the diffusion of the technology in Asia, where initial costs are much lower (Remf *et al*., 2017). Financial schemes to allow households to afford biogas systems is of utmost importance. Another highly-ranked external threat is the uncertainty of feedstock supply and its sustainability in the long-term. As with larger-scale facilities, feasibility studies of the biogas plant can help to mitigate this threat.

3.2. Latin America and the Caribbean

3.2.1. Biogas at household level

Figure 5 shows the most relevant SWOT factors for biogas at household level, as identified by the interviewees. Only factors that were identified by more than one interviewee are included.

Strengths

- Environmental co-benefits (that are not seen with other renewable energies)
- Production of digestate that can be used as fertiliser in vegetable gardens (reduced use of chemical fertiliser and better productivity)
- Energy access for cooking
- Time savings when replacing fuelwood for cooking
- Energy independence
- Valorisation of the organic waste of the family
- Reduction in GHG emissions

Weaknesses

- High costs of installation (need to also buy the new stove)
- Requires time and effort to operate and maintain the digester

Opportunities

- Availability of local materials for construction
- Improved health - replacement of fuelwood for cooking reduces respiratory diseases
- Availability of feedstock

Threats

- Competition with other energy sources that are easily accessible and cheap (e.g. LPG, solar and woodfuel)
- Lack of capacity on *how* to produce biogas (due to lack of capacity building initiatives)
- Biogas seen as ‘last resort’ after all other energy options due to the complicated operation maintenance of AD compared with other energy sources (e.g. LPG)
- Lack of understanding of the benefits of biogas
- Climatic conditions (including temperature, access to water) can influence productivity
- Programmes that give ADs for free are not sustainable as the farmer/household does not see the value and will not maintain/repair it properly
- Lack of training in formal educational institutes
- Lack of national businesses in value chain that provide biogas products and services (increased costs due to need for importation)
- Areas where ADs could be inviting are the poorest areas that cannot afford them

Figure 5 – Most relevant SWOT factors for biogas at household level as identified by interviewees

In LAC, at the household level, the factors that affect success of biogas value chains appear to be broadly similar to those identified at the global scale. Similarly to other studies in LAC, the interviewees identified the GHG mitigation potential of biogas systems as a key strength of the technology, as well as the time savings in cooking and improved health when replacing fuelwood, use of digestate in family farming, and access to modern energy services. However, it was interesting to note that some of the stereotypical strengths of biogas technology are not considered positive in all countries, showing the need to take local context into consideration. For example, one interviewee from Colombia mentioned the negative image of biogas for rural women in the country because it deducts from their social time spent whilst collecting fuelwood for cooking. The interviewees emphasised the environmental co-benefits of the technology as a key strength, and identified the availability of feedstock and local materials for construction of the ADs as important opportunities.

In terms of barriers to the uptake of biogas, the weaknesses and threats identified were similar to those found by other authors (e.g. Garfí *et al.*, 2016; Garwood, 2010), such as high costs of installation (because new cooking facilities are also required as well as the investment in the AD itself), lack of capacity with need of capacity building initiatives, and competition with inexpensive alternative fuels. On top of this, the interviewees identified the extra time and effort required to operate and maintain the AD as one of the key barriers to uptake of biogas technology. Indeed, one interviewee mentioned that, at this scale, biogas is a last resort fuel that is installed only in isolated areas where LPG cannot be transported and there is limited availability of wood fuel. Another key threat identified was the lack of knowledge of the population both on how to operate an AD but also on its benefits for the household.

To enhance the positive factors of biogas at household level and overcome some of the barriers identified, it is important that the local population is made aware of the benefits of biogas and is trained on how to properly operate and maintain the AD systems. This could lead to greater uptake by the population (who would be more aware of the benefits to them from the use of the technology), the growth of a national biogas sector to construct and maintain ADs, and a reduction in the number of abandoned ADs through misuse. Therefore, the household biogas sector could be promoted through capacity building initiatives, both in terms of professional training for construction and maintenance, as well as in terms of awareness raising and training for users.

In the past, some initiatives have sought to eliminate the initial investment cost of the AD system by providing the technology for free. However, many of the interviewees mentioned that this is ineffective in promoting biogas as it does not create ownership of the system and reduces its perceived value to users, which means that when the system malfunctions or fails, they are less willing to invest in fixing it. Therefore, many interviewees instead stressed the importance of awareness raising in the benefits of biogas, and at most only partial subsidies for the initial investment.

3.2.2. Biogas for productive and industrial use

From the full list of factors on biogas at productive and industrial use scale, the six most relevant factors were selected for use in the survey; Figure 6 provides an overview of this list.

Strengths

- Treatment/management of wastes and/or residues
- Reduction in GHG emissions
- Sale/use of digestate as organic fertiliser
- Reduction in contamination of waterbodies
- Reduction in contamination of soil
- Added value to waste streams

Weaknesses

- High initial investment cost
- Costly transportation of feedstock and diluted digestate
- Complicated technology that requires time and effort for maintenance
- Technology not adapted to the realities of the country
- High cost of advanced technologies for upgrading biogas
- Costly and inefficient technology for electricity generation

Opportunities

- Incentivising biogas through tax exemptions
- Creation of skilled employment with improved wages
- Fostering investment and providing income security through Power Purchase Agreements (PPAs)
- Alignment with NAMAs and UNFCCC commitments
- Greater access to international markets due to meeting environmental requirements and selling 'green' product
- Incentivising biogas through environmental regulations on waste treatment

Threats

- Incompatibility of animal husbandry
- Poor functioning of carbon credit markets (i.e. high transaction costs and low carbon value)
- Financing problems (i.e. high collateral/guarantees and lack of funding)
- No government incentives specifically for biogas
- Low cost of electricity means biogas is not competitive
- Subsidies for alternative fuels (e.g. LPG, heavy oil) means biogas is not competitive

Figure 6 – Most 'relevant' factors of the SWOT analysis on biogas at productive and industrial use scale

At the productive and industrial use scale, the benefits of biogas emphasised by the interviewees were the environmental co-benefits of the technology in terms of GHG emissions mitigation, and reduction of soil and water contamination from proper treatment of wastes and residues. The main opportunities for biogas value chains at this scale therefore lie in utilising the available incentives for ‘environmentally friendly’ technologies, such as PPAs for renewable energies, national/international funding for GHG mitigation projects, tax exemptions, access to international markets for ‘green’ certified products, etc.

Weaknesses of biogas at this scale were centred on the costs of the technology, both in terms of initial investment cost, as well as high running costs of transporting feedstock/digestate, and upgrading biogas and producing electricity. However, it seems that these concerns expressed by the interviewees are linked to the threats to biogas that were identified, such as lack of dedicated incentives for biogas, low costs of electricity that make electricity generation from biogas uncompetitive, lack of functioning credit markets, subsidies that reduce the cost of fossil fuels, and the difficulties of accessing financing. Another key threat identified for biogas produced from livestock waste was the extensive nature of animal husbandry practices that renders the management of the waste for biogas complicated.

The best ways to promote biogas in LAC follow from the threats identified by the interviewees (lack of dedicated incentives for biogas, low costs of electricity that make electricity generation from biogas uncompetitive, the lack of functioning credit markets, subsidies that reduce the cost of fossil fuels, and the difficulties of accessing financing for large-scale biogas projects). There are a number of instruments that could be used to overcome these barriers.

Incentives are one such instrument. Dedicated incentives for biogas, such as increased tax exemptions, special prices for the buying of biogas or electricity, and subsidies for biogas projects, could help to improve the return from biogas ventures. Indeed, the RenovAr programme in Argentina has been successful in providing a guaranteed price for selected biogas projects in order to create long term stability for investments.

Regulations on waste treatment could also represent an instrument to promote the uptake of biogas. This is the case, for example, in Guatemala, where the valorisation of the negative environmental impacts of waste, and the consequent regulations on how waste can be disposed, have meant that biogas has become an economically viable alternative to waste disposal. In this case, the production of energy from biogas is a bonus.

Finally, given that biogas at this scale is a costly investment, it is extremely important that the correct financing instruments are in place. Interviewees expressed concern that finance institutions are currently unaware of the benefits of large-scale biogas operations, which leads to low financing opportunities and high collateral requirements for loans. This could be overcome both through increasing awareness in financing institutions but also through initiatives by international funds (e.g. IADB, World Bank) that provide guarantee mechanisms for collateral. This collateral fund could then be used for plants that have viable projects and contracts for the sale of the biogas or electricity, but lack the money to guarantee the financing. This again is already the case in Argentina, where IBRD provides collateral for projects under the RenovAr programme. The next section provides a case study in Argentina.

3.3. Case Study - Argentina

3.3.1. Background

Argentina is described as "one of the most promising markets for renewables in Latin America" (Yaneva *et al*., 2018, p.10). For power generation, Law 27 191 (2015) on the 'National Development Regime for the use of Renewable Energy Sources', sets a target for 20 percent to come from renewable sources by 2025 (increasing from just 1.8 percent in 2016). In order to obtain this ambitious target, Argentina has a number of programmes aimed to stimulate investment in renewable energy.

'Plan RenovAr' is the flagship programme that was initiated in 2016 in order to give predictability for investments in renewable energy (MINEM, 2016). It provides fiscal incentives to renewable power generation projects through a number of mechanisms, including PPAs that provide a guaranteed price per MW. There have so far been two rounds of contracts awarded through RenovAr: in Round One, 9 MW capacity was awarded for biogas (with average price paid of 154 USD/MWh); and in Round Two, 35 MW capacity was awarded to biogas projects (with average price of 156.8 USD/MWh). In order to facilitate the initial capital investment required for such projects, the World Bank (through IBRD) offers guarantees for projects that have been awarded tenders (Yaneva *et al*., 2018, p.28).

There are also other programmes that promote the use of renewables for power generation, such as the 'Renewable Source Electric Power Term Market Regime (MATER)', which facilitates contracts between large private firms, and the Fund for distributed generation – *Fondo Para la Generación Distribuida de Energías Renovables (Fodis)* – which provides "incentives, including tax certificates, accelerated amortization on assets, VAT rebate as well as access to finance with preferential rates" (Yaneva *et al.*, 2018, p.33). For rural electrification, there is also the Project for Renewable Energy in Rural Markets (PERMER), which started in 1999 to provide off-grid rural electrification, mainly with solar PV.

As well as the promotion of renewable energy in general, Argentina has projects to specifically promote bioenergy. The PROBIOMASA project – *Proyecto para la promoción de la energía derivada de biomasa* – is a project for the promotion of energy derived from biomass. The project notes that "it is important to highlight that the potential for energy use of biomass in Argentina is much greater than its current use and for its future development it is necessary to carry out an important task of disseminating the existing possibilities and technologies for its use" (Secretaría de Energía, n.d.). Therefore, the project aims to increase the amount of energy produced from biomass at the national, provincial and local level. For biogas, they have a number of technical papers, such as the 'Theoretical-practical Guide on Biogas and Biodigestors' (FAO, 2019), as well as capacity building initiatives, such as scholarships for biogas courses.

Although renewable energy initiatives are widespread, they tend to mostly promote solar and wind power, and there are limited programmes specifically aimed at biogas in the country. Indeed, out of 147 projects awarded during the existing rounds of RenovAr, only 26 of these were for biogas; these projects amounted to 44 MW of the total combined capacity of 4,466 MW awarded for all projects.

One such dedicated policy is the 2018 Resolution on the use of Biofertiliser. This resolution seeks to promote the economic valuation of the digestate produced from anaerobic digestion through the establishment of minimum criteria for its sustainability (Secretary of Environment and Sustainable Development of Argentina, 2019). It is hoped that this legislation will allow for the future commercialisation of the digestate produced from anaerobic digestion (Energía Estratégica, 2018).

Although dedicated biogas policies are scant in the country, public perception of biogas technology in Argentina is positive, with many people believing that it has a high potential for development in the country (Hilbert, 2016, p.24). Furthermore, research has shown that biogas at productive and industrial scale, especially for the treatment of sewage sludge and OFMSW with anaerobic digestion "has great potential for reducing the environmental impact and increasing the economic and energetic value of the substances via the production of biomethane, electricity and, potentially, fertiliser" (Morero *et al*., 2016, p.195).

3.3.2. The most important factors for the success of productive and industrial biogas value chains in Argentina

The pairwise comparisons generated from the survey for the factors in each SWOT category were used to produce a ranking of the importance of the factors for the national situation in Argentina using an AHP analysis. The decision matrices, principle Eigen values and consistency ratios for each SWOT category can be found in Annex 6.

The final SWOT for biogas at productive and industrial use scale in Argentina, including the rankings of the most important factors can be found in Table 5.

Rank	Strengths	Weaknesses	Opportunities	Threats
1	Reduction in contamination of waterbodies	High initial investment cost	Fostering investment and providing income security through PPAs	Subsidies for alternative fuels (e.g. LPG, heavy oil) means biogas is not competitive
2	Treatment/management of wastes and/or residues	Costly transportation of feedstock and diluted digestate	Incentivising biogas through environmental regulations on waste treatment	Financing problems (i.e. high collateral/guarantees and lack of funding)
3	Reduction in contamination of soil	High cost of advanced technologies for upgrading biogas	Creation of skilled employment with improved wages	No government incentives specifically for biogas
4	Added value to waste streams	Costly and inefficient technology for electricity generation	Incentivising biogas through tax exemptions	Low cost of electricity means biogas is not competitive
5	Sale/use of digestate as organic fertiliser	Complicated technology that requires time and effort for maintenance	Alignment with NAMAs and UNFCCC commitments	Poor functioning of carbon credit markets (i.e. high transaction costs and low carbon value)
6	Reduction in GHG emissions	Technology not adapted to the realities of the country	Greater access to international markets due to meeting environmental requirements and selling 'green' product	Incompatibility of animal husbandry

Table 5 – National SWOT Analysis of biogas at productive and industrial use scale in Argentina, with rankings

The most highly ranked strength was the ‘reduction in contamination of waterbodies’ through the use of anaerobic digestion to treat waste streams that would otherwise pass untreated into the environment. Interestingly, both the reduction of contamination of water and soil were ranked higher than the GHG mitigation potential of the biogas technology. This could potentially be because the pollution of the environment from untreated waste in Argentina is a more proximate problem than the effects of climate change. In countries where the impacts of climate change are more heavily felt (for example in tropical regions that are more effected by the increased incidence of tropical storms), the GHG mitigation potential of biogas may be ranked higher. This would be an interesting comparison for future research.

The highest ranked weakness of biogas systems was the high initial investment cost. This could be linked to the fact that financing problems (i.e. high collateral requirements and lack of funding) were ranked as the second most important threat, meaning that it is difficult to find funding to overcome this investment cost.

The most highly ranked opportunity for biogas value chains was 'fostering investment and providing income security through PPAs'. In Argentina, the RenovAr programme (described in detail in Section 3.2.4) provides PPAs for renewable energy projects, including biogas, and is now going into its third round of tenders. This government policy is obviously viewed as an important opportunity by stakeholders in Argentina. The second most highly ranked opportunity was 'incentivising biogas through environmental regulations on waste treatment'.

3.3.3. Policies that have been important for promoting productive and industrial biogas in Argentina and what is still needed to encourage its uptake

As well as the pairwise comparisons, the respondents from both surveys provided some information on the policies that are already present in Argentina to promote the production and use of biogas at productive and industrial use scale. The full list of all responses (translated into English where necessary) can be found in Annex 5.

For the policies already existing in Argentina, the following policies were highlighted by respondents:

- RENOVAR
- PROBIOMASA
- MATER
- PROBIOGÁS
- PERMER
- Resolution on the use of biofertiliser

Some of these are national programmes (e.g. RENOVAR, PROBIOMASA, MATER and the resolution on the use of biofertiliser – detailed in Section 3.3.1) that have been instrumental for promoting productive and industrial biogas in Argentina. Furthermore, specific projects were identified, such as the Probiogas project jointly developed by UNDP and the Ministry of Environment and Sustainable Development with funding from GEF. The objective of the project is to demonstrate that the plants and the systems of generation and use of biogas that generate organic urban solid waste, such as landfills and ADs, are sustainable from the technical, environmental, institutional and economic-financial point of view, so that they can be incorporated into integrated urban solid waste management (MSW) projects that are implemented and can be adequately operated by the municipalities (Government of Argentina, n.d.).

As well as the policies that are already available in Argentina to promote biogas, the respondents were also asked to highlight policies that could further promote its uptake in the country. The full list of all responses (translated into English where necessary) can be found in Annex 5.

Box 1 gives an overview of the responses that were received.

Box 1 – Policies suggested by survey respondents to further promote biogas at productive and industrial use scale

Summary of the policies suggested to promote the uptake of biogas at productive and industrial scale

• Rules/standards for:
  ○ the use of biomethane injection in existing natural gas network through distributed energy law;
  ○ the design of biogas plants;
  ○ the use of RNG (Renewable Natural Gas - compressed biogas) in vehicles and incorporation of a mixing quota for compressed gas;
  ○ the commercialization of organic fertilizer; and
  ○ residue treatment by agriculture and agro-industry (and appropriate enforcement).
• Economic incentives:
  ○ Tax benefits (e.g. for imports of equipment and components)
  ○ Feed-in-tariffs for electric power
  ○ Economic recognition of positive externalities through policies that promote the circular economy
  ○ Municipal assistance policy for use of urban waste and local agroindustry
• Clear long-term rules – e.g. stable contracts for a guaranteed minimum demand
• Greater financing, i.e. more government resources
• Update of the National Biofuels Law
• Wastewater treatment using anaerobic digestion by the State
• Development of entire national value chain, including suppliers of equipment
• Carbon tax
• Include anaerobic digestion as one of the key technologies for the climate change agenda and compliance with the commitments of the Paris agreement.

Of these further actions that could be carried out to encourage the uptake of biogas in the country, in particular, respondents saw an increased need for rules and standards on the use of upgraded biogas both in the national grid and in the vehicle fleet, the use of digestate as fertiliser, and the design of the biogas plants themselves. Furthermore, they also recognised that regulation and appropriate enforcement of residue/waste treatment by agriculture and agro-industry would also promote the use of biogas.

Survey participants also identified a need to economically recognise the positive externalities of biogas that accrue to society as a whole, such as reductions in GHG emissions and deforestation. Previous literature has also noted the importance of valuing these positive externalities, and frameworks have been developed to this end (e.g. Srinivasan, 2008). Taking these externalities into account could be done through further economic incentives for biogas in the country, such as tax benefits on the imports of equipment and components, more extensive feed-in-tariffs for electric power and a municipal assistance policy for the use of urban waste and local agroindustry. A fully functioning carbon tax scheme would also help in the full evaluation of environmental externalities and could help to improve the competitiveness of biogas.

In general, survey participants thought that more emphasis on biogas was required by the government in order to promote the technology. This includes: updating the National Biofuels Law; increasing government resources; promoting biogas as a key technology for the national commitments under the Paris Agreement (NDCs); and introducing State-led projects using biogas to treat OFMSW. This latter suggestion is in line with previous research that highlights the benefits of the use of anaerobic digestion for the treatment of such wastes (e.g. Morero *et al*., 2016). A good summary of what is needed from the public sector was provided by one respondent, who said that “The bioenergy policy requires a long-term commitment, adequate financing tools for the sector and intensive training”.

Finally, the need to create a national value chain for the biogas technology was highlighted. This would ensure that the technology was adapted to the national context, reduce costs in terms of equipment, and ensure services for operation and maintenance.

3.4. Asia

3.4.1. Household-decentralized level

Figure 7 shows the most relevant SWOT factors identified in this level. The factors were based both on the literature review as well as on the interviews with experts.

Strengths

- By-product can be used as natural fertilizer
- Reduce GHG emissions
- Substitution of kerosene, firewood, LPG and charcoal
- Availability of feedstocks
- Public health improvement
- Reduction of deforestation
- Thermal energy generated as a consequence of electricity production
- Valorization of the organic waste for families

Weaknesses

- High cost
- Lack of maintenance of digesters
- Lack of planning and feasibility studies
- Low efficiency in the use of biogas
- Lack of heaters for winter conditions
- Structure, principles and performance of the digester vary from country to country

Opportunities

- International support
- High cost of traditional fossil fuels
- Potential feedstocks that are currently not used
- Availability of prefabricated digesters
- Carbon credit trading
- Government subsidies or tax excemptions (e.g. China and India)
- Woman empowerment

Threats

- Lack of financial support
- Less expensive energy sources
- Low acceptance due to cultural beliefs
- Lack of Know-How knowlege regarding operation and maintenance
- Natural disasters
- Rapid development of urban areas, and the consequent migration of people to urban cities

Figure 7 – Most 'relevant' factors of the SWOT analysis on biogas in the household-decentralized level.

In Asia, at household-decentralized level, it has been observed, according to the literature review, that the most relevant (and most frequently mentioned) strengths were: the reduction of GHG emissions, availability of feedstocks, the substitution of the use of kerosene, firewood and charcoal, and last but not least, the use of the digester's by-product as fertilizer, substituting the use of chemicals. During the interviews, experts confirmed that the factors found in the literature review were accurate, and also recalled the importance of the substitution of LPG by biogas.

According to the Asean Post, the reduction potential of CO_2 could be as significant as 1 Billion Tonnes per year in South East Asia (considering the use of improved cook stoves in 60 million households) (Ggnanasagaran, 2018). In addition, a study conducted in China and Sri Lanka illustrated that installation of biogas systems decreased household usage of coal and wood by 68 percent and 74 percent respectively in China, whilst in Sri Lanka, the introduction of biogas for cooking has resulted in an 84 percent fall in firewood consumption (de Alwis, 2002). This represents a strength not only in terms of saving time and money for cooking, but also in terms of reduction of household air pollution (IRENA, 2017).

The main opportunities identified at this scale are: the support of international and governmental institutions; the increased use of energy in Asia, which could potentially increase the production of biogas; and the high cost of traditional fuel, which could be replaced with more sustainable and environmentally friendly sources such as biogas. Regarding international support, it is important to mention the contribution of SNV (Netherland Development Organization), which focus mainly on low-income households and businesses to support them in accessing biogas technology.

During the interviews, experts agreed on the abovementioned opportunities, but some of them stated that they have also noticed important opportunities in terms of women's empowerment in their countries of expertise. Given that biogas replaces traditional woodfuel, it can reduce the time needed for collecting biomass, thus freeing up time for other productive activities. This is the case for both women and children, who have extra time for other activities, including education.

Weaknesses at this scale were mainly centred on costs, especially in terms of initial investment. A study in this field shows that in seven Asian countries, farmers classified as medium or high income comprised 95 percent of those adopting biogas technology (Ni & Nyns, 1996). Regardless of the international and governmental support and the availability of pre-manufactured low-cost units, many families and small farms from low-income countries are still struggling with high cost and with relative low efficiency in the use of biogas (Cheng *et al.*, 2013). In rural Thailand, high cost and lack of financial support continue to be one of the biggest barriers for the development of this technology (Personal Communication with expert, 2020). In Viet Nam, several examples of difficulties in management procedures have been identified, including the injection of extra water into the ADs, which reduces the efficiency of the digestion process and leads to an excessively diluted digestate; consequently, this is discharged directly into the environment instead of being used as fertilizer owing to problems of management and transport of large quantities of liquid. In addition, it was found that mismanagement of ADs can lead to emissions of methane into environment, either because of unrepaired cracks or the intentional release of biogas when production exceeds demand (FAO, 2018). This was confirmed during the interviews, as the most relevant weaknesses identified were lack of management knowledge and methodologies, and inefficient use of feedstocks due to lack of knowledge.

Besides weaknesses, threats were also identified. Lack of financial support resulted in the biggest threat at this scale, as most positive aspects mentioned above would not be possible without proper financing. While biogas systems greatly reduce the cost of cooking over their lifetimes, their high upfront costs restrict uptake. For this reason, only an estimated 20-30 percent of households in South Asia and South East Asia may be able to afford domestic biogas systems (IRENA, 2017).

Another important threat identified was lack of knowledge or technical support in some areas in Asia. Lack of construction and maintenance skills is a key reason why not all biogas plants in some Asian countries (e.g. India) are in use (IRENA, 2017).

Finally, countries located in earthquake, flooding and tsunami areas might have a high risk of damage of the equipment if a natural catastrophe takes place (Cheng *et al.*, 2013).

Most of the interviewees agreed that the most relevant threats were the competitive price of LPG, subsidies for fossil fuels and lack of sufficient subsidies for biogas. In addition, lack of education may also represent a barrier considering the skills needed to operate an AD.

3.4.2. Centralized level

Figure 8 shows the most relevant SWOT factors at the centralized level for biogas use in Asia. As at household level, the factors were identified both through a literature review and interviews with experts.

Strengths

- Sale/ Use of by-products as fertilizers
- Availability of feedstocks
- Reduction in GHG emissions
- Local health improvement
- Added value to waste streams
- Money and time savings by the use of improved cook stoves (running with biogas)
- Odour reduction

Weaknesses

- High capital investment needed
- High maintenance cost
- Lack of planning and feasibility studies
- Structure, principles and performance of digester vary from country to country
- High operation costs under winter conditions

Opportunities

- Government and international support
- Increase in the use of energy in Asia and high cost of traditional fuel sources
- Improve the livelihood of the local population
- Use of wasted residues
- Government subsidies and tax exemptions
- Woman empowerment

Threats

- Lack of maintenance due to lack of qualified technicians
- Subsidies for fossil fuels, making biogas less competitive
- Cost increase during winter
- Low acceptance due to cultural beliefs
- Lack of regulation/policies specific for biogas
- Regulation of the use of by-products
- High costs of feedstocks caused by the increase on prices by the industries which intend to increase profit from their by-products.
- Natural Disasters (Earthquakes, Tsunamis, etc.)

Figure 8 – Most 'relevant' factors of the SWOT analysis on biogas at the centralized level.

In the analysis, strengths emphasize the availability of feedstocks, the use of by-products as organic fertilizers and the reduction of GHG emissions, especially by substituting use of fossil fuels (IRENA, 2017).

During the interviews, experts mentioned that the main strengths were the ability to handle large supply flows, the use of the digestate as organic fertilizer, and the potential reduction of GHG emissions and the contribution for improving odour problems.

The main opportunities identified at this scale lie in government and international support, where it is important to recall China's government subsidies programme that plays an important role in biogas uptake in China. Large scale projects in China receive subsidies of 25-45 percent from national government and 5-25 percent from local government (IRENA, 2017). Experts agreed that existing subsidies in some countries may be an opportunity to invest at this scale, while Feed-in-tariffs may also encourage the use of biogas.

At centralized scale, it has been observed that Asia is one of the most promising markets in terms of biogas production due to the influence of fast-growing economies like India and China that hold a huge potential in the area of biogas development. Indeed, another important opportunity, identified both in the literature and interviews, is the development and population growth of Asia that would imply an increase of energy demand and the use of new energy sources, creating a potential market for the production and use of biogas. As an illustrative example, India has been projected to be the most populous country in the world by the year 2030, and its energy demand will also have a significant growth (Mohan *et al.,* 2006).

The investment in this technology may also represent an opportunity for job creation and women's empowerment.

Weaknesses were also identified at this scale, and the most relevant was the need of high capital investments that represents a barrier for organizations or investors when considering the construction of a biogas plants.

High cost and poor quality of maintenance was also considered a weakness and seems to be linked with the lack of qualified construction and maintenance technicians (identified as a threat), since the low offer of qualified technical service may imply either a high cost or technicians without proper technical education for a lower cost. This threat may also be linked to the variation of structure quality and performance, since qualification of experts also varies between developed and developing countries in Asia.

In addition to the high costs at this scale, the wide range of alternatives and approaches when choosing the system may lead to misinterpretation which make it difficult for the client to evaluate and make a decision (Personal Communication, February 19, 2020).

Another threat mentioned by some experts was that the use of digestate may be regulated in some countries and therefore make its use difficult. Furthermore, there is the problem of the valorisation of waste streams through the establishment of markets for waste products, which increases the costs of the feedstock for anaerobic digestion and compromises the competitiveness of biogas production.

Lack of qualifications may have serious consequences in the operation of biogas plants. In fact, it has already been observed in a case in India, where a significant number of digesters are not operating due to lack of qualified technicians for their maintenance (IRENA, 2017).

Lastly, some zones in Asia with high seismic activities may not be appropriate for the installation and operation of a biogas plant, since natural disasters may easily damage the digesters (Shikun Cheng, 2013).

3.5. Case Study – Japan

3.5.1. Background

This case study is adapted from Asai *et al*. (2019). In this study, Shihoro Hokkaido region in Japan was chosen as a case (**Error! Reference source not found.**). In Shihoro, arable cropping and large-scale f arming comprise 60 percent of total land area. Potato, wheat, sugar beet, and read bean are the main crops, whilst the large-scale farming is dairy cattle, with an average of 216 cows per farm. For dairy farming, free-stall cattle barn systems with the latest technologies have been introduced, along with expanded farm size and increasing number of cattle. This increase in the amount of livestock manure causes problems of water and air pollution, as well as increasing labour input for composting manure. As a result, manure is underutilized as a biomass resource. For these reasons, in Shihoro, the first biogas plant was launched in 2003, and currently a total of 15 plants are in operation.

Electric power generated by biogas plants can be sold through feed-in-tariff (FIT) schemes. Therefore, most plants sell their power to the local power company and the power is used locally. Co-generated heat is used for heating systems, milking systems and processing manure in farms. In terms of digestate, it is used for organic fertilizer in their own grassland and arable land in nearby farmers.

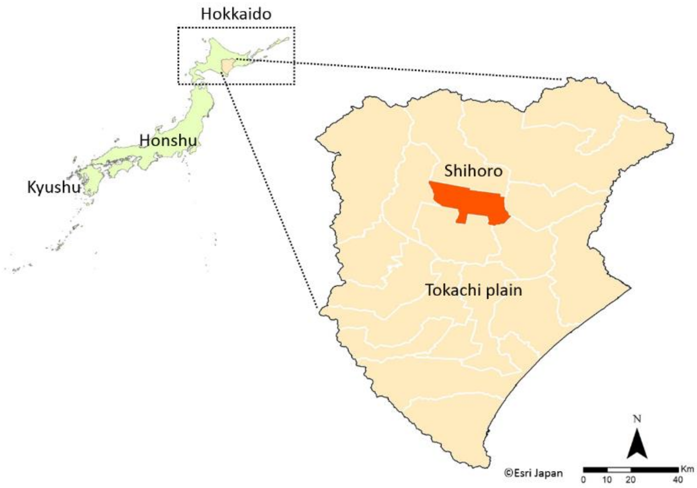

Figure 9 – The location of Shihoro in Hokkaido, Japan

3.5.2. Methodology

This study uses SWOT analysis. Data for the analysis were provided by a survey conducted in Asai *et al*. (2019). This interview survey was conducted in winter in 2016-2017, and in total 22 respondents in different stakeholder groups shared their views on biogas systems. The stakeholders included 7 dairy farmers (of which 3 have installed biogas plants), 7 arable farmers (of which 4 apply digestate), 2 employees of agricultural cooperatives, 2 biogas engineers, 2 municipal government officers and 2 researchers. From the survey, we obtained data on SWOT variables, and in total 162 variables were collected. Using these data, we classified the variables into strengths, weaknesses, opportunities and threats. In addition, each variable was reclassified into three stakeholder types: dairy farmer, arable farmer and non-farmer.

3.5.3. Results

Strengths

Among variables in this category, the major strength is income from selling electric power (Table 6**Error! Reference source not found.**). This is not only for dairy farmers but also for arable farmers and non-farmers; nearly half of them recognized income from power as a strength.

Reduction of odour during application of compost is the largest strength of digestate application. Also, half of respondents recognized the benefit from the reduced cost for fertilizer purchase through digestate application.

With regard to the strengths for local communities, all three types of stakeholders expect environmental benefits: reduced greenhouse gases, water pollution and odours. Whereas non-farmers also expect improved energy security, dairy and arable farmers do not well recognize this kind of strength for local communities.

Strengths

Category	Variables	Citation frequency (1)	Dairy farmers	Arable farmers (2)	Non-farmers (2)	P2 (3)
Digestate	Reduced odor from spreading digestate compared with composts	14	4 (57.1)	4 (57.1)	6 (75.0)	NS
Local community	Environmental benefits	13	5 (71.4)	4 (57.1)	4 (50.0)	NS
Biogas plant	Additional source of income	12	5 (71.4)	3 (42.9)	4 (50.0)	NS
Digestate	Reduced fertilizer costs through digestate substitution	11	3 (42.9)	3 (42.9)	5 (62.5)	NS
Biogas plant	Reduced energy costs through self-provision (e.g.,., hot water)	10	3 (42.9)	3 (42.9)	4 (50.0)	NS
Local community	Improved energy security	9	2 (28.6)	3 (42.9)	4 (50.0)	NS
Biogas plant	Utilization of available resources	8	2 (28.6)	3 (42.9)	3 (37.5)	NS
Biogas plant	Reduced workload for manure handling	7	2 (28.6)	1 (14.3)	4 (50.0)	NS
Biogas plant	Farm enlargement as biogas plants can handle additional amount of manure produced	7	4 (57.1)	1 (14.3)	2 (25.0)	NS
Digestate	Recovery of fermentation residuals in agriculture	6	1 (14.3)	1 (14.3)	4 (50.0)	NS
Digestate	Quick-release nitrogen fertilizer	6	1 (14.3)	2 (28.6)	3 (37.5)	NS
Local community	Improved understanding of residents toward dairy farming	6	3 (42.9)	0 (0.0)	3 (37.5)	NS
Biogas plant	Proper management of manure (reduced pollution/contamination risk)	5	4 (57.1)	1 (14.3)	2 (25.0)	NS
Digestate	High fertilizer value for grassland	5	1 (14.3)	2 (28.6)	2 (25.0)	NS

(1) Only variables whose citation frequency is not less than five are shown in the table.

(2) Figures in bracket are share of respondent mentioned among all respondents.

(3) Results are based on Fisher's exact test. NS: no statistically significant association ($p > 0.1$). Statistically significant associations ($p < 0.05$) are emphasized in boldface.

Table 6 – Strength variables identified and their citation frequency

Weaknesses

The biggest weakness related to biogas plants is cost (Table 7); 15 stakeholders – including all dairy farmers – regard the large investment for plant construction as a weakness. Among them, eight also mentioned that this is the critical weakness preventing small- and medium-sized dairy producers from installing biogas plants. Other weaknesses were related to digestate application: high transportation costs, limited timeframe for digestate application, and requirement of new equipment.

Weaknesses

Category	Variables	Citation frequency (1)	Dairy farmers	Arable farmers (2)	Non-farmers (2)	P2 (3)
Biogas plant	High investment and running (e.g.,., repair) costs	15	7 (100)	3 (42.9)	5 (62.5)	0.081
Digestate	High transportation costs and road conditions	9	2 (28.6)	6 (85.7)	1 (12.5)	0.016
Digestate	Limited timeframe for digestate application	8	1 (14.3)	6 (85.7)	1 (12.5)	0.005
Digestate	Requirement of spreading equipment and its cause of soil compac	6	0 (0.0)	5 (71.4)	1 (12.5)	0.002

(1) Only variables whose citation frequency is not less than five are shown in the table.
(2) Figures in bracket are share of respondent mentioned among all respondents.
(3) Results are based on Fisher's exact test. NS: no statistically significant association ($p > 0.1$). Statistically significant associations ($p < 0.05$) are emphasized in boldface.

Table 7 – Weakness variables identified and their citation frequency

Opportunities

The most frequently mentioned opportunity was the establishment of new projects for joint biogas plants that can reduce costs for each individual farm (Table 8). Continuation of or increases in the level of current public support is recommended by dairy and non-farmers. The majority of non-farmers thought that for further promotion of biogas plants, more technical development is needed to produce biogas at lower costs and with more efficiency.

Regarding the opportunities for stimulating digestate use, the most common suggestion was increased financial support to purchase new equipment and the use of contractors to handle digestate collection and spreading.

Opportunities

Category	Variables	Citation frequency (1)	Dairy farmers	Arable farmers (2)	Non-farmers (2)	P2 (3)
Biogas plant	Establishment of the joint biogas plant to share costs	8	5 (71.4)	0 (0.0)	3 (37.5)	0.021
Biogas plant	Continuation of the current FIT or even raising the purchase price	7	3 (42.9)	0 (0.0)	4 (50.0)	NS
Digestate	Subsidy for new equipment and using a contractor to handle/spread digestate	7	4 (57.1)	3 (42.9)	0 (0.0)	0.058
Digestate	Clarification of the actual merits of digestate as fertilizer	6	2 (28.6)	3 (42.9)	1 (12.5)	NS
Digestate	Technical support to develop a crop nutrition plan including digestate use	5	1 (14.3)	2 (28.6)	2 (25.0)	NS
Local community	Use of energy and heat in e.g., public buildings and horticulture	5	1 (14.3)	0 (0.0)	4 (50.0)	0.081

(1) Only variables whose citation frequency is not less than five are shown in the table.
(2) Figures in bracket are share of respondent mentioned among all respondents.
(3) Results are based on Fisher's exact test. NS: no statistically significant association ($p > 0.1$). Statistically significant associations ($p < 0.05$) are emphasized in boldface.

Table 8 – Opportunity variables identified and their citation frequency

3.4. Threats

The main future threat dairy farmers perceived was potentially higher competition for gaining access to fields as the number of biogas plants increased in the neighbourhood (Table 9). Among non-farmers, more than half of them were unsatisfied with the current electric power sales such as limited grid access and competition with other renewable energy sources.

Many arable farmers were not inclined to use digestate as a substitute for chemical fertilizer regardless of their previous digestate use. In contrast to the major strength of reducing odour, two arable farmers still perceived that digestate has an unpleasant odour.

As well as these difficulties for the actual usage of digestate, non-technical constraints were also identified. Some arable farmers were afraid to use it because of limited knowledge and practices. It should be noted that most of these technical and non-technical threats to digestate use were mentioned by arable farmers, while only a few variables are raised by the other two groups.

Threats

Category	Variables	Citation frequency (1)	Dairy farmers	Arable farmers (2)	Non-farmers (2)	P2 (3)
Digestate	Expected high competition for available farmland to spread digestate	10	5 (71.4)	3 (42.9)	2 (25.0)	NS
Biogas plant	Limited grid access and competition with other renewables (solar PV)	9	2 (28.6)	1 (14.3)	6 (75.0)	0.052
Biogas plant	Dependence of feed-in tariff on political circumstances/Lack of long-term perspective	6	3 (42.9)	0 (0.0)	3 (37.5)	NS
Digestate	Unclear impacts on yield/Limited knowledge and practices	6	1 (14.3)	5 (71.4)	0 (0.0)	0.005
Digestate	Preference of composted manure over liquid digestate	6	2 (28.6)	4 (57.1)	0 (0.0)	0.039
Biogas plant	Insufficient government support, late payment, and high competition to be supported	5	1 (14.3)	1 (14.3)	3 (37.5)	NS

(1) Only variables whose citation frequency is not less than five are shown in the table.

(2) Figures in bracket are share of respondent mentioned among all respondents.

(3) Results are based on Fisher's exact test. NS: no statistically significant association ($p > 0.1$). Statistically significant associations ($p < 0.05$) are emphasized in boldface.

Table 9 – Threat variables identified and their citation frequency

3.5.4. Discussion and conclusions

Stakeholders commonly perceive that biogas systems can bring (1) additional sources of income, (2) reduced energy costs through self-provision, (3) reduced odour from spreading digestate compared to composted manure, (4) reduced fertilizer costs through digestate substitution, and (5) various environmental benefits.

We found that many dairy farmers are fascinated by income from electric power sales. In our study site, selling electric power through FIT scheme is available, and dairy farmers recognize that its income is important for stable farm management. However, high investment and future policy reform on FIT scheme can be big threats for both dairy farmers and non-farmers. In addition, if dairy farmers expand their farm size only for the sake of higher income from power sales, it directly links with increase in livestock manure and with higher competition for available farmland for digestate application. Dairy farmers also recognize increasing number of biogas plants as a threat. Previous studies pointed out that increases in biogas plants can lead to increases in environmental burdens (Carrosio, 2013; Reise *et al*., 2012).

In this study, we also found that arable farmers, who are crucial stakeholders, do not necessarily recognise the usefulness of digestate. Conventional compost can be stored on a shelf, while liquid digestate requires a storage tank and re-application of composted manure as a soil amendment, causing extra application costs. Notably, most of the weakness variables related to digestate were pointed out by arable farmers, and in threat variables, dairy and non-farmers do not recognize threats related to digestate such as arable farmers' high preference for composted manure.

These findings imply that dairy and non- farmers regard digestate as “useful fertilizer for arable farmers” and think the utilization of digestate is responsible for arable farmers, while arable farmers regard digestate as “useless and low value residue or waste”, and there is a gap in the recognition between dairy and non-farmers, and arable farmers.

4. LIMITATIONS AND FUTURE RESEARCH

Although efforts were made to ensure the validity of the research, the study does have a number of limitations, due to the fact that it was conducted as part of the work of the GBEP Secretariat and as such received no specific funding or time allocation for its development. It therefore represents an initial analysis upon which further, more in-depth research can be conducted.

4.1. Africa

The result of the SWOT analysis on large-scale biogas systems provides a list of all factors deemed important for the success of large-scale biogas plants in Africa but does not provide a comparison of the importance of these factors. It would therefore be interesting to conduct the AHP analysis for the large-scale biogas system. Furthermore, there was no attempt to analyse medium-scale biogas systems, which are becoming increasingly important in the African context. Further studies could take this scale into account.

The sample of people surveyed may not be representative of the views of all stakeholders, as they represent participants invited or attending the GBEP Bioenergy Week in Ghana. However, there was a broad range of respondents from many sectors of society and regions of Africa, thus ensuring a variety of views.

4.2. Latin America and the Caribbean

Convenience sampling was used for the selection of respondents of the survey. One problem with this sampling technique is that generalisations cannot be made from samples conducted using this method. However, the opportunity to carry out the analysis in this manner means that quantitative data could be collected where in other scenarios it would not have been possible within the restraints of the study (Bryman, 2016, p.187). The findings from the survey will hopefully serve to provide a platform for further research.

From the results of the interviews, six factors were identified as relevant for each SWOT category. To overcome the potentially subjective nature of the choice of factors (as identified by Brudermann *et al*., 2015), the selection was based on the frequency of the coded responses provided during the interviews.

4.3. Asia

In order to conduct an AHP analysis, a survey was prepared and submitted to relevant experts from different areas of Asia who were participants of the GBEP Bioenergy Week 2019 held in Manila, The Philippines, 25-27 June 2019. Unfortunately, due to the lack of responses, the methodology had to be changed and data collection from experts was done through interviews. Although these interviews provided interesting qualitative data that support and validate the study, they did not provide sufficient data to carry out a separate analysis. Furthermore, the sample of interviewees is not representative of all stakeholders, as convenience sampling was used to select experts from the researchers' professional network. However, individual experience of the interviewees warrantee a wide range of responses that include different views based on each individual experience that include a variety of Asian countries.

Future studies could focus on carrying out AHP analysis to rank the importance of the SWOT factors identified in this study.

5. CONCLUSIONS

5.1. Africa

5.1.1. Large scale biogas

At large scale, the SWOT analysis demonstrates the variety of both internal and external benefits (or factors for success) of biogas systems, in terms of social, economic and environmental factors. It shows that the most relevant weaknesses and threats to the system are also varied, but focus on financial barriers, the problems of identifying sustainable feedstock sources, and the lack of knowledge of the potential for biogas that impedes investment.

5.1.2. Small scale biogas

As with large-scale biogas systems, financial constraints and sustainability of feedstock were identified as important factors that may impede the success of small-scale biogas business models. However, at this scale, cultural acceptability is also an important issue. With education campaigns and financial incentives for biogas plant construction, it may be possible to overcome these issues.

For both scales, feasibility assessments are extremely important in order to ensure that there is sustainable feedstock availability, acceptance of the technology by local populations, positive environmental externalities, and viable economic returns.

5.2. Latin America and the Caribbean

5.2.1. Household level biogas

At household scale, the benefits of anaerobic digestion at the global level are well known and documented in the literature – e.g. GHG mitigation, improved health, production of organic fertiliser, environmental co-benefits and access to modern energy services – and the perceptions of the interviewees on the strengths and opportunities of biogas in LAC were in line with previous studies. However, the interviewees emphasised the need to always take local context into consideration when designing and implementing biogas projects in order to ensure their success.

In terms of the negative factors related to biogas at household scale in LAC, the inexpensiveness and ease of alternative fuels was seen by the interviewees as a key barrier. Where this is related to subsidies for alternative fuels (e.g. LPG), interviewees suggested that a reduction or elimination of these subsidies could increase the competitiveness of biogas. However, it is also important to consider the social and economic effects of such policies; where biogas is promoted as a means to provide modern energy services, these policies may in fact have the contrary effect of increasing fuel costs for poor households, thereby reducing energy access.

Given the low cost of alternative fuels, the environmental co-benefits of the technology were seen by the interviewees as a key strength that needs to be further publicised and promoted, as they vastly increase the utility of the biogas system compared with alternatives. However, awareness of these benefits was perceived by interviewees to be low in many countries. A further negative factor identified through interviews was the lack of capacity to operate and maintain the ADs. Many interviewees suggested that this lack of understanding of biogas should be overcome through awareness raising and training initiatives, which could be carried out by national governments, international initiatives or local grassroots organisations.

5.2.2. Biogas for productive and industrial use

The interviewees emphasised a number of strengths and opportunities for biogas for productive and industrial use in LAC, including: proper treatment of wastes, reducing contamination of surrounding ecosystems; climate change mitigation benefits; adding value to waste streams to improve business prospects; and creating new jobs with improved incomes.

Out of these identified benefits, the survey participants identified the main strengths of biogas at this scale in Argentina to be the environmental co-benefits through reduction in contamination of soil and water from bad waste management. Through the valuation of these co-benefits in economic models, regulations could be put in place to penalise bad waste disposal and therefore incentivise biogas as a competitive solution; this was seen to have worked well in Guatemala and could be adopted by other countries in LAC.

Turning to the negative factors, some of the main problems for biogas at this scale in LAC, as identified by the interviewees, are high costs (both initial costs of capital investment and running costs for producing electricity or upgrading biogas). The survey in Argentina showed that supporting investment is therefore important – to be done through instruments that guarantee investment security, such as PPAs that ensure stable income (e.g. RenovAr). Interviewees in LAC noted that a key threat to biogas is the lack of tailored policies. However, programmes such as RenovAr, that have different prices for different renewables, are able to specifically incentivise large-scale biogas projects along with other renewables; this could represent a successful formula across the region.

5.3. Asia

5.3.1. Household-Decentralized level

At household-decentralized scale, both the literature and interviewed experts agreed that the most important strengths were the reduction of GHG emissions, the substitution of fossil fuels by biogas, and the use of by-products as fertilizers. They also recalled the importance of the replacement of LPG by biogas.

When discussing the opportunities and threats, it was mentioned by both experts and literature sources that even when there are subsidies and policies in some countries that might represent an opportunity in terms of biogas development, they are considered weak. At the same time, other subsidies and policies for fossil fuels make the development of biogas less competitive. Development of dedicated policies for biogas, increased activities of capacity development and training, as well as reduction of fossil fuel subsidies are strongly recommended to encourage biogas development.

5.3.2. Centralized level

At centralized scale, Asia represents one of the most promising biogas markets worldwide. The rapid growth of Asia's population represents an opportunity to diversify energy sources. In addition to this, government subsidies programs may represent an opportunity for further development.

The main benefits identified and validated by experts at this scale were the ability to handle large supply flows, the use of the digestate as organic fertilizer, the potential reduction of GHG emissions, and last but not least, the contribution to improve odour problems.

The main barriers identified at this scale were the need for high capital investment and lack of financing. Furthermore, during the interviews, one of the experts with broad experience in South East Asia stated that recently, even though feedstocks are available, their cost has been rising after industries noted that they could make revenues by selling their by-products, making biogas less competitive.

As in the household level, further development of policies in combination with increased activities of capacity development and training, as well as reduction of fossil fuel subsidies are strongly recommended to encourage biogas development.

5.4. Final remarks

Given that each regional analysis was conducted specifically for the region, slightly different scales and terminology have been used for each. This makes comparison between the regions quite difficult. However, there are some common themes that arise in the analyses that should be noted.

There are many common **strengths** of biogas technology. First and foremost, anaerobic digestion provides modern renewable bioenergy. However, in many cases it is the co-benefits that arise from the switch to biogas that drive uptake. Examples of these co-benefits are the ability to use diverse residue and waste streams as feedstock, substitution of traditional biomass or fossil fuel energy (with the subsequent reductions in household air pollution and GHG emissions, respectively), improved waste disposal/sanitation resulting in reduced contamination of surrounding soils and water, and the use of digestate as fertiliser to increase crop yields and/or reduce the use of chemical fertiliser.

At all scales in all regions, high initial investment in ADs for biogas production is a **weakness** that prevents uptake of the technology; this is both for households looking to buy small digesters as well as industry investing in large-scale biogas plants. Although the problem is the same, the solution at the different scales across the various regions could be very different. Examples of identified solutions range from microfinance at household level to FITs and tax exemptions at larger scales. Familiarising finance institutions with the benefits of biogas is also significant for facilitating investments.

Another common difficulty identified across regions is the problem of adapting biogas **technology** that has been designed for another region to regional/national/local circumstances. Knowledge of AD construction and operation continues to grow, and alleviates this problem. However, one of the key findings of this report is that biogas technology requires context-specific feasibility studies (as with any new bioenergy venture) to ensure its functionality and sustainability in the given situation. Networks of practitioners, such as REBIOLAC in LAC, are integral to support knowledge transfer and cooperation towards this goal. Furthermore, capacity development and training activities to improve management and efficiency of ADs, at all levels, are extremely important.

To overcome some of the hurdles to biogas development, solid **policies** are required. In general, robust policies dedicated to biogas are not present in most countries. However, examples exist of policies that are successfully promoting biogas both at small and large scale through, for example, subsidies, tax exemptions to imports of materials, indirect incentives from regulations on waste treatment, PPAs/FITs and guarantees for investment. Carbon markets are also an option for improving returns on investment in biogas but up to now still seem to be underused for the sector. Finally, market distortions resulting from fossil fuel subsidies make biogas (and other renewable energy sources) uncompetitive in many countries.

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ANNEX 1

Survey on large-scale biogas

Respondents of the survey were presented with a list of potential factors for each category of the SWOT analysis and asked to identify all factors that they deemed important in the African context, based on their experience. The survey was divided into four sections – strengths, weaknesses, opportunities and threats. The question for each section and the list of all potential factors can be found below.

Strengths

Which among the aspects listed below, are the major strengths of large-scale biogas technology in Africa? Strengths are internal factors that are favourable for achieving the system's objective. Please indicate all of the potential strengths of large scale biogas systems in an African country in which you are based or have experience in. Please indicate any extra strengths that do not correspond to the categories below in the space provided.

Energy	**Environmentally-friendly technology**	**Positive impact for agricultural soil due to the application of biogas co-product (digestate)**	**Health benefits**
Additional source of income Cut down energy costs through self-provision Utilization of locally available feedstock and waste management Reduced use of other type of fuel (i.e. liquid fuel, wood) Other (please specify)	Reduces the use of other type of fuel (e.g. fossil fuel, wood) and the related environmental impacts Effective use of agro-industrial waste: easy and healthy waste disposal Save the forest: low dependence on forest wood Low emissions of greenhouse gases (outdoor air pollution) Low emissions of non-GHG gases and air pollutants (e.g. particulate matter) Reduced emissions of odours	Increase crop yield Reduce land degradation Reduce the need for chemical fertilizers Increase soil quality (soil organic matter content) and fight soil depletion Increase soil C stock and help mitigate climate change Other (please specify)	Improved community sanitation Reduced number of sanitation-related diseases and sicknesses due to poor waste management Other (please specify)

	Reduced water pollution Other (please specify)		

Weaknesses

Which, among the aspects listed below, are the major weaknesses of the biogas technology in Africa? Weaknesses are internal factors that are unfavourable for achieving the system's objective. Please indicate all potential Weaknesses that could affect a large scale Biogas system in an African country in which you are based or have experience in. Please indicate any extra weaknesses that do not correspond to the categories below in the space provided.

Lack of human capacity	**Economic Aspects**	**Financial Aspects**	**Feedstock concerns**
Lack of technology know-how in plant management Lack of know-how in digestate utilization Potential underutilization of plant capacity Lack of know-how for plant maintenance Competition with alternative technologies Lack of interest in applying digestate as soil amendment Lack of flexibility: difficulty in adapting the plant to the use of different feedstock Poor communication strategy useful to spread the technology Other (please specify)	High cost for collecting and transporting the feedstock Cost and concerns for transporting the processed residual product High maintenance cost High need of manpower Lack of use for heat generated Lack of local availability of production facilities Other (please specify)	Low financial returns Limited financial access for initial investment High initial investment for plant setting Long time for return on investment Other (please specify)	Lack of suitable feedstock No regular feedstock supply (i.e. because of seasonality) Competition for the use of feedstock Lack of data on feedstock availability, e.g. types, quantity available, seasons and locations Cultural/religious restrictions on use of certain feedstock Other (please specify)

Opportunities

Which, among the aspects listed below, are the major opportunities of the biogas technology in Africa? Opportunities are External factors that are favourable for achieving system's objective. Please indicate all potential opportunities that could affect a large scale Biogas system in an African country in which you are based or have experience in. Please indicate any extra opportunities that do not correspond to the categories below in the space provided.

Financial opportunities	**Employment opportunities**	**Economic development**	**Social opportunities**
Existence of government subsidies for reducing the environmental impact of agro-waste industries Existence of incentives for production of renewable energy Existence of incentives for employment creation Attract public funding Earn C credits Existence of feed-in tariff Other (please specify)	Technicians for optimizing plant performance considering the locally available feedstock Skilled employees for checking plant performance Development of new training activities: teachers and educational experts Managers and employees for plant operation and maintenance Other (please specify)	Added value for existing business value chains Development of new enterprise for collecting, transporting and selling agro-industrial waste as feedstock. (Creation of consortium) Development of new enterprise for collecting and selling digestate to farmers as fertilizer substitute Associations among producers Reduced dependency on energy imports Other (please specify)	Socio-economic development Improve the livelihood of local population Building capacities Increased access to energy for local populations Other (please specify)

Threats

Which, among the aspects listed below, are the major threats of the biogas technology in Africa? Threats are external factors that are unfavorable for achieving system's objective. Please indicate all potential threats that could affect a large scale Biogas system in an African country in which you are based or have experience in. Please indicate any extra threats that do not correspond to the categories below in the space provided.

Economic and Financial aspects	**Environmental aspects**	**Feedstock**	**Social threats**	**Inadequacy of logistic and infrastructure**

Lack of understanding of technology among financial institutions High cost of capital Policy and administrative barriers Artificially low energy prices due to fossil fuel subsidies (e.g. coal) Lack of feed-in tariff Fluctuation of cost for the Biogas Plant Other (please specify)	Possibility of accidental emissions of methane in the atmosphere Lack of water resources Other (please specify)	Competition with alternative uses of feedstock (e.g. fuel, building material, etc.) Availability and affordability of feedstock in the long term Lack of availability of suitable feedstock Other (please specify)	Low acceptance from local population Small scale agriculture is not adapted to large scale technology Cultural or religious restrictions on use of certain feedstock Poor attitude towards new technologies Other (please specify)	Lack and/or inadequacy of local power grid able to absorb extra energy production Lack and/or inadequacy of transportation routes for feedstock and by-product Lack and/or inadequacy of means of transport for feedstock and by-product Other (please specify)

ANNEX 2

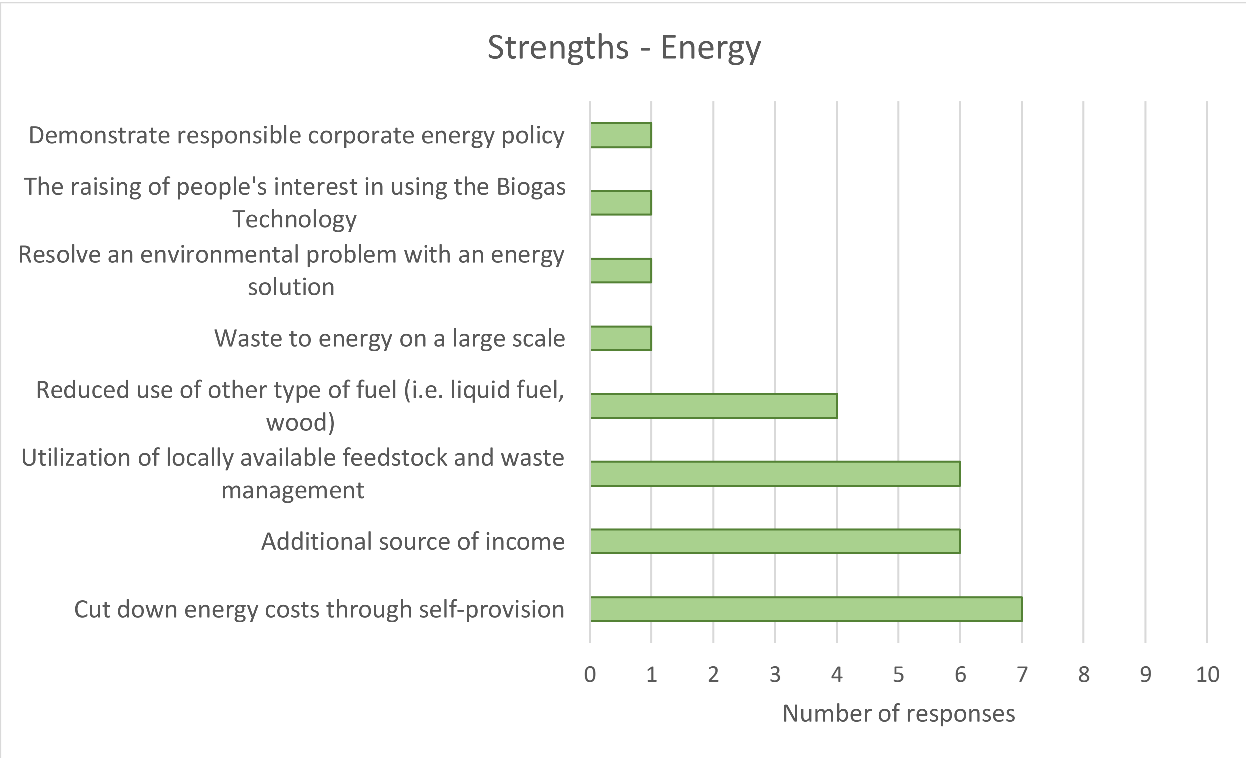
Results of survey on large-scale biogas business model

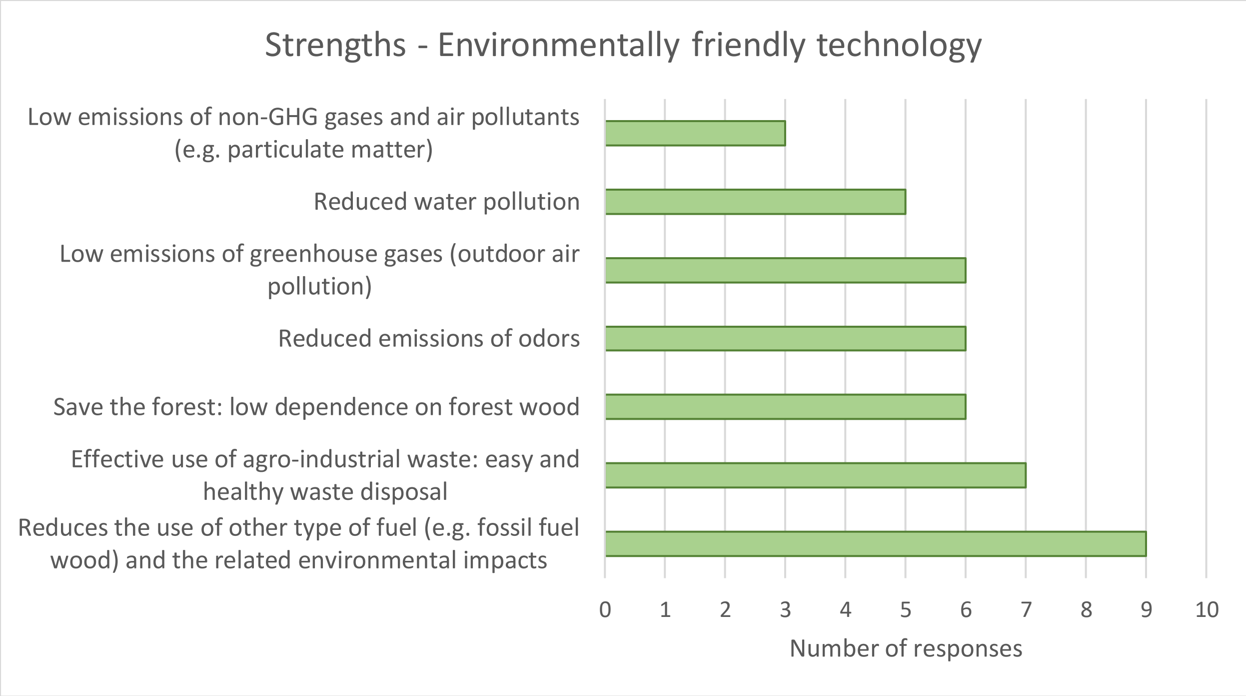
The following graphs represent the responses of ten participants to an online survey conducted by the GBEP Secretariat and ECREEE on 'SWOT analysis on large-scale biogas systems in Africa'.

The participants based their responses on their experiences and expertise in Africa, specifically in Ghana, Benin, Nigeria, Sierra Leone, Liberia, and Togo (although the results are also relevant for other countries as some respondents based their responses on wider experience).

For each category of the SWOT (strengths, weaknesses, opportunities and threats), the respondents were asked to identify (from a possible list) all potentially relevant factors for large-scale biogas business models in Africa, and to identify any other factors that may be important. The graphs below indicate how many participants deemed each factor potentially important (those with greater response rate are therefore deemed more relevant).

Strengths (internal factors)




Strengths - Environmentally friendly technology
Low emissions of non-GHG gases and air pollutants (e.g. particulate matter)
Reduced water pollution
Low emissions of greenhouse gases (outdoor air pollution)
Reduced emissions of odors
Save the forest: low dependence on forest wood
Effective use of agro-industrial waste: easy and healthy waste disposal
Reduces the use of other type of fuel (e.g. fossil fuel wood) and the related environmental impacts
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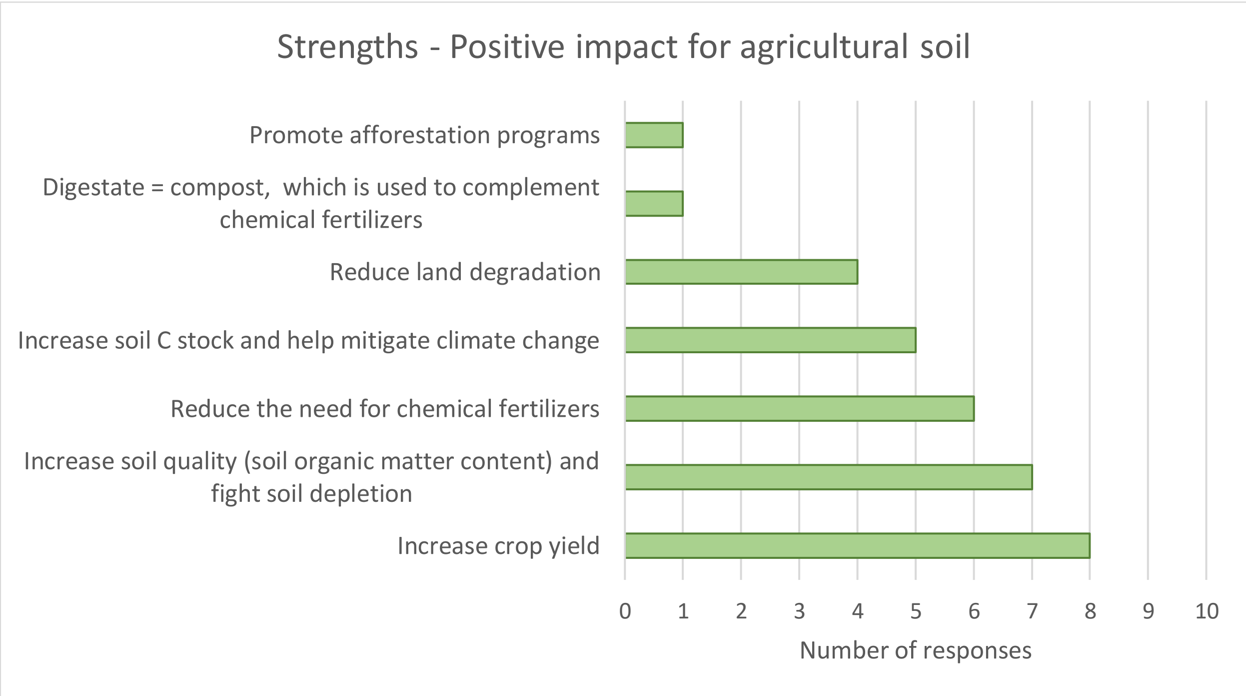
Number of responses


Strengths - Positive impact for agricultural soil
Promote afforestation programs
Digestate = compost, which is used to complement chemical fertilizers
Reduce land degradation
Increase soil C stock and help mitigate climate change
Reduce the need for chemical fertilizers
Increase soil quality (soil organic matter content) and fight soil depletion
Increase crop yield
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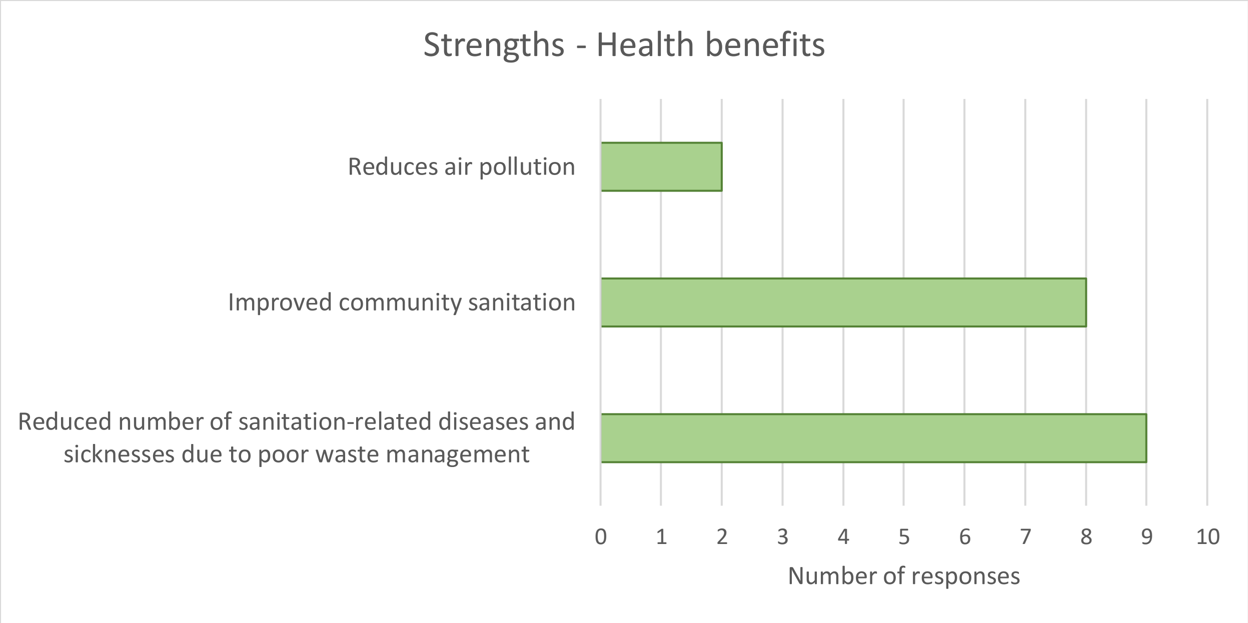
Number of responses



Strengths - Health benefits
Reduces air pollution
Improved community sanitation
Reduced number of sanitation-related diseases and sicknesses due to poor waste management
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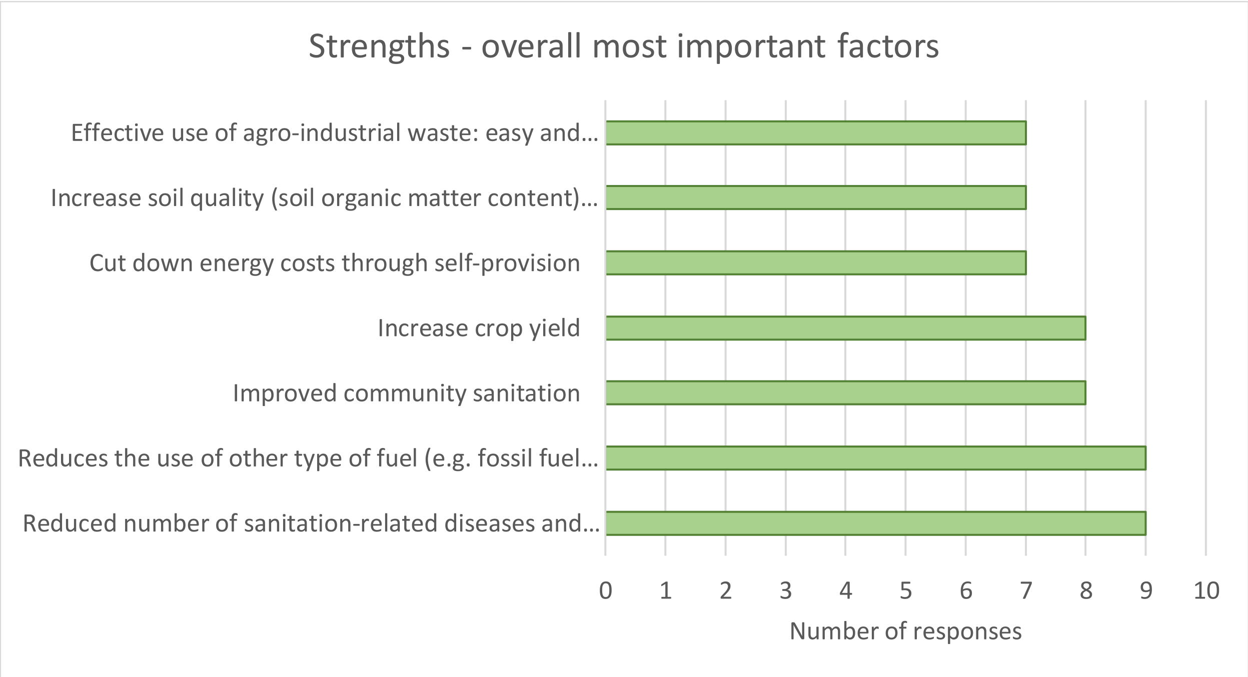
Number of responses



Strengths - overall most important factors
Effective use of agro-industrial waste: easy and...
Increase soil quality (soil organic matter content)...
Cut down energy costs through self-provision
Increase crop yield
Improved community sanitation
Reduces the use of other type of fuel (e.g. fossil fuel...
Reduced number of sanitation-related diseases and...
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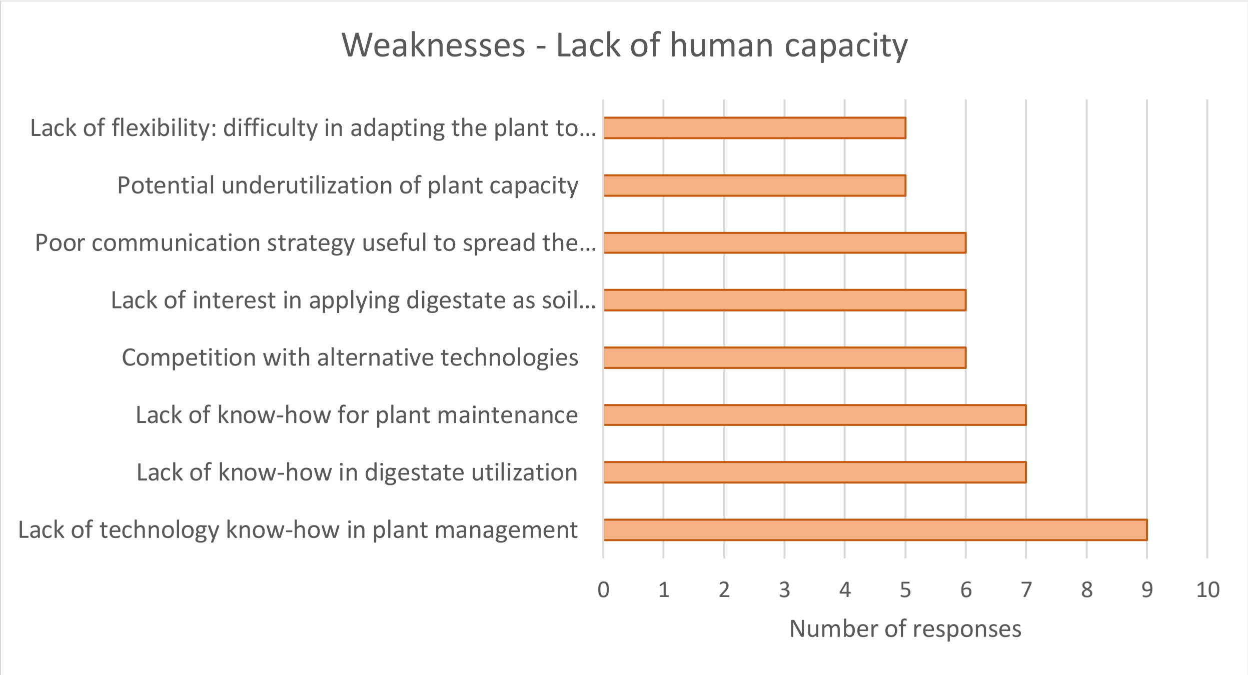
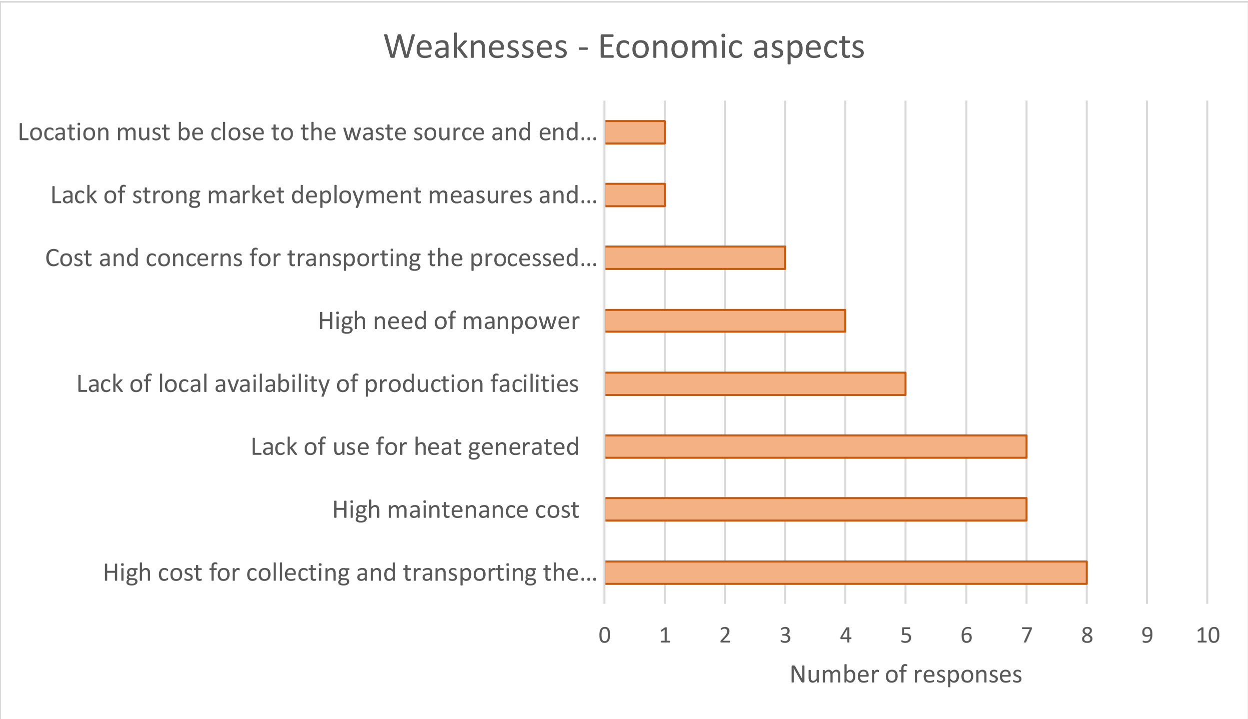
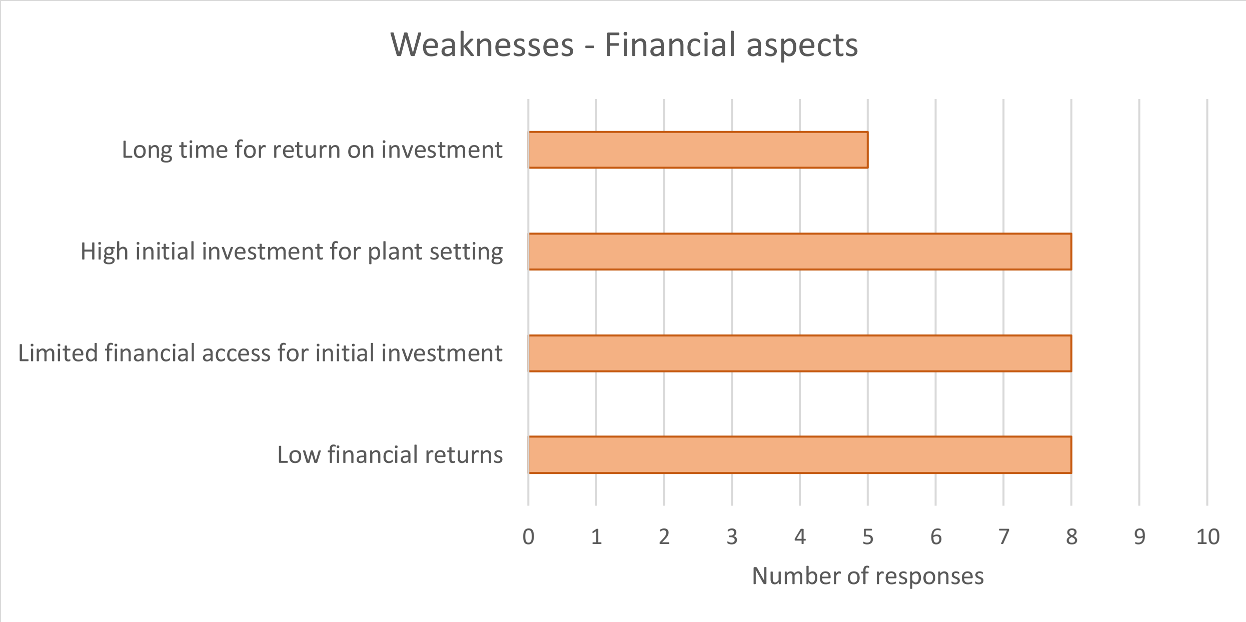
Weaknesses (internal factors)






Weaknesses - Financial aspects
Long time for return on investment
High initial investment for plant setting
Limited financial access for initial investment
Low financial returns
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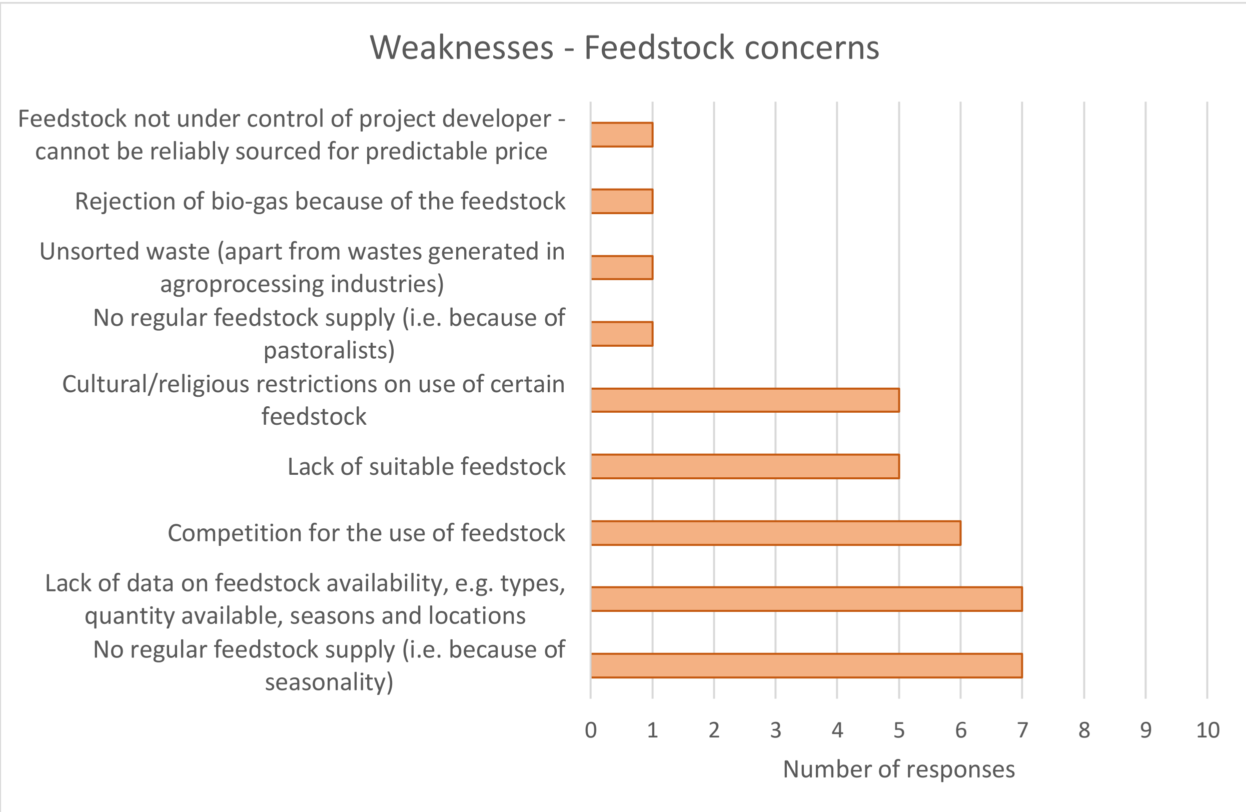
Number of responses


Weaknesses - Feedstock concerns
Feedstock not under control of project developer - cannot be reliably sourced for predictable price
Rejection of bio-gas because of the feedstock
Unsorted waste (apart from wastes generated in agroprocessing industries)
No regular feedstock supply (i.e. because of pastoralists)
Cultural/religious restrictions on use of certain feedstock
Lack of suitable feedstock
Competition for the use of feedstock
Lack of data on feedstock availability, e.g. types, quantity available, seasons and locations
No regular feedstock supply (i.e. because of seasonality)
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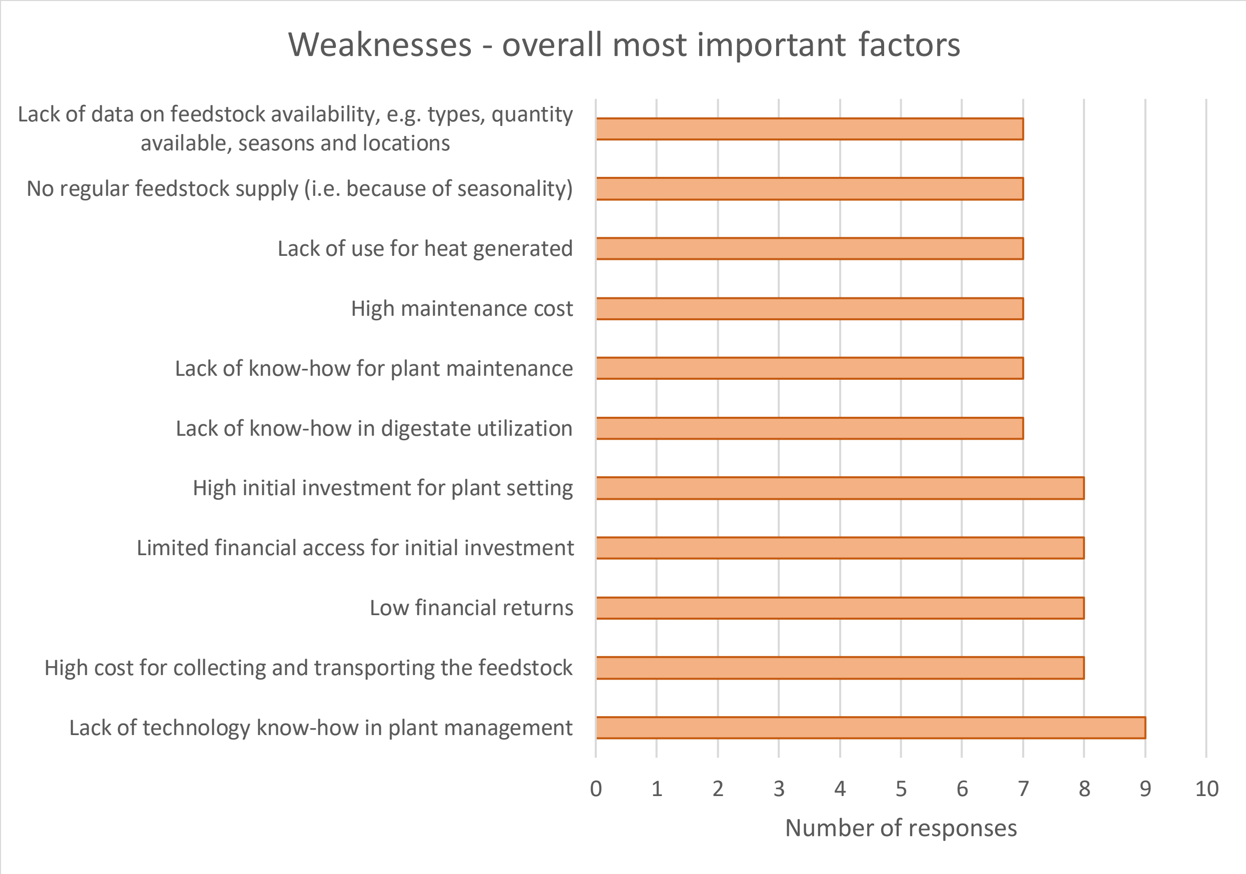
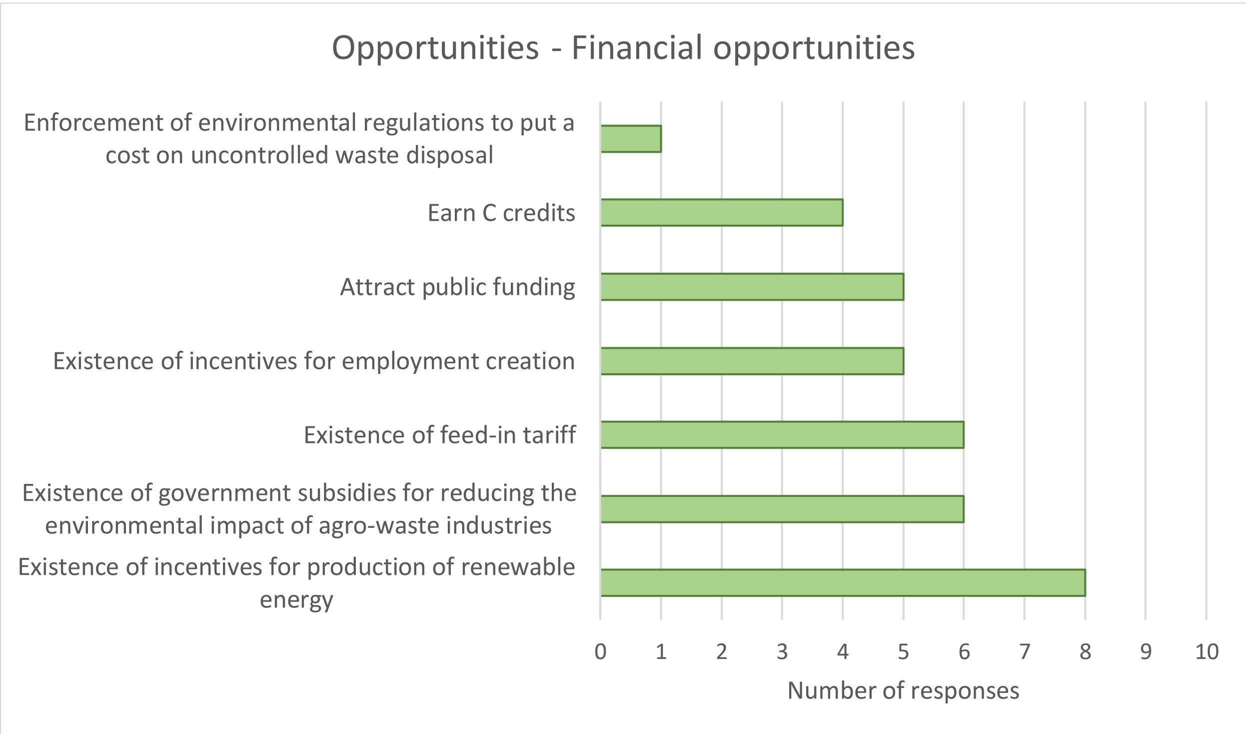
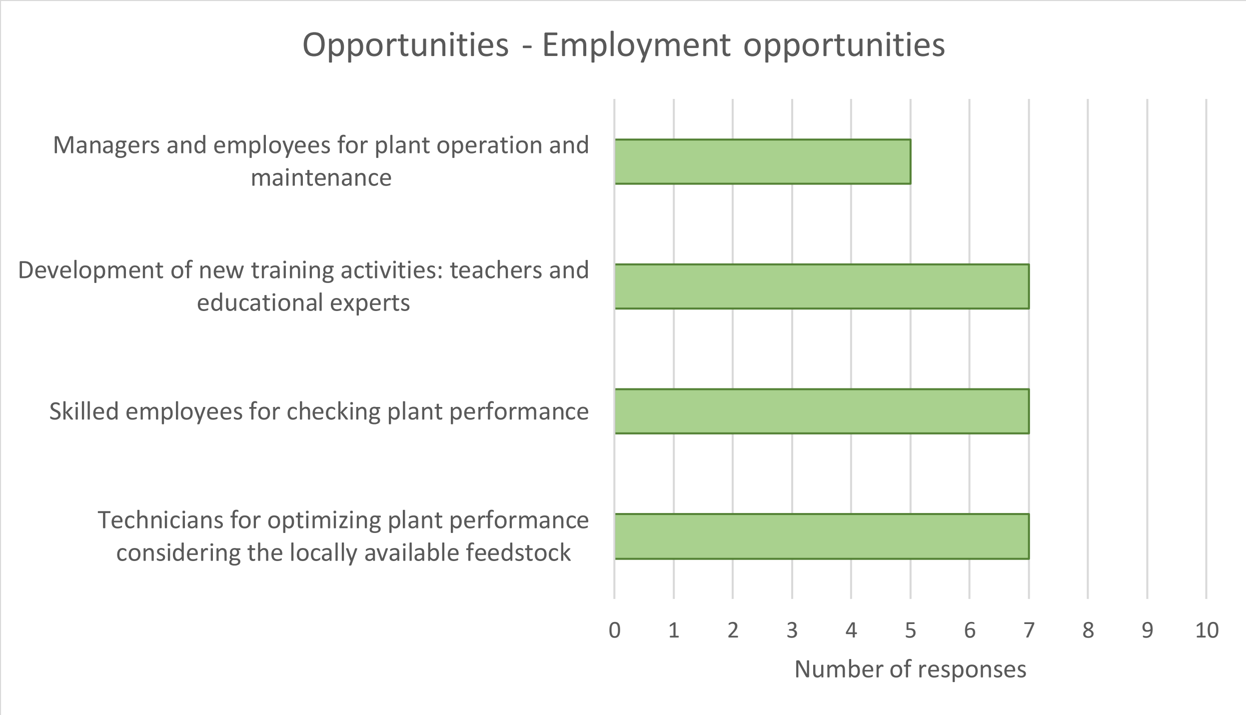
Number of responses



Opportunities (external factors)




Opportunities - Employment opportunities
Managers and employees for plant operation and maintenance
Development of new training activities: teachers and educational experts
Skilled employees for checking plant performance
Technicians for optimizing plant performance considering the locally available feedstock
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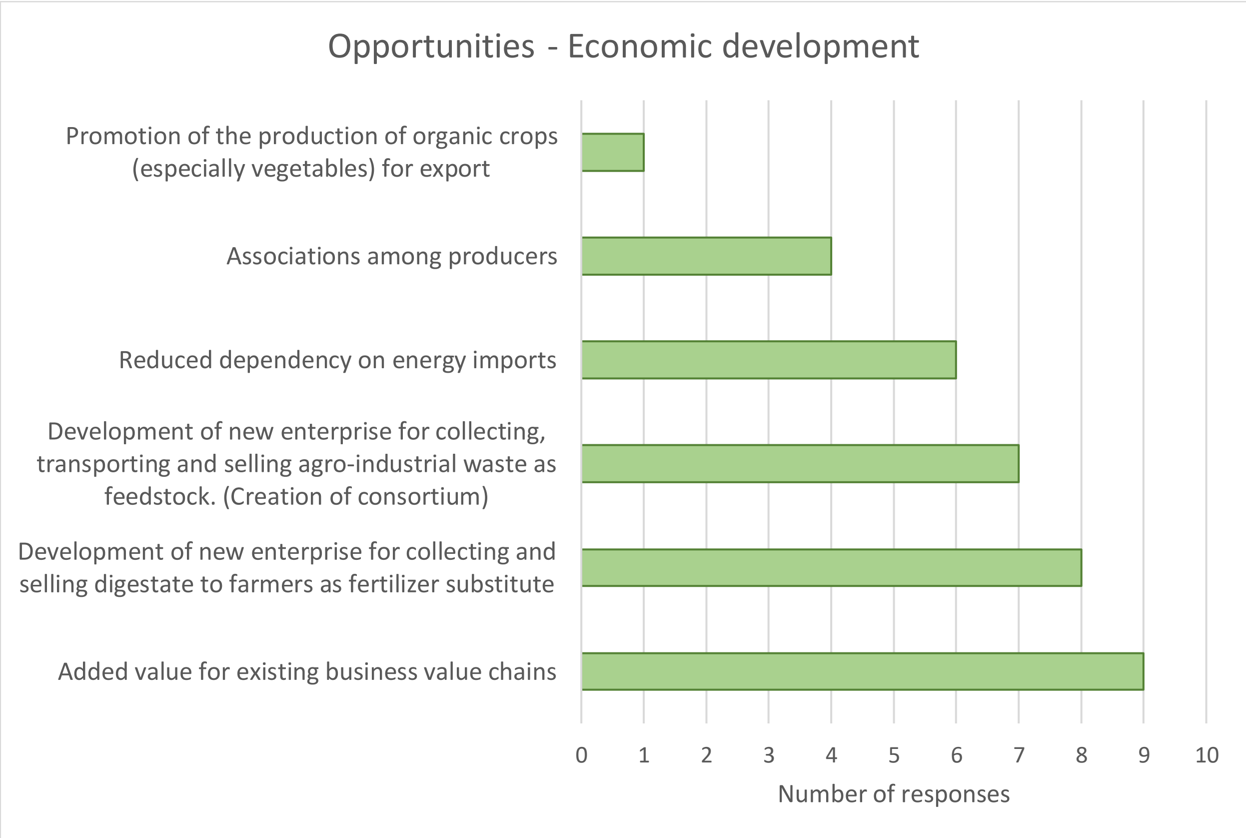
Number of responses


Opportunities - Economic development
Promotion of the production of organic crops (especially vegetables) for export
Associations among producers
Reduced dependency on energy imports
Development of new enterprise for collecting, transporting and selling agro-industrial waste as feedstock. (Creation of consortium)
Development of new enterprise for collecting and selling digestate to farmers as fertilizer substitute
Added value for existing business value chains
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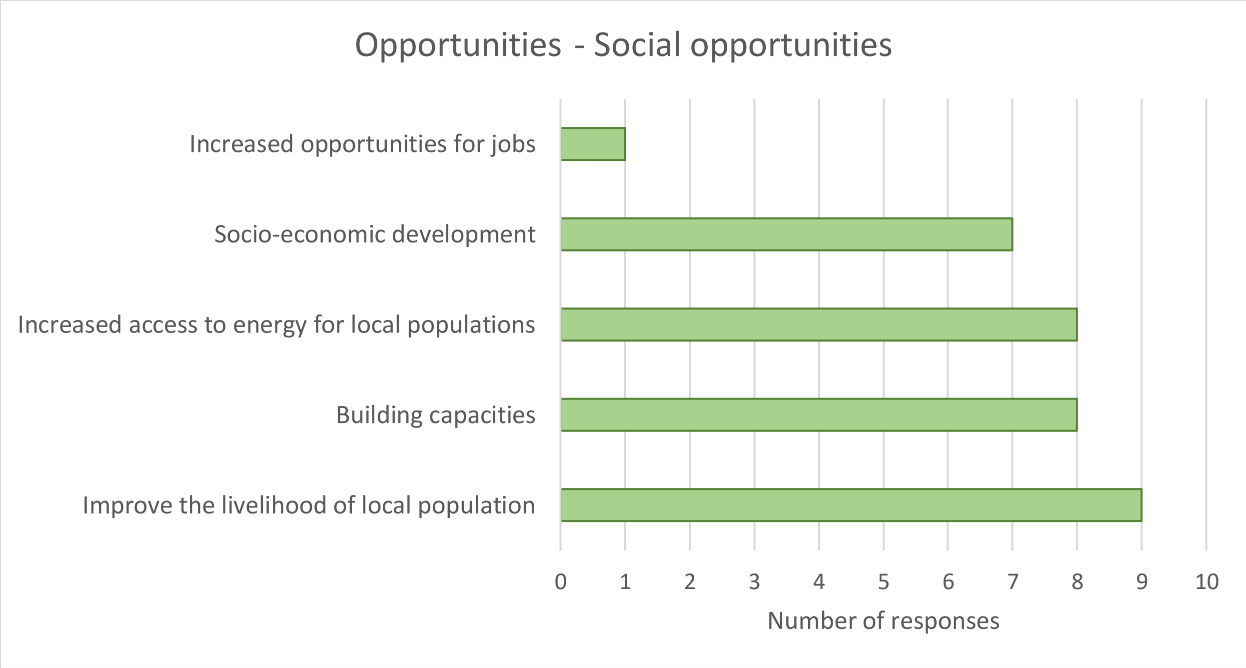
Number of responses


Opportunities - Social opportunities
Increased opportunities for jobs
Socio-economic development
Increased access to energy for local populations
Building capacities
Improve the livelihood of local population
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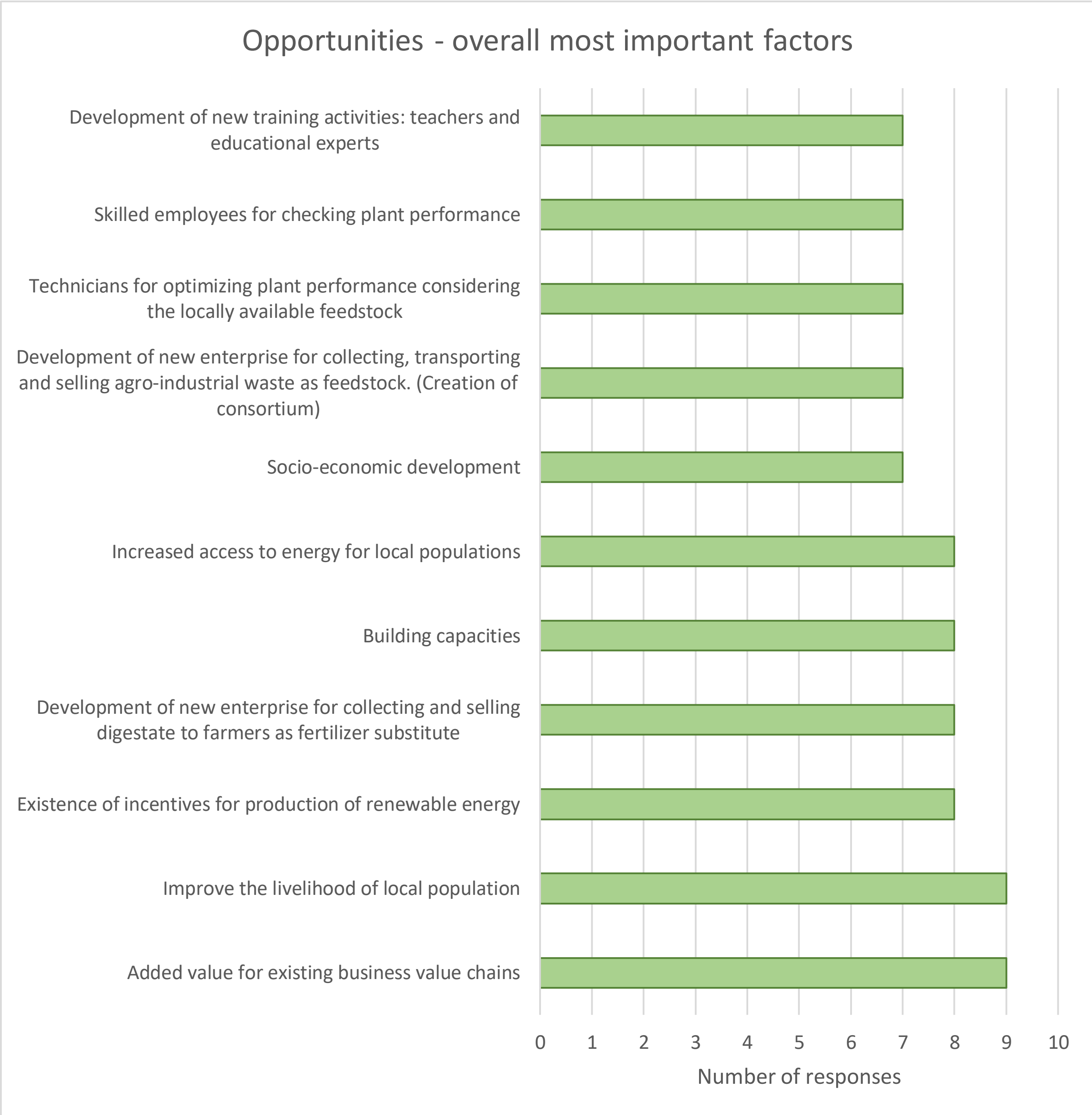
Number of responses



Opportunities - overall most important factors
Development of new training activities: teachers and educational experts
Skilled employees for checking plant performance
Technicians for optimizing plant performance considering the locally available feedstock
Development of new enterprise for collecting, transporting and selling agro-industrial waste as feedstock. (Creation of consortium)
Socio-economic development
Increased access to energy for local populations
Building capacities
Development of new enterprise for collecting and selling digestate to farmers as fertilizer substitute
Existence of incentives for production of renewable energy
Improve the livelihood of local population
Added value for existing business value chains
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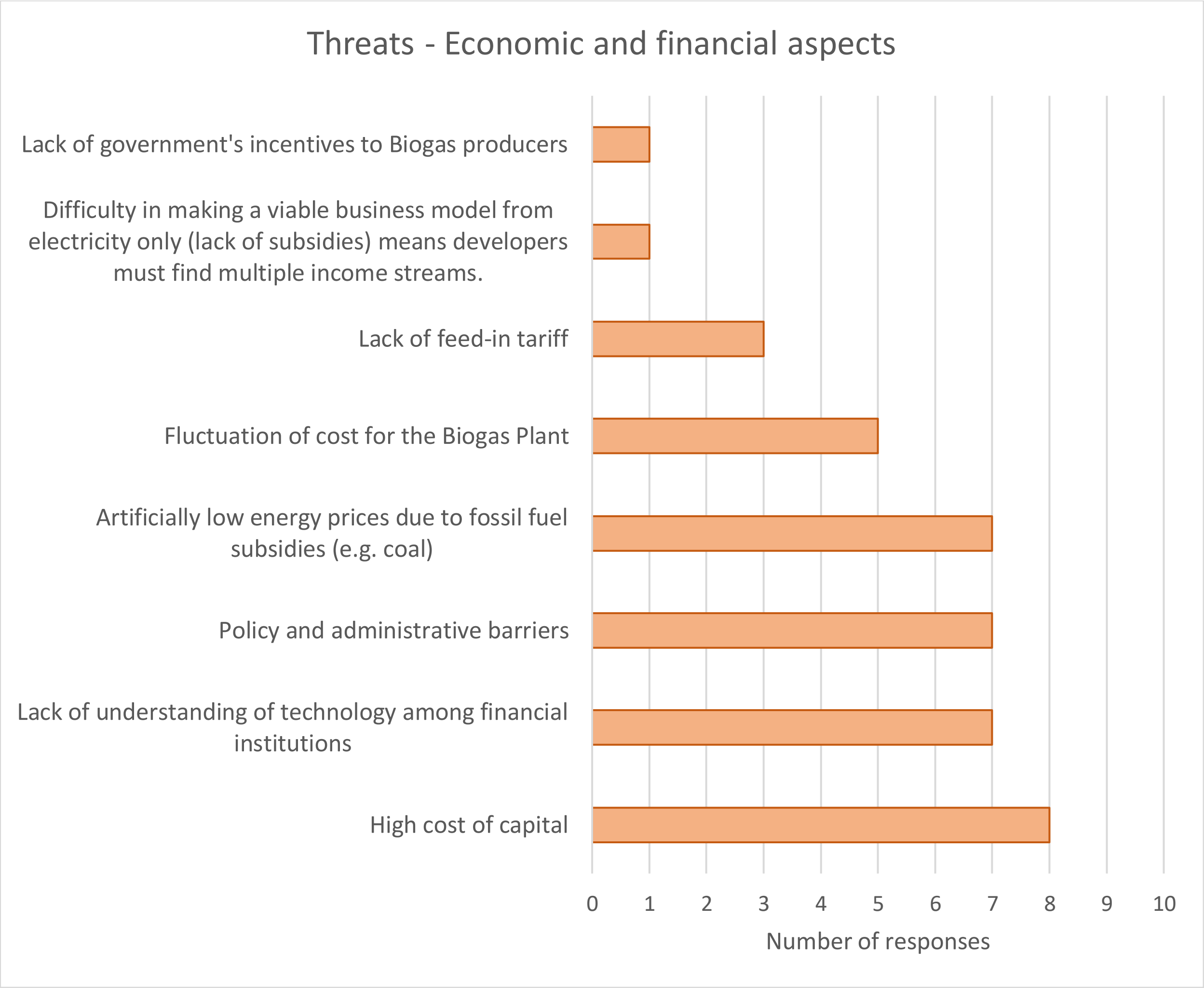
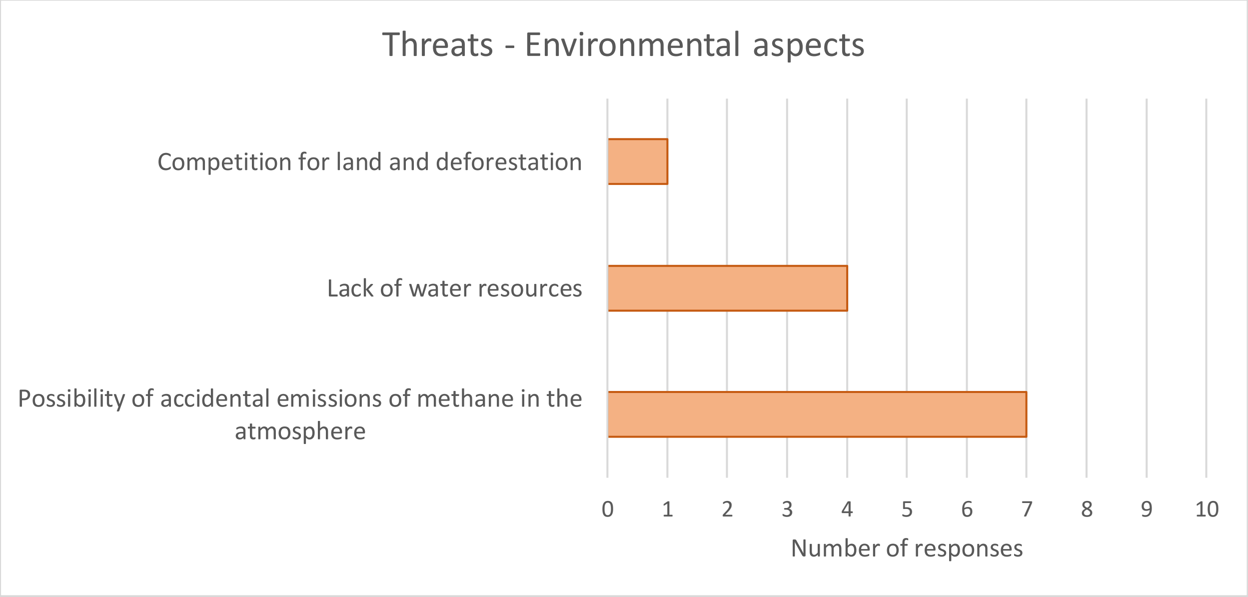
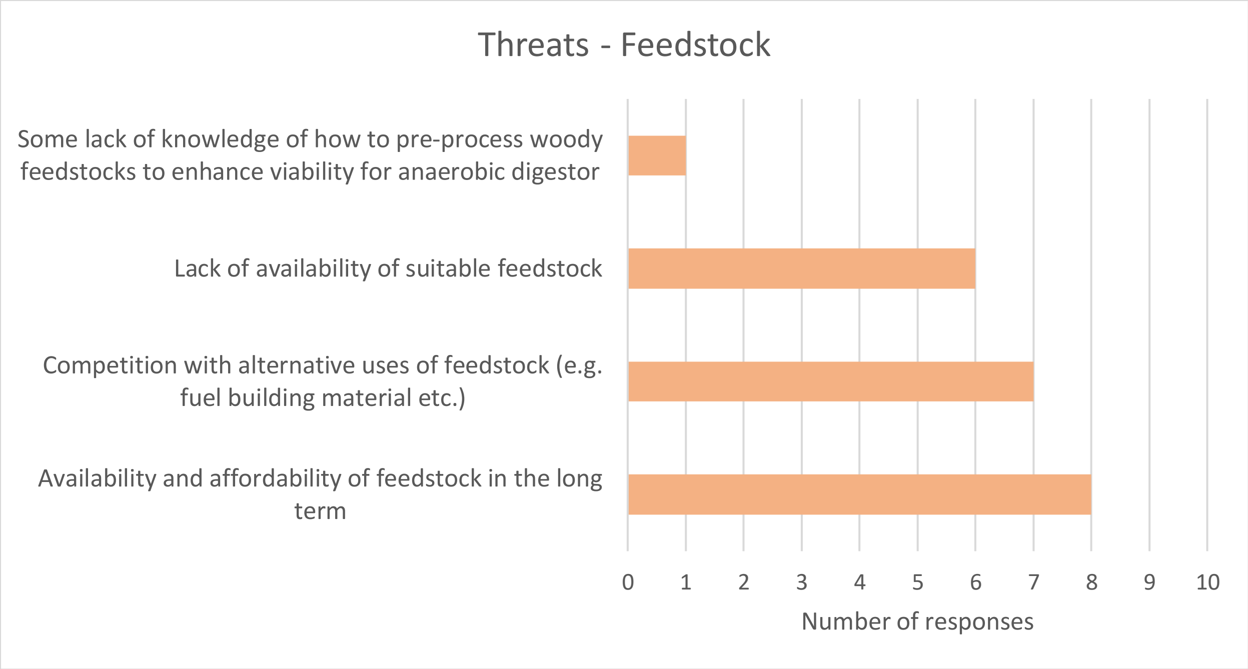
Number of responses

Threats (external factors)







Threats - Feedstock
Some lack of knowledge of how to pre-process woody feedstocks to enhance viability for anaerobic digestor
Lack of availability of suitable feedstock
Competition with alternative uses of feedstock (e.g. fuel building material etc.)
Availability and affordability of feedstock in the long term
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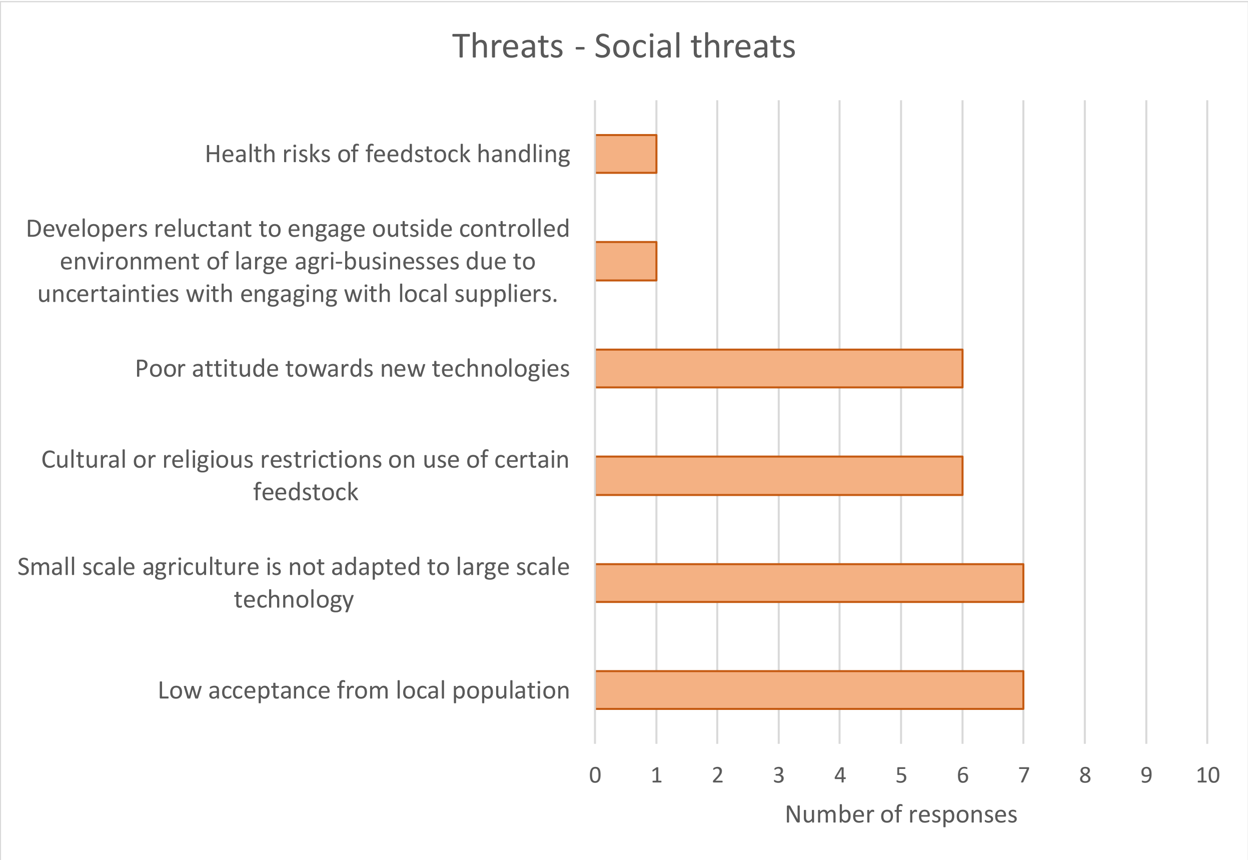

Threats - Social threats
Health risks of feedstock handling
Developers reluctant to engage outside controlled environment of large agri-businesses due to uncertainties with engaging with local suppliers.
Poor attitude towards new technologies
Cultural or religious restrictions on use of certain feedstock
Small scale agriculture is not adapted to large scale technology
Low acceptance from local population
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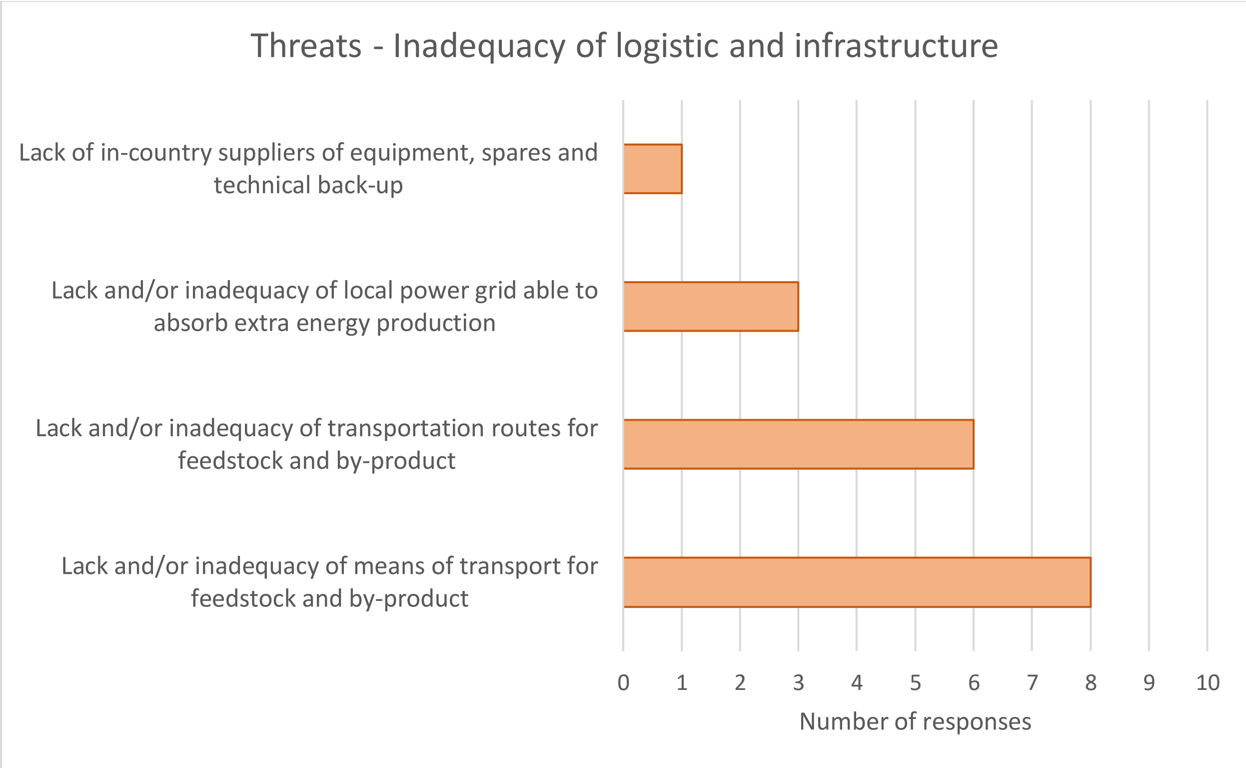
Number of responses


Threats - Inadequacy of logistic and infrastructure
Lack of in-country suppliers of equipment, spares and technical back-up
Lack and/or inadequacy of local power grid able to absorb extra energy production
Lack and/or inadequacy of transportation routes for feedstock and by-product
Lack and/or inadequacy of means of transport for feedstock and by-product
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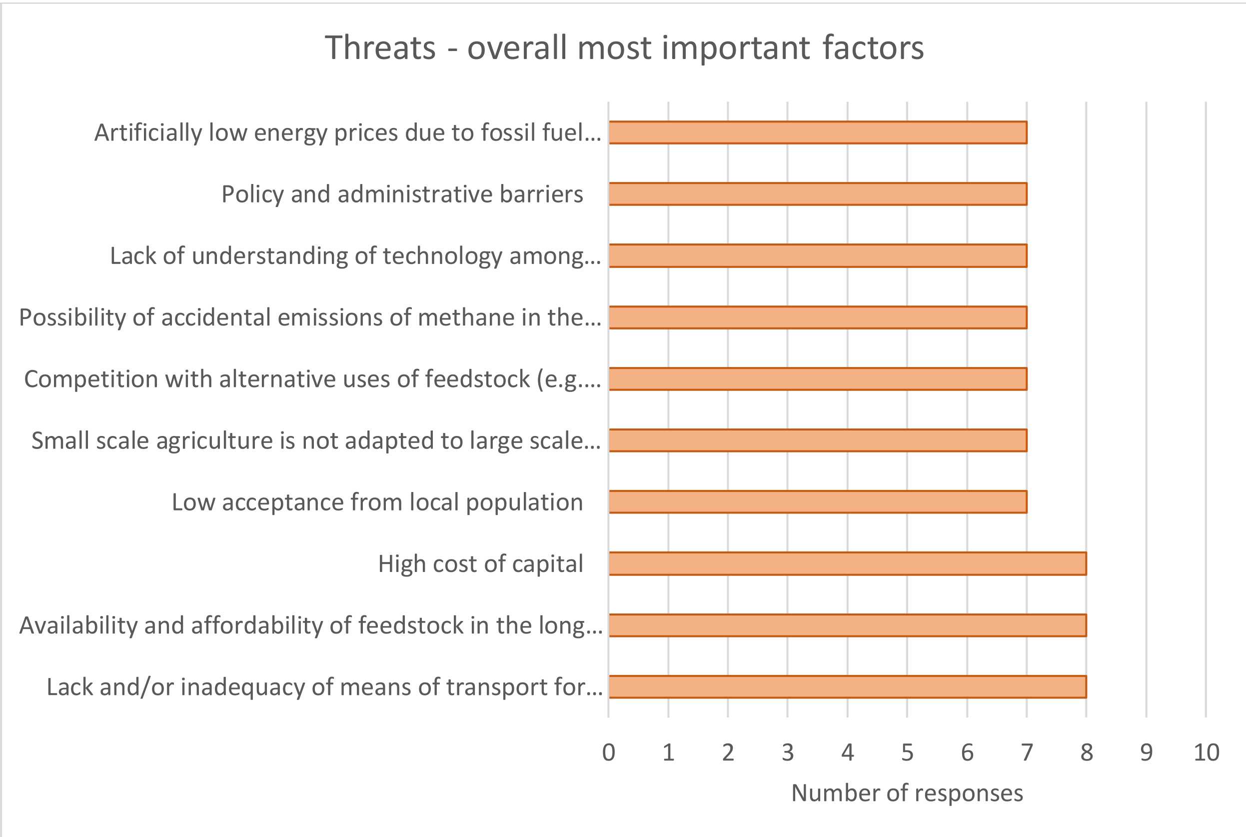
Number of responses


Threats - overall most important factors
Artificially low energy prices due to fossil fuel...
Policy and administrative barriers
Lack of understanding of technology among...
Possibility of accidental emissions of methane in the...
Competition with alternative uses of feedstock (e.g....
Small scale agriculture is not adapted to large scale...
Low acceptance from local population
High cost of capital
Availability and affordability of feedstock in the long...
Lack and/or inadequacy of means of transport for...
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Number of responses

ANNEX 3

AHP Analysis for Africa

All AHP analysis was carried out using online software from "AHP Online System – BPMSG" (Goepel, 2018). The following sections provide the priorities given by the decision matrix for each of the categories of the SWOT analysis, along with the consistency ratio.

Strengths

Decision Matrix

	S1	S2	S3	S4	S5	S6
S1	1	4.00	0.50	2.00	0.50	0.33
S2	0.25	1	1.00	2.00	2.00	3.00
S3	2.00	1.00	1	5.00	3.00	2.00
S4	0.50	0.50	0.20	1	0.50	1.00
S5	2.00	0.50	0.33	2.00	1	2.00
S6	3.00	0.33	0.50	1.00	0.50	1

Principal eigen value = 7.31

	S1	S2	S3	S4	S5	S6
Priority	18.23%	18.76%	26.27%	7.22%	15.41%	14.10%
Rank	3	2	1	6	4	5

Consistency Ratio = 20.90%

Weaknesses

Decision Matrix

	W1	W2	W3	W4	W5	W6
W1	1.00	0.33	0.33	1.00	2.00	0.33
W2	3.00	1.00	0.50	2.00	3.00	0.50
W3	3.00	2.00	1.00	2.00	5.00	1.00
W4	1.00	0.50	0.50	1.00	4.00	0.50
W5	0.50	0.33	0.20	0.25	1.00	0.33
W6	3.00	2.00	1.00	2.00	3.00	1.00

Principal eigen value = 6.19

	W1	W2	W3	W4	W5	W6
Priority	9.24%	18.64%	27.75%	12.94%	5.45%	25.99%
Rank	5	3	1	4	6	2

Consistency Ratio = 3.08%

Opportunities

Decision Matrix

	O1	O2	O3	O4	O5	O6
O1	1	3.00	5.00	0.50	1.00	3.00
O2	0.33	1	4.00	1.00	1.00	2.00
O3	0.20	0.25	1	0.33	2.00	0.33
O4	2.00	1.00	3.00	1	2.00	2.00
O5	1.00	1.00	0.50	0.50	1	1.00
O6	0.33	0.50	3.00	0.50	1.00	1

Principal eigen value = 6.77

	O1	O2	O3	O4	O5	O6
Priority	26.22%	17.43%	8.02%	24.52%	12.36%	11.46%
Rank	1	3	6	2	4	5

Consistency Ratio = 12.34%

Threats

Decision Matrix

	T1	T2	T3	T4	T5	T6
T1	1	4.00	1.00	0.50	0.25	3.00
T2	0.25	1	2.00	0.50	0.33	3.00
T3	1.00	0.50	1	0.50	1.00	3.00
T4	2.00	2.00	2.00	1	1.00	3.00
T5	4.00	3.00	1.00	1.00	1	1.00
T6	0.33	0.33	0.33	0.33	1.00	1

Principal eigen value = 7.03

	T1	T2	T3	T4	T5	T6
Priority	17.53%	12.58%	13.96%	22.75%	25.29%	7.89%
Rank	3	5	4	2	1	6

Consistency Ratio = 16.38%

ANNEX 4

SWOT factors for LAC

Table 10 SWOT analysis for biogas at household level

Strengths	Relevance	Weaknesses	Relevance	Opportunities	Relevance	Threats	Relevance
environmental co-benefits not seen with other renewable energies	3	high costs of installation (need to also buy the new stove)	7	availability of local materials for construction	2	competition with other energy sources that are easily accessible and cheap (e.g. LPG is subsidised, solar is cheap, woodfuel is cheap/free)	7
production of digestate that can be used as fertiliser in vegetable gardens (reduced use of chemical fertiliser and better productivity)	3	requires time and effort to operate and maintain the digester	5	Improve health - replacement of fuelwood for cooking reduces respiratory diseases	2	lack of capacity on HOW to do biogas (due to lack of capacity building initiatives)	5
energy access for cooking	2	difficult to install biogas in city households where air pollution is worst		availability of feedstock	2	biogas seen as 'last resort' after all other energy options due to its complicated operation maintenance of AD compared with other energy sources (e.g. LPG)	5
time savings when replacing fuelwood for cooking	2	households require cooperative to produce enough feedstock		use of ADs where energy access is low		lack of understanding of the benefits of biogas	4
energy independence	2	implementation requires lots of skills and human resources		funding from government for training, capacity		climatic conditions (including temperature,	3

				building, and feasibility studies		access to water) can influence productivity	
valorisation of the organic waste of the family	2	low productivity due to lack of heating and mixing		positive impression of using residues		programmes that give ADs for free are not sustainable as the farmer/household does not see the value and will not maintain/repair it properly.	2
reduction in GHG emissions	2	need to heat digestate to kill pathogens – difficult for small scale ADs		tax exemptions on imports		lack of training in formal educational institutes	2
production of energy in isolated areas where there are no other energy sources		co-generation cost too high at small-scale		reduction in woodfuel use reduces pressure on forests		lack of national businesses in value chain that provide biogas products and services (increasing costs due to need for importation)	2
improvements in health from replacement of fuelwood for cooking				biogas can be used where LPG cannot be transported		areas where ADs could be inviting are the poorest areas that cannot afford them	2
costs				LPG stove can be converted to biogas for low cost		strict regulations of use of digestate for agriculture	
reduction in contamination of groundwater				Improved health - household waste management improvements reduce infectious diseases		fuelwood has already been replaced by LPG – limited health impacts of introducing biogas	

reduction of contamination of soil				gender – reduces time collecting biomass (women typically collect biomass)		policies for energy access focus on electricity	
reduction in costs to family in purchase of fuelwood				gender – household finances (women have to find money to buy fuelwood)		biogas at small scale does not produce electricity – and everybody wants electricity	
Improve family socio-economic conditions						at household scale, biogas cannot be commercialised to allow pay-back of loans used to construct it	
						no government incentives for biogas	
						lack of funding	
						safety regulations that make it more difficult to install an AD	
						lack of subsidies for renewable energy	
						technology providers are not paid to support maintenance	
						lack of standardised, adapted materials for ADs, e.g. UV protection, easy to install and easy to repair	
						cost of construction materials is expensive – PVC not eligible for tax exemption because used for many products	

						Biogas is not a priority investment for households	
						savings from buying chemical fertiliser not taken into account in financial formula	
						cultural unacceptability of cooking with animal/human waste	
						competition with improved wood cookstoves	
						Lack of coordination between ministries of government	

Table 11 SWOT analysis for biogas for productive and industrial use

Strengths	**Relevance**	**Weaknesses**	**Relevance**	**Opportunities**	**Relevance**	**Threats**	**Relevance**
Treatment/management of waste/residues	5	High initial investment cost	3	Tax exemptions (e.g. VAT on imports of equipment and income tax on utility) incentivise biogas uptake	6	Incompatability of animal husbandry (cows for meat are normally kept in the fields – difficult to collect manure; AND excessive dilution of residues due to washing)	7
Reduction in GHG emissions	5	transportation of feedstock and diluted digestate is costly	2	Creates skilled employment with improved wages	5	Poor functioning of carbon credit markets (e.g. high transaction costs of and low carbon value)	5

Sale/use of digestate as organic fertiliser	4	Complicated technology that requires time and effort for maintenance.	2	Availability of PPAs foster investment and provide income security	5	Financing problems (e.g. conservative banks that do not know biogas technology and this uncertainty around technology leads to high collateral/guarantees and lack of funding)	5
Reduction in contamination of waterbodies	4	Technology is not adapted to the realities of the country (e.g. CR - different phases in electricity grid creates incompatibility between electricity grid and generator)	2	Alignment with NAMAs and UNFCCC commitments	2	No government incentives specifically for biogas – e.g. tax breaks for electricity generated; feed-in tariffs; facilitation of credit; PPAs for renewable energy	4
Reduction of contamination of soil	3	High cost of more advanced technologies for upgrading biogas		Greater access to international markets due to meeting environmental requirements and selling 'green' product	2	Low cost of electricity means biogas is not competitive	3
Gives value to waste streams	3	Electricity generation is costly and inefficient		Environmental regulations on how to treat biomass/waste incentivise biogas uptake	2	Subsidies for alternative fossil fuels (e.g. LPG, heavy oil) means biogas is not competitive	3
Savings in disposal costs of agricultural wastes	2	Not cost competitive without incentives		Long-term sustainable feedstocks	2	No market for digestate	2

Digestate improves productivity when used as a soil amendment (as compared with untreated effluents)	2			Good for isolated areas (e.g. Waste/wastewater treatment in areas with no waste treatment/disposal facilities)	2	Unfavourable climatic conditions (temperature and humidity) for biogas production (more energy required to heat system)	2
Energetic autonomy	2			Government funding for co-financing biogas projects		Strict regulations of use of digestate for agriculture	2
Proper treatment of methane from landfills improves safety				Sale of electricity between private businesses (e.g. national policy – Market Time (MATER) – Argentina)		No capacity building initiatives	2
Predictability of biomass (more than solar and wind)				Use of carbon credits		Biogas not seen as a priority so people do not want to use their limited financial credit for investing in it	2
Savings of buying electricity (due to own production)				legislation making it mandatory for the gas utilities to buy biomethane and inject into the national gas grid		Economic models do not take into account the environmental and social externalities of biogas in financial evaluation of projects	2
Avoid environmental problems and the associated fines and problems with local communities				Funding from NGOs		No standards or regulations for the quality or safety of digestate	2

Reduction in chemical fertilizer use				Set of national requirements for the functioning of ADs (technical, meteorological conditions, etc.) to facilitate feasibility studies		Low capacities for operation and maintenance	2
On-farm use of biogas for refrigeration				Biogas pilots installed in education centres to demonstrate the benefits of the technologies to students		No coordinated policy on using biogas for national energy production	2
Increased income				Management of waste of multiple farms/businesses (and payment for this waste management as one of the income streams)		Lack of awareness and understanding of biogas technology	2
Favourable investment cost				Improve health - reduce sickness		Lack of companies that can operate the plants	
Local energy production				mandatory investment of oil industry and electric utilities to invest in R&D projects in renewable energy (e.g. Brazil)		Methane leakage as excess biogas is let out of AD and there is no flaring of because too expensive	
Improvement of carbon footprint of value chain				Creates economic system that brings jobs e.g. electrician technical support, supplier of raw		Projects are more expensive than international average	

				materials, equipment, etc.			
Long life-span				Reduction in imports of agricultural inputs		Lack of regulations for the disposal of wastes	
				National development banks have funding for renewable energy development (although maybe not specific to biogas)		Technology providers are not paid to support maintenance	
				Benefits for the whole community		Competition of digestate with highly concentrated chemical fertiliser	
						No institution that trains professionals for working with biogas	
						Threshold on size of plants without government support (smaller plants require feed-in-tariffs)	
						No technology for scrubbing or compression (upgrading) of biogas	
						Competition with LPG that is well established	
						No proper feedstock assessments	
						Subsidies for renewables are not an energy priority for policy	

						For urban waste need to change collection system to ensure separation of organics for anaerobic digestion	
						Automated system means that the plant does not require many people to work – low job creation	
						Sugarcane resiudues already have a value as a fertiliser	

ANNEX 5

Responses to online survey – Policies in Argentina

Please list the policies that you are aware of in your country/ies that facilitate the uptake of biogas at productive and industrial use scale (where more than one country, please specify).
• "Act 26093, enacted in May 2006, and its Regulatory Decree 109/2007, created the regulatory and promotional framework for the introduction of biofuels in the Argentine energy matrix. "Project for the Promotion of Energy Derived from Biomass" (PROBIOMASA) created in 2012. Two calls for tender were made for renewable energy for power generation. One tender had special conditions for biomass based energy. Bioeconomy policies and initiatives in the Agroindustry Government Secretariat (Food and Bioeconomy Secretariat/Directorate of Bioenergy)" • "Programa RenovAr" • "There is a renewable energy promotion law with mandatory quotas with increasing percentages of renewables that meet all the demand." • "Generation plans – RenovAr" • "PROBIOMASA (FAO + Ministry of Agroindustry) tangentially addresses it. It is the oldest and most expanded program. Currently the RENOVAR renewable energy production credit programs have a specific chapter dedicated to biogas projects." • "law of renewable energies, decentralized renewable energies, and the so-called 'Mater', contracts between privates" • "Biofuels Law (16,093), RenovAr Program (tenders for renewable energy, Probiomasa Program of the Ministry of Agroindustry." • "Probiogás Program: This project was carried out between the Ministry of Environment and Sustainable Development and the United Nations Development Program (UNDP). The objective is to demonstrate that the plants and the systems of generation and use of biogas that generate organic urban solid waste, such as landfills and biodigesters, are sustainable from the technical, environmental, institutional and economic-financial point of view, so that they can be incorporated into integrated urban solid waste management (MSW) projects that are implemented and can be adequately operated by the municipalities." • "RenovAr Program 2016-2025"

- "Biogas and biodigesters Course (https://cursos.energizar.org.ar/cursos/informacion/8/curso-de-introduccion-a-los-biodigestores). PROBIOMASA, Project for the promotion of energy derived from biomass (http://www.probiomasa.gob.ar/sitio/es/capacitacion.php?play=0&clave=12)"
- "Probiomasa Project that opportunely generated the support for the development of RenovAr tenders in the area of biomass"
- "RenovAr"
- "Investment subsidies; RenovAr plan for the purchase of electricity"
- "RenovAr Program"
- "Integral Plan RenovAr Round 1, 1.5, 2 and 2.5; and specific financial policies"
- "RenovAr program. Resolution 19/19 for the use of biofertilizer. Increase in controls over effluent dumping."
- "RenovAr Plan, 105 anaerobic biodigestion plants, mostly located in the Province of Santa Fe."
- "Renewal tenders + certain financing lines (few given the context)"
- "PROBIOMASA: Secretary of the Government of Agribusiness. Promotion of energy derived from biomass."
- "PROBIOGAS: Secretariat of the Environment Government. Promotion of biogas production from Urban Solid Waste"
- "INTI - BIOGAS: National Institute of Industrial Technology INTI. It has a specific Work Area that studies techniques and technologies for the production of Biogas."
- "RENOVAR: Secretariat of Energy Government. It carries out tenders to increase the generation of Renewable Energies under a legal framework that guarantees the acquisition of the generated energy and offers quotas for energy generated from biomass."
- "PERMER: Energy Government Secretariat. Promotion of Renewable Energies in Rural Markets"
- "In 2015, Law 27,191 was passed, which establishes a 20% generation of electricity from renewable sources at the country level by the year 2025."

- “RENOVAR – Law 26190/2006 and its amending Law 27191/2016: "National Promotion Regime for the Use of Renewable Sources of Energy Destined to the Production of Electric Power".”
- “RENOVAR program for the supply of electricity from renewable energies.”
- “Resolution 19/2019 on the use and agricultural application of digestate from anaerobic digestion plants.”
- “There is a framework law 26.190 / 2006 "National Promotion Regime for the Use of Renewable Sources of Energy Destined to the Production of Electric Power" and regulations and public tenders to generate installed power (Tenders to renew). Within this, biogas is considered for the production of electricity. In terms of bidding prices, the prices assigned by the government are not as favorable as they are for wind and photovoltaic.”
- “PROBIOMASA Program”
- “RenovAr Plan (Law 27,191)”
- “The only policy I know is in the generation of electric power, where a higher rate per MWh generated from biogas than with other fuels is paid”
- “In the province of Santa Fe, the government has as a policy the development of bioenergies, especially biogas. Today we have the following programs: Energy Education (107 biodigesters in schools), Production + Energy (Pre-feasibility study and basic engineering for companies), Digestion + Active (Recovery of unused biodigesters), Provincial Certification Made with Renewable Energies (Certification Energy) https://www.santafe.gov.ar/index.php/web/content/view/full/202790”
- “There are specific calls for renewable energy focused in electricity called Plan RenovAr. Within those calls there is a specific section for biogas projects.”
- “RENOVAR (electricity production tenders)”
- “Agronomic use of digestate - environmental secretary – government”
- “Renewable energy calls – RENOVAR”

In your opinion, what extra policies are required to stimulate the development of biogas?

- “An open window program with clear rules and an adequate financing policy”
- “Economic recognition of positive externalities with respect to the use of waste, reduction of pollution of water, soil, air and atmosphere. Possibility of commercializing the waste of the digest as biofertilizer.”
- “Enable commercialization of organic Fertilizer from biodigesters. Regulate injection of purified biogas to the natural gas network. Regulate distributed energy law with benefits to those who inject into the network.”
- “Economic incentives are required to close the cycle, currently a very low price is paid for energy derived from biogas. In turn, specific policies aimed at promoting the development of this technology (including its effect on the circular economy) such as tax benefits, clear long-term rules and / or greater financing.”
- “A municipal assistance policy that technically and economically allows thousands of rural municipalities that today have thermoelectric generation, to use their urban waste and local agroindustry. Also helping to give a solution to the waste.”
- “Update the National Biofuels Law”
- “Policies that promote the circular economy in productive processes in order to value externalities that produce biogas projects. For example, reducing transport costs and consequently fuel.”
- "Develop plans for small generators, due to the fact that in order to produce minimum MWh, large agricultural undertakings are necessary that make it impossible for small and medium producers to industrialize and become generators. The inclusion of these small and medium-sized generators generates the rapid diffusion of technology if it becomes a profitable option.”
- “Wastewater treatment, which is carried out by the state, should be one of the pioneers in stimulating development.”
- “The bioenergy policy requires a long-term commitment, adequate financing tools for the sector and intensive training.”
- “There is a need to promote a better use of energy output (biomethane, thermal use etc.). Also there is a need to develop other by-products as fertilizers.”

- “Make tax discount for imports of equipment and different components broader and more real; harder policies of rollover parameters for agro-industrials; development of specific supplier of component and component for biogas industry.”
- "Rules-standards for the design of biogas plants”
- “Rules-standards for the use of biomethane injection in existing pipelines”
- “Rules-standards for the use of RNG (Renewable Natural Gas - compressed biogas) in vehicles”
- “Integral and efficient use of energy produced; carbon tax; and residue treatment enforcement.”
- “Policies that look at biogas for uses other than power generation (use of the biomethane, for example).”
- “Bigger tax incentives; Duty Free imports for biogas technology; and legislative advantages for the use of digestate.”
- “It is necessary to promote biogas for thermal energy or to be used as compressed biomethane (CNG) or virtual gas pipeline to displace LNG”
- “Include in RenovAr: take into account the labour used as social employment policy and not just a cheap rate.”
- “I think the approach is adequate, lack resources to reinforce it.”
- “The externalities of the biogas are not taken into account neither in the final prices of the energy nor in the promotion benefits, a true shame.”
- “Integrate biogas into the primary energy matrix. Include anaerobic digestion as one of the key technologies for the climate change agenda and compliance with the commitments of the Paris agreement. Seeking to understand their role from the management of urban, agro-industrial and agricultural waste.”
- “Argentina is experiencing a very severe economic problem, which motivates the lack of financial policies that allow the development of this technology.”

- “Implementation of sustainable development policies that demonstrate the capacity in the efficient use of energy, articulating productive strategies for the promotion of projects with a tendency to the production of bioenergetics.”
- “Lines of financing according to the investment, laws that oblige the treatment of agro-industrial waste and promote the biogas as a form of treatment.”
- “Greater incorporation of national component”
- “I do not know the details: I estimate that financial benefits and stable contracts for a guaranteed minimum demand. All this for a certain period of time, then the project must be able to sustain itself. In many cases, it will be logical to install a biodigester to avoid the cost of acquiring energy, gas or electricity from an external supplier.”
- “Incorporation of a mixing quota for compressed gas”
- “Law for gas mixing with biogas”
- “Technological and regional development”
- "Feed-in-tariff for electric power”
- “Economic incentives and / or financing for small and medium producers or agro-industries”

ANNEX 6

AHP analysis of SWOT factors for Argentina

All AHP analysis was carried out using online software from "AHP Online System – BPMSG" (Goepel, 2018). The following sections provide the priorities given by the decision matrix for each of the categories of the SWOT analysis, along with the consistency ratio.

Strengths

Key for codes

Strengths	Code
Treatment/management of wastes and/or residues	S1
Reduction in GHG emissions	S2
Sale/use of digestate as organic fertiliser	S3
Reduction in contamination of waterbodies	S4
Reduction in contamination of soil	S5
Added value to waste streams	S6

Decision Matrix

	S1	S2	S3	S4	S5	S6
S1	1	5	5	0.333333	1	1
S2	0.2	1	0.333333	0.2	0.333333	0.333333
S3	0.2	3	1	0.333333	1	1
S4	3	5	3	1	3	3
S5	1	3	1	0.333333	1	1
S6	1	3	1	0.333333	1	1

Priority and ranking

	S1	S2	S3	S4	S5	S6
Priority	21%	4%	11%	37%	13%	13%
Rank	2	6	5	1	3	3

AHP Parameters

Principal eigen value	6.350751
Consistency Ratio (CR)	6%

Weaknesses

Key for codes

Weaknesses	Code
High initial investment cost	W1
Costly transportation of feedstock and diluted digestate	W2
Complicated technology that requires time and effort for maintenance	W3
Technology not adapted to the realities of the country	W4
High cost of advanced technologies for upgrading biogas	W5
Costly and inefficient technology for electricity generation	W6

Decision Matrix

Decision Matrix	W1	W2	W3	W4	W5	W6
W1	1	3	3	5	3	3
W2	0.333333	1	1	3	3	3
W3	0.333333	1	1	1	0.333333	1
W4	0.2	0.333333	1	1	0.333333	0.333333
W5	0.333333	0.333333	3	3	1	1
W6	0.333333	0.333333	1	3	1	1

Priority and ranking

Priority	37%	21%	10%	6%	14%	11%
Rank	1	2	5	6	3	4

AHP Parameters

Principal eigen value	6.496754
Consistency Ratio (CR)	8%

Opportunities

Key for codes

Opportunities	Codes
Incentivising biogas through tax exemptions	O1
Creation of skilled employment with improve`d wages	O2
Fostering investment and providing income security through PPAs	O3
Alignment with NAMAs and UNFCCC commitments	O4
Greater access to international markets due to meeting environmental requirements and selling 'green' product	O5
Incentivising biogas through environmental regulations on waste treatment	O6

Decision Matrix

Decision Matrix	O1	O2	O3	O4	O5	O6
O1	1	3	0.2	1	1	0.333333
O2	0.333333	1	0.333333	1	3	1
O3	5	3	1	5	5	1
O4	1	1	0.2	1	1	0.333333
O5	1	0.333333	0.2	1	1	0.333333
O6	3	1	1	3	3	1

Priority and ranking

Priority	12%	13%	36%	8%	7%	24%
Rank	4	3	1	5	6	2

AHP Parameters

Principal eigen value	6.572458
Consistency Ratio (CR)	9%

Threats

Key for codes

Threats	Codes
Incompatibility of animal husbandry	T1
Poor functioning of carbon credit markets (i.e. high transaction costs and low carbon value)	T2
Financing problems (i.e. high collateral/guarantees and lack of funding)	T3
No government incentives specifically for biogas	T4
Low cost of electricity means biogas is not competitive	T5
Subsidies for alternative fuels (e.g. LPG, heavy oil) means biogas is not competitive	T6

Decision Matrix

Decision Matrix	T1	T2	T3	T4	T5	T6
T1	1	0.333333	0.142857	0.2	0.333333	0.142857
T2	3	1	0.2	0.2	0.333333	0.2
T3	7	5	1	1	3	1
T4	5	5	1	1	3	0.333333
T5	3	3	0.333333	0.333333	1	0.333333
T6	7	5	1	3	3	1

Priority and ranking

Priority	3%	6%	26%	22%	10%	33%
Rank	6	5	2	3	4	1

AHP Parameters

Principal eigen value	6.269125
Consistency Ratio (CR)	4%

ANNEX 7

SWOT factors for Asian countries

Household-decentralized level

		ITEM	SOURCE	Frequency
INTERNAL ORIGIN	STRENGTHS (S)	Substitution of kerosene, firewood, LPG and coal (S_1)	(Bhattacharya, Thomas and Salam, 1997) (Bond and Templeton, 2011) (Tam and Thanh, 1983) (Wang *et al.*, 2016) (FAO, 2018) (FAO, 2012)	6/31
		Reduce GHG emissions (S_2)	(Bhattacharya, Thomas and Salam, 1997) (Liang *et al.*, 2008) (Wang *et al.*, 2016) (IEA Bioenergy, 2019) (ESCAP- United Nations, 2007) (Deng *et al.*, 2017)	6/31
		Public health improvement (S_3)	(Bond and Templeton, 2011) (ESCAP- United Nations, 2007) (Deng *et al.*, 2017)	3/31
		Reduction of deforestation (S_4)	(Tam and Thanh, 1983) (Bond and Templeton, 2011)	2/31
		Availability of feedstocks (S_5)	(FAO, 2018) (Tam and Thanh, 1983) (Bhattacharya, Thomas and Salam, 1997) (ESCAP- United Nations, 2007)	4/31
		Thermal energy generated as consequence of electricity production (S_6)	(FAO, 2018) (FAO, 2012)	2/31
		By-product can be used as natural fertilizer (S_7)	(Wang *et al.*, 2016) (SNV, 2018) (Bhattacharya, Thomas and Salam, 1997) (IEA Bioenergy, 2019) (ESCAP- United Nations, 2007) (Bond and Templeton, 2011) (Deng *et al.*, 2017)	7/31
		Valorization of the organic waste of families (S_8)	(ESCAP- United Nations, 2007)	1/31
	WEAKNESSES (W)	Lack of maintenance of digesters (W_1)	(Bond and Templeton, 2011) (Cheng *et al.*, 2013) (FAO, 2012) (Tam and Thanh, 1983)	4/17
		Lack of planning and feasibility studies (W_2)	(Tam and Thanh, 1983) (FAO, 2012) (FAO, 2018)	3/17
		High cost (W_3)	(Tam and Thanh, 1983) (Cheng *et al.*, 2013) (Bond and Templeton, 2011) (FAO, 2018) (Liang *et al.*, 2008)	5/17
		Low efficiency in the use of biogas (W_4)	(Tam and Thanh, 1983) (Cheng *et al.*, 2013)	2/17
		Structure, principles and performance of digester vary from country to country. (W_5)	(Cheng *et al.*, 2013)	1/17
		Lack of heaters for winter conditions (W_6)	(FAO, 2018) (Bond and Templeton, 2011)	2/17

		ITEM	SOURCE	Frequency

		Potential feedstocks that are not currently used (O_1)	(Bhattacharya, Thomas and Salam, 1997) (Tam and Thanh, 1983)	2/21
		International support (O_2)	(SNV, 2018) (Ghimire, 2013) (Bond and Templeton, 2011) (Liang *et al.*, 2008) (FAO, 2018) (FAO, 2012) (Wang *et al.*, 2016) (Anenberg *et al.*, 2013) (FAO, 2007) (Pappalardo, 2019)	10/21
		High cost of traditional fuel sources (O_3)	(Pappalardo, 2019) (Tam and Thanh, 1983) (Takeshita, 2009)	3/21
		Availability of prefabricated digesters (O_4)	(Pappalardo, 2019) (IRENA, 2017)	2/21
		Carbon credit trading (O_5)	(Cheng *et al.*, 2013)	1/21
		Government subsidies or tax exemptions (e.g. China and India) (O_6)	(Liang *et al.*, 2008)	1/21
		Woman empowerment (O_7)	(IRENA, 2017)	2/21
	THREATS (T)	Low acceptance due to cultural beliefs (T_1)	(Personal Communication with expert, 2020) (Tam and Thanh, 1983)	2/14
		Less expensive energy sources (T_2)	(IRENA, 2017) (Liang *et al.*, 2008) (FAO, 2012)	3/14
		Rapid development of urban areas, and the consequent migration of people to urban cities (T_3)	(IRENA, 2017)	1/14
		Lack of financial support (T_4)	(Wang *et al.*, 2016) (Tam and Thanh, 1983) (Cheng *et al.*, 2013) (Bond and Templeton, 2011) (FAO, 2018)	5/14
		Lack of Know-How knowledge regarding operations and maintenance (T_5)	(Liang *et al.*, 2008) (Tam and Thanh, 1983)	2/14
		Natural disasters (T_6)	(FAO, 2012)	1/14

Centralized level

		ITEM	**SOURCE**	**Frequency**

	STRENGHTS	Availability of feedstocks (S_1)	(Cheng *et al.*, 2013) (Bhattacharya, Thomas and Salam, 1997) (Tam and Thanh, 1983) (FAO, 2018) (Wang *et al.*, 2016) (Ggnanasagaran, 2018)	6/31
		Sale / Use of by-products as fertilizers (S_2)	(Junginger, Koppejan and Goh, 2019) (Bhattacharya, Thomas and Salam, 1997)(SNV, 2018) (Ghimire, 2013) (Wang *et al.*, 2016) (Ggnanasagaran, 2018) (IEA Bioenergy, 2019) (FAO, 2018)	8/31
		Reduction in GHG emissions (S_3)	(ESCAP- United Nations, 2007) (Bhattacharya, Thomas and Salam, 1997) (Ggnanasagaran, 2018) (Junginger, Koppejan and Goh, 2019) (Junginger, Koppejan and Goh, 2019)	5/31
		Local health improvement (S_4)	(ESCAP- United Nations, 2007) (Bond and Templeton, 2011) (ESCAP- United Nations, 2007) (Deng *et al.*, 2017)	4/31
		Added value to waste streams (S_5)	(Buysman and Mol, 2013) (Sherrard, 2016) (Ggnanasagaran, 2018)	3/31
		Money and time savings by the use of improved cook stoves (running with biogas) (S_6)	(ESCAP- United Nations, 2007) (Ggnanasagaran, 2018) (Wang *et al.*, 2016)	3/31
		Odour reduction	(IRENA, 2017) (Giuliani, 2020)	2/31
	WEAKNESSES	Lack of planning and feasibility studies (W_1)	(Personal Communication with expert, 2020) (FAO, 2018)	2/13
		High capital investment needed (W_2)	(FAO, 2012) (FAO, 2018) (ESCAP- United Nations, 2007) (IRENA, 2017)	4/13
		High maintenance cost (W_3)	(Bond and Templeton, 2011) (FAO, 2012) (ESCAP- United Nations, 2007)	3/13
		Structure, principles and performance of digester vary from country to country. (W_4)	(Cheng *et al.*, 2013) (Tam and Thanh, 1983)	2/13
		High operation costs under winter conditions (W_5)	(Cheng *et al.*, 2013) (ESCAP- United Nations, 2007)	2/13

		ITEM	SOURCE	Frequency
EXTERNAL ORIGIN	OPPORTUNITIES	Government and International support (O_1)	(FAO, 2018) (Wang *et al.*, 2016) (Pappalardo, 2019) (FAO, 2012) (ESCAP- United Nations, 2007)	5/19
		Increase in the use of energy in Asia and high cost of traditional fuel sources. (O_2)	(FAO, 2007) (Tam and Thanh, 1983) (Takeshita, 2009) (Pappalardo, 2019)	4/19
		Improve the livelihood of the local population (O_3)	(Cheng *et al.*, 2013) (Sherrard, 2016) (Ggnanasagaran, 2018)	3/19
		Use of wasted residues (O_4)	(Bioenergy International , 2019) (FAO, 2012) (Bhattacharya, Thomas and Salam, 1997)	3/19
		Government subsidies and tax exemptions. (O_5)	(Tam and Thanh, 1983) (IRENA, 2017)	2/19
		Woman empowerment (O_6)	(Bond and Templeton, 2011)	2/19
	THREATS	Cost increase during winter (T_1)	(Personal Communication with expert, 2020) (ESCAP- United Nations, 2007) (Cheng *et al.*, 2013)	3/18
		Low acceptance due to cultural beliefs (T_2)	(Bond and Templeton, 2011) (Tam and Thanh, 1983)	2/18
		Subsidies for Fossil Fuels, making biogas less competitive (T_3)	(ESCAP- United Nations, 2007) (ESCAP- United Nations, 2007) (Asian Development Bank, 2016)	3/18
		Lack of maintenance due to lack of qualified technicians (T_4)	(FAO, 2012) (Tam and Thanh, 1983) (Bond and Templeton, 2011) (Cheng *et al.*, 2013) (ESCAP- United Nations, 2007)	5/18
		Lack of regulation/policies specific for biogas. (T_5)	(IRENA, 2017) (IRENA, 2017)	2/18
		Natural Disasters (Earthquakes, Tsunamis, etc.) (T_6)	(Bond and Templeton, 2011)	1/18
		Regulation of the use of by-products (T_7)	(Personal Communication with expert, 2020)	1/18
		High costs of feedstocks caused by the increase on prices by the industries which intend to increase profit from their by-products. (T_8)	(Personal Communication with expert, 2020)	1/18