Demonstrating the potential of biogas to contribute to the SDGs

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Executive Summary

Introduction

This report analyses the contribution of biogas towards SDGs 2 (Zero Hunger), 7 (Affordable and Clean Energy) and 13 (Climate Action). In doing so, it addresses four research questions:

1. How can the direct impacts of biogas support the achievement of the SDGs (specifically SDGs 2, 7 and 13)?
2. What are the best mechanisms (including but not limited to climate financing, pay-for-success models and other impact monetisation) to expand the use of this technology based on its impact?
3. How can this impact be better tracked, measured, and understood?
4. How does this impact vary between different market segments?

This paper was produced by IPE Triple Line for the Shell Foundation, in close partnership with Sistema.bio, a social enterprise which manufactures, markets, and sells bio-digesters to low-income farming communities in Central America, East Africa, and South Asia.

Context

Biogas is an environmentally friendly renewable fuel produced by the breakdown of organic waste. Bio-digesters facilitate this process and capture the methane produced by the anaerobic digestion of waste. The organic waste is primarily animal manure, although specialised bio-digesters can also process a range of other organic material. Biogas is a versatile fuel that can be used for cooking, heating, lighting, power generation, as well as in transport applications. In addition, bio-digesters produce a substrate called bio-slurry as a by-product. This is an effective organic fertiliser which has a significant positive impact on yields and on long-term soil health.

Bio-digesters can be deployed in a range of different contexts, including on an industrial scale on large commercial farms and processing facilities, at a community level, and on a household-level for smallholder farmers. The focus of this report is on household-level systems. These typically produce enough gas for household cooking, whilst larger systems may also produce surplus gas to be used in heating or as energy for productive assets (e.g. refrigerator facilities for storing milk).

Bio-digesters typically require at least two cows (or equivalent livestock) to produce enough organic waste to have a meaningful impact for a household, as well as access to water. Bio-digesters are typically sold on credit provided by the distributor, recognising that the up-front cost is beyond the means of most smallholder farmers.

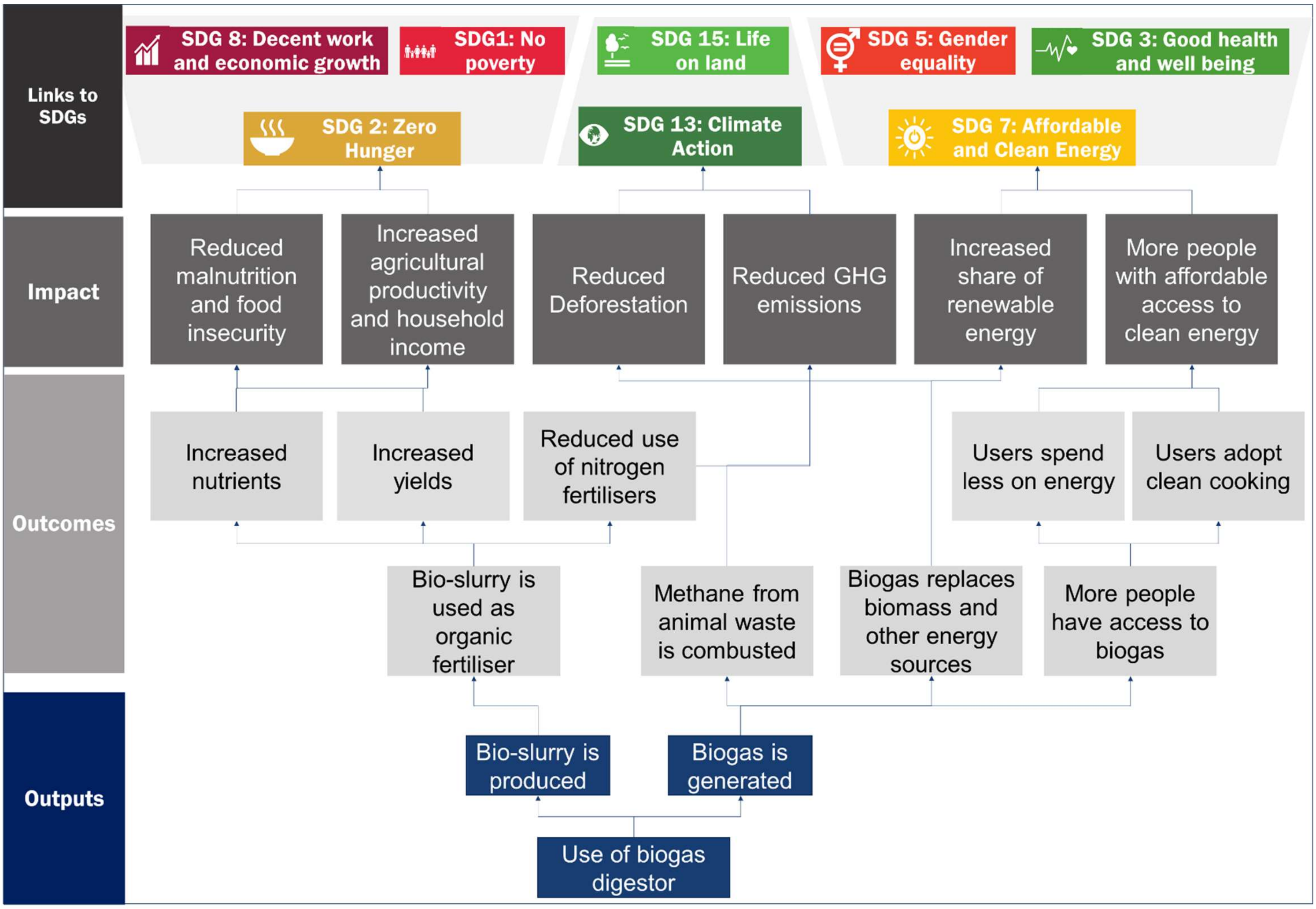
Biogas has significant potential as a technology to enable energy access, improve the economic returns to smallholder farming, address climate change, and mitigate health concerns – but this potential is largely unrealised. In Africa, for example, there are estimated to be over 30 million households with the right conditions to adopt biogas, but the number of installed and operational bio-digesters is less than 1% of that. The market is similarly under-developed in Central and South America. An important exception to this global picture is East Asia, and particularly China, where biogas accounts for 12% of total energy use. Historically, China has accounted for over 90% of biogas installations, demonstrating that the technology can work at significant scale. The potential of biogas as an impact technology is increasingly recognised, as demonstrated by the major World Bank report *The Power of Dung*, released in 2019.

Assessing biogas' contribution to the SDGs

The project team employed a Theory of Change (ToC) approach to illustrate the relationship between biogas and SDGs 2, 7, and 13 (see Figure 1). A ToC is a tool to map out impact pathways and highlight complex causal mechanisms in an easily accessible visual way. Analytically, a ToC enables clear identification of the 'intermediary stages' between biogas products and their impact on specific SDGs.

Using the Theory of Change as a framework, we assessed the strength of evidence for each impact pathway, drawing upon secondary research, data provided by Sistema.bio, and stakeholder interviews. This helped illustrate the robustness of the contribution to each SDG, and where there were evidence gaps. During this process, we also identified how impact varied between different groups and different market segments, addressing the fourth research question.

Figure 1. Biogas Theory of Change



SDG 2 – Zero Hunger

Biogas has a strong relationship with SDG 2 on Zero Hunger, with a clear link towards addressing food insecurity. This is most powerfully demonstrated with the impact of bio-slurry on the SDG 2 target around increasing smallholder farmer productivity and income. Improving smallholder productivity and increasing the supply of nutritious food to local markets is an essential mechanism in the global challenge of zero hunger and food insecurity. Productivity improvements are primarily due to the positive impact on yields and reduced malnutrition from using bio-slurry as an organic fertiliser. Although the extent of yield improvement varies by context, as an illustrative example bio-slurry has been shown to increase yields of maize in Kenya by 40%. In addition, application of bio-slurry can increase the nutritional quality of agricultural produce. This relationship holds across different contexts and crop types and is supported both by scientific studies as well as insights from farmers. The impact on yields is likely to be greatest for smaller farmers, where prevailing usage rates of fertiliser are lower. Bio-slurry also contributes to the development of more sustainable and resilient agricultural systems, which again has a strong relationship with ensuring food security in rural communities.

There is less explicit evidence that biogas directly addresses food insecurity for households that own bio-digesters. There is limited research on the extent to which biogas adopters are food insecure, but data from both from the wider literature and from Sistema.bio's own customer base that customers are unlikely to be at the bottom of the pyramid, and so unlikely to be food insecure in the first place. However, given the impact of bioslurry on yield and other cost savings, it is clear that biogas could make a significant impact on food insecurity for adopters – if their right support mechanisms were in place to enable bottom of the pyramid consumers to access the technology.

SDG 7 – Affordable and Clean Energy

Biogas clearly contributes towards increasing access to affordable and clean energy. Biogas is a clean energy with a positive environmental impact, and furthermore it typically displaces 'unclean' energies, such as traditional biomass and fossil fuels. As well as the environmental benefits, there are also significant health advantages in cooking with biogas compared with alternative energy sources, particularly wood and other biomass sources on traditional stoves.

A bio-digester also generates significant energy savings. The extent of these savings will depend on the type of bio-digester, prevailing energy sources, and the degree that other energy sources are fully displaced by biogas. Through generating energy savings, biogas makes energy more affordable for low-income populations. However, whilst the energy savings from a bio-digester will pay-back the cost of purchase well within the 20-year lifespan of the bio-digester, it will typically not generate enough short-term savings to cover the cost of repayments over a typical 1-2 year repayment period.

SDG 13 – Climate Action

There is a robust link between biogas and SDG 13. Combustion of biogas captured via a bio-digester converts methane that otherwise would be released directly into the atmosphere into carbon dioxide. Given that methane is a much more powerful greenhouse gas, the net effect of this process is beneficial to the environment. Furthermore, the use of biogas in cooking typically displaces other, non-sustainable energy sources, including biomass, kerosene, and Liquified Petroleum Gas (LPG). These energy sources all are contributors to greenhouse gas emissions.

Widespread adoption of biogas may also lead to reduced deforestation. There is clear evidence that biogas displaces wood as a fuel source, and that a significant of proportion of wood used in cooking derives from non-renewable sources. However, there is limited research on the direct link between biogas and reduced deforestation, either at a local or a community level.

Using impact-based monetisation to scale biogas

As described above, biogas generates significant impact across multiple SDGs, with strong evidence across SDGs 2, 7 and 13. This opens more options for the expansion of the technology, by leveraging the impact of biogas to raise financing from other stakeholders. This section sets out the challenges to expansion, before exploring different impact-based monetisation mechanisms from the perspective of biogas companies.

Biogas' business model is cash-intensive, requiring significant financing for the manufacture of bio-digesters, marketing, sales, and providing a repair and maintenance network. Given that trained mechanics need to install and maintain the system, it is more difficult to cut costs by partnering with other distributors. Furthermore, biogas companies normally offer bio-digesters on credit, which is a necessity given the cost of the bio-digesters relative to the household income of their customers – household level bio-digesters typically cost between $500 to $1000, which is beyond the means of smallholder farmers without credit. However, this creates a significant cash-flow cycle, with biogas companies taking up to two years to realise the cash from a sale. It also means that biogas companies must be able to assess the creditworthiness of customers to some degree of accuracy and increases the risks of expanding to new geographies and markets as customer profiles change.

This report sets out several impact-based mechanisms for financing the expansion of biogas. Although widely prevalent and likely to continue playing a significant role, grant-based funding is not a sustainable mechanism and does not offer the long-term stability needed to drive expansion. Carbon-offsets is an encouraging market that has been growing rapidly, and platforms such as Gold Standard have recognised and marketed the impact of biogas. After the initial costs of certification, funding can be used flexibly and does not create balance sheet liabilities. Crowd-based financing has also been growing extremely rapidly and can now fund large multi-million credit sizes over a multi-year period. However, particularly at larger deal sizes the interest rates are significant and can create currency mismatches on the balance sheets of biogas companies. Other mechanisms explored in this paper include development impact bonds, off balance-sheet securitisation, and governmental subsidy programmes. Development impact bonds are still at a nascent stage, off balance-sheet securitisation requires significant portfolio sizes to be cost-effective, and government subsidy programmes are dependent on local political will and budget capacity.

To support both biogas companies and funders understand where to target their support, each impact monetisation mechanism was mapped onto the four key stages of growth: product developing, initial piloting, transition to scale, and scale and expansion. This provides a framework for biogas companies to understand what financial instrument they should be aiming for given their level of development, and for investors, donors, and governments on where they are best placed to provide support.

Table 1. Identifying the right mechanism to support different stages of growth

Impact monetisation mechanism	Product development	Piloting phase	Transitions to scale	Scale up and expansion
Grants	●	●	●	○
Equity impact investment	●	●	○	○
Debt impact investment			●	●
Carbon financing			●	○
Crowd-sourced financing		●	●	
Securitisation			○	●
Development impact bonds		○	●	○
Government subsidy programmes	○	○	○	●

Key

● Mechanism is targeted towards supporting this stage of growth

○ Mechanism is partially targeted towards supporting this stage of growth

Measuring, tracking, and understanding the impact of biogas

Impact-based monetisation requires clear and rigorous results measurement, to demonstrate and persuade stakeholders that this impact is worth financing. This means developing systems to measure, track, understand, and communicate the impact of biogas to external stakeholders. Using the Theory of Change and drawing on pre-existing global indicator frameworks, we developed a comprehensive and straightforward set of indicators to assess biogas' contribution to SDGs 2, 7, and 13. In addition to providing definitions of indicators and mapping them onto the Theory of Change, there is also guidance on how indicators should be used and how they can be integrated into pre-existing data collection systems. A summary is set out in Table 2 below.

Table 2. Suggested indicators – Summary table

TOC hypothesis	#	Indicator	SDG 2	SDG 7	SDG 13	Ease of collection
Increased number of people have access to biogas	1	**Number of new people with access to biogas**		X		
	1.1	**Number of new households with access to biogas**				
	1.2	**Number of people per new household with access to biogas**				
Methane from animal waste is converted through combustion	2	**Amount of manure used in bio-digester over the reporting period**	X		X	
Bio-slurry is used as organic fertiliser	3	**Number of customers using bio-slurry as organic fertilisers for the first time.**	X		X	
	3.1	**Number of customers applying fertilisers properly**				
Increased yields	4	**Number of customers reporting increased yields following the use of bio-slurry as fertiliser for the first time**	X		X	
	5.1	**Average percentage yield increase**				
Reduced use of nitrogen fertilisers	6	**Number of customers reporting reduced use of nitrogen fertilisers for the first time**	X		X	
	6.1	**Total decrease in nitrogen fertiliser consumption over the reporting period**				
Users spend less on energy	7	**Number of customers reporting energy savings for the first time**	X	X		
	7.1	**Average decreased in spending on energy**				
Biogas replaces biomass and other GHG emitting sources of energy	8	**Number of households reporting reduced consumption of biomass and other GHG emitting sources of energy for the first time.**		X	X	
	8.1	**Average reduction in GHG emitting sources of energy**				
Users adopt clean cooking	9	**Number of customers using clean cookstoves for the first time**		X		
Increased nutrients	10	**N/A**	X			

In combination with collecting quantitative data, this report also emphasises the importance of qualitative data collection, and sets out two methodological tools – 'outcome harvesting' and 'most significant change' – to collect data. Qualitative data collection is critical in developing a holistic overview of impact, and in understanding impact from the customer and beneficiary perspective. It also helps to generate powerful stories which can be used in communication and marketing material.

Conclusions

Biogas has a robust relationship with SDGs 2, 7, and 13, generating significant economic, social, and health impacts for low-income smallholder farmers whilst also contributing to the global challenges of climate change. Importantly, there is strong evidence for the most important impact mechanisms across geographies, contexts, and target groups, including the impact of bio-slurry on agricultural yield, the displacement of greenhouse gas emitting energy sources, and the reduction in methane emissions from animal waste. To a large extent, these findings are generalisable, despite the different contexts in which bio-digesters are employed.

There are a range of impact-based financing mechanisms which biogas companies could use to scale. Perhaps the most promising in the short-run whilst companies are still seeking to scale are carbon-offsets and crowd-based financing. Biogas companies with significant customer portfolios could also explore off balance-sheet securitisation, whilst development impact bonds may develop as a more feasible funding option in the future.

Contents

1 Introduction

This report examines the impact of biogas, specifically in relation to SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). It was produced by IPE Triple Line for the Shell Foundation, working in close partnership with Sistema.bio, a social enterprise which manufactures, markets, and sells bio-digesters to low-income smallholder farmers in Central America, East Africa, and South Asia.

Report structure

The structure of this report is as follows:

- Section 2: Methodology – setting out the research questions, the approach, and the objectives of this paper
- Section 3: Context – providing an overview of biogas technology, current usage, potential market size, and key enabling environment factors
- Section 4: Assessing biogas' contribution to the SDGs – using Theories of Change to map out how biogas contributes towards the SDGs, and conducting a rigorous strength of evidence assessment
- Section 5: Using impact to scale – analysis of biogas' financial constraints to scale, and of the advantages and disadvantages of different impact monetisation mechanisms
- Section 6: Measuring and tracking biogas' contribution to the SDGs – presenting a quantitative framework of indicators which maps onto the Theories of Change for biogas, as well as qualitative tools to develop a holistic picture of impact
- Section 7: Conclusions

2 Methodology and research questions

2.1 Research questions

The Terms of Reference set out 4 research questions for the study to answer. These are:

1. How can the direct impacts of biogas support the achievement of the SDGs (specifically SDGs 2, 7 and 13)?
2. What are the best mechanisms (including but not limited to climate financing, pay-for-success models and other impact monetisation) to expand the use of this technology based on its impact?
3. How can this impact be better tracked, measured, and understood?
4. How does this impact vary between different market segments?

The methodology employed in this research was based on the following two principles:

- Leveraging the experience, data and knowledge of Sistema.bio by working in close collaboration throughout this research;
- Orientating research towards documenting evidence and generating learning in a way that is relevant, useful and accessible to investors and policymakers.

2.2 Mapping out links to SDGs with Theories of Change and understanding impact between different market segments

We have answered the first and fourth research questions by using Theories of Change supported by a strength of evidence assessment, to give stakeholders a visual and credible demonstration of how biogas links to the SDGs.

Step 1 - Developing Theories of Change (ToC)

To address the first research question, we have used ToC to map out the links between biogas products and the SDGs, based on collaborative workshops with Sistema.bio and the Shell Foundation. A ToC is a tool that maps out impact pathways between an activity or intervention and a high-level impact, and highlights complex causal mechanisms in an easily accessible visual way. Analytically, a ToC enables clear identification of the 'intermediary stages' between the use of biogas products and their impact on specific SDGs. By identifying the outcomes that must be in place (and how these relate to each other causally), it helps to uncover critical assumptions that can then be validated and tested.

Step 2 - Assessing the strength of evidence

Once the impact pathways were defined, we assessed the strength of evidence for each linkage and underlying assumption. This helped illustrate the robustness of the data supporting each linkage, and where the evidence gaps were. During this process, we also identified how impact varied between different groups and different market segments, addressing the fourth research question.

2.3 Using impact to scale

Our focus then shifted to exploring how biogas technology could be scaled, leveraging the impact identified in the strength of evidence assessment.

Based on Key Informant Interviews (KIIs), and a short literature review, we identified:

- What financial constraints to scale biogas companies faced, based both on the business model and typical funding mechanisms
- Which funding modalities are appropriate for biogas companies at different stages of growth

2.4 Tracking, measuring, and understanding impact

Impact-based monetisation requires frameworks for tracking and measuring impact, to demonstrate and verify to external stakeholders that their financing is generating impact. Our approach to developing better impact indicators built on our Theory of Change, using that framework to identify indicators and proxy metrics. We took a two-fold approach. Firstly, we assessed existing global and industry impact frameworks, and secondly identified proxy metrics which mapped onto the Theory of Change that companies could use to track impact.

Step 1 –Assessment of existing measurement frameworks

We identified indicators that mapped onto the Theory of Change. Sources included the Global Indicator Framework for the SDGs, the Impact Assessment Tools piloted by the Clean Cooking Alliance, and IRIS+, a framework developed by the Global Impact Investing Network (GIIN). We engaged with Sistema.bio and other companies operating in this space to understand the types of data they were collecting as part of their normal business operations.

Step 2 –Identification of proxy metrics

We have tried to identify simple, proxy metrics that build on existing data, which linked to global frameworks for assessing progress towards the SDGs. The Theory of Change helped identify the use of proxy metrics to assess higher-level outcome and impact indicators. In answering the third research question, we worked with Sistema.bio to understand their perspective on data collection expectations, and how they use impact data when engaging with donors, investors, and policymakers.

3 Context

3.1 The technology and its potential

3.1.1. What is biogas, and what are bio-digesters?

Biogas is an environmentally friendly renewable fuel produced by the breakdown of organic matter such as food scraps, animal and human waste by microorganisms in the absence of oxygen in a process of anaerobic digestion. A closed environment where this can take place is known as a bio-digester. Biogas can be used in a variety of ways including as vehicle fuel and for heating and electricity generation.

A bio-digester breaks down organic material in an oxygen-free environment to produce a renewable energy source, biogas and a substrate, bio-slurry, that can be used as fertiliser. Biogas is a versatile fuel that can be used for cooking, heating, lighting, and power generation, as well as in transport applications.

3.1.2. Types of bio-digesters

There are a number of different types of bio-digester. The focus of this study is domestic and smaller scale rural installations rather than large scale commercial types. These are described in the table below.

The primary difference between bio-digesters is between batch and continuous plants. Batch biogas designs are filled completely and then emptied completely after a fixed time period. Large gasholders for storage or a series of bio-digesters are required for uniform gas supply from batch plants.

Table 3: Type of bio-digesters[1]

Type of digester	Description	Regional deployment
Fixed-dome plant	Inlet chamber feeding into the digester which is topped by a dome expansion chamber with a gas release point.	Primarily in China, but also employed in diverse developing countries
Floating drum plant	Underground digester and moving gas-holder. Gas is collected in a gas drum which rises and falls according to the amount of gas connected.	India
Ballon/bag digester	Plastic bag connected to an input pipe, introducing the feedstock. An output pipe which removes the slurry, and a third pipe from the top of the back functions as the biogas outlet pipe	Mainly Latin American countries

Continuous biogas designs can be filled and emptied on an ongoing basis. The continuous types of biogas designs are more suitable for rural households as they enable a constant supply of gas without additional infrastructure.

The type of bio-digester sold by Sistema.bio is a lightweight bag digester that use balloon or tubes made from polyethylene or a plastic bag. They have several advantages in that they are cheaper, use less material, can be set up in a single day, require less manure for start-up, and convert waste into energy more quickly.

3.1.3. What is the size of the market?

The potential for impact is linked first and foremost to the potential for market growth. According to the International Energy Agency (IEA), biogas has the potential to deliver close to 600 million tonnes of oil equivalent (Mtoe) of low-carbon energy, and developing countries account for two third of this global potential. In particular, smallholder farmers represent a market with an attractive growth potential. Small and family-operated farms make up most of the world's 570 million of farms. [2,3] Overall, the FAO estimates that 72% of these farms operate on less than one hectare.[4] It is estimated that about half of small farms produce sufficient organic waste to power a Sistema.bio anaerobic digester[5], a number expected to grow as the demand for livestock product is projected to double over the next 20 years.[6]

At the same time, smallholder farmers have a high need to improve their productivity, not only to meet the growing demand for food, but also to reduce poverty, and demand for fertiliser is thus strong. However, the price of fertiliser is often a key barrier for smallholder farmers. In addition, smallholder farmers also have unmet energy needs. They often lack access to energy for household consumption and productive use – for instance to power irrigation systems and agricultural equipment. Globally, about 770 million people still live without access to electricity.[7] Bio-digesters thus have the potential to appeal to smallholder customers by meeting their demand for both energy and fertilisers, and reducing associated costs.

To date, there are close to 50 million micro-scale digesters and biogas stoves worldwide. According to IRENA statistics, global electricity generation from biogas grew from 46,108 GWh in 2010 to 87,500 GWh in 2016, which represents a 90% growth in six years and reflect a growing demand for bio-digesters.[8] Over the next 7 years, the overall market for bio-digesters is expected to growth at a compound annual growth rate of 6%.[9]

Africa

The market for small scale bio-digesters remains underdeveloped.[10] SNV Netherlands Development Organisation estimates that the number of households qualifying for digesters in Africa amounted to 32.9 million in 2018[11], yet the number of installed bio-digesters is less than 1% of that. The two main drivers for the technical potential for household bio-digester are the number of cattle (at least 3 heads) on-yard and the number of agricultural households having access to water.[12] Biogas in Africa is produced mostly from agricultural waste and human excrement in urban settings[13] since livestock waste and agricultural residues are hard to collect from widespread grazing lands. In particular, livestock, agricultural and horticultural production sites can offer scaling opportunities for biogas feedstock. Alternatively, lower-cost small-scale digesters and other models may make rural biogas production more practical. Even though biogas systems in Africa have high upfront costs of USD 500 to USD 1,500, they are cost effective. For instance, lifetime costs are the lowest among cooking technology options, which makes them competitive[14]. Based on an SNV study, countries with the greatest technical potential biogas markets are:

Table 4: Biogas potential by country

Country	Biogas potential (number of households, thousands)
Egypt	1,054
Ethiopia	5,429
Kenya	2,230
Mali	1,398
Niger	1,334

Nigeria	3,528
Sudan	2,219
Tanzania	2,403
Uganda	3,069

To date, bio-digesters are still not widespread on the continent. There is a growing market amongst small-scale livestock farmers in East Africa. The Africa Biogas Partnership Programme (ABPP), a public-private partnership between Hivos and SNV Netherlands Development Organisation, had installed 46,000 digesters by 2016 and announced plans to extend the programme to a further 100,000 households by 2017 in East Africa (Kenya, Ethiopia, Uganda, the United Republic of Tanzania) and West Africa (Burkina Faso)[15]. The EIA estimates that overall, current biogas use in Africa is around 5,000 tonnes of oil equivalent.[16] This low penetration rate shows that there is an opportunity for growth.

Asia

Asia is home to 74% of the world's farms and 420 million smallholder farmers, and represents the biggest potential market for small scale bio-digesters. Bio-digesters are already a widespread technology in the region, as Asia has seen an exceptional uptake in the past decade[17]. Tens of millions of small digesters are used in households or on small farms to produce gas for cooking in China, Nepal, India and parts of Southeast Asia. China has been developing biogas since the 1960s and is a global leader in the direct use of biogas for heat, accounting for 90% of biogas installations globally[18] with 426 million units installed at the end of 2016[19]. In 2012 alone, 5 to 7 million new biogas digesters were deployed in the country[20]. Between 2003 and 2012, total investments in biogas were near USD 15 billion[21]. According to the EIA, developing countries in Asia hold 30% of the potential for biogas production, and by 2040, China, India and other developing countries in Asia are projected to lead the demand for biogas.[22]

Latin America

Farms in Latin America and the Caribbean only accounts for 4% of farm holdings worldwide[23], but according to the EIA, Central and South America accounts for 20% of the overall biogas production potential.[24] However to date, the Latin American market is still in its infancy. Even though the first biodigesters were introduced in the 70s and 80s, uptake has been very low.[25] For instance, SNV reported that from the early nineties up to 2018, only 1,582 biodigesters where installed in Latin American where it provided support, which contrasts sharply with numbers for Africa (86,355) and Asia (780,735). This was associated with a higher average investment cost than in the other two continents.[26] According to the Inter-American Development Bank (IADB), factors that are limiting the expansion of the market include both economic and institutional factors, cultural issues and technical considerations. The high costs of inputs and follow-up maintenance requires a sustained biodigester programme that includes innovative financing mechanisms and inter-institutional collaboration. Economies of scale will also eventually drive down the cost.[27]

3.2 The enabling environment

Beyond the potential market size, the scaling of bio-digesters and potential for impact also depends on the enabling environment. In particular, a favourable legal and regulatory environment is essential to the development of a biogas market. Regulatory vacuum creates uncertainty among consumers and discourages private investments. Financial incentives such as tax exemptions and subsidies can also facilitate scaling by reducing the high investment cost.

Conversely, the growth of the biogas market can be limited by subsidies to competing sources of energy.[1] Significant subsidy schemes have been set up for LPG, for example, even though biogas is more environmentally friendly and delivers significant secondary benefits[28]. Customers' perception of biogas is

[1] ESMAP/The World Bank. "The Power of Dung." 2019

also a key factor for uptake. In many countries, past poor performance from bio-digesters has tarnished biogas' image. In addition, biogas deployment is also affected by socio-cultural factors, which can hinder behaviour change. For instance, while clean cooking is one key advantage of biogas, some countries encounter some resistance to the displacement of charcoal, which is traditionally used for cooking. Finally, institutional support and stakeholder coordination is key to creating an enabling environment. Uptake is likely to be higher when central and local government play an active role in creating a holistic support ecosystem including financial service providers, skills training institutions and business support organisations, and research institutions.

4 Assessing biogas' contribution to the SDGs

RQ 1: How can the direct impacts of biogas support the achievement of the SDGs (specifically SDGs 2, 7 and 13)?

RQ 4: How does this impact vary between different market segments?

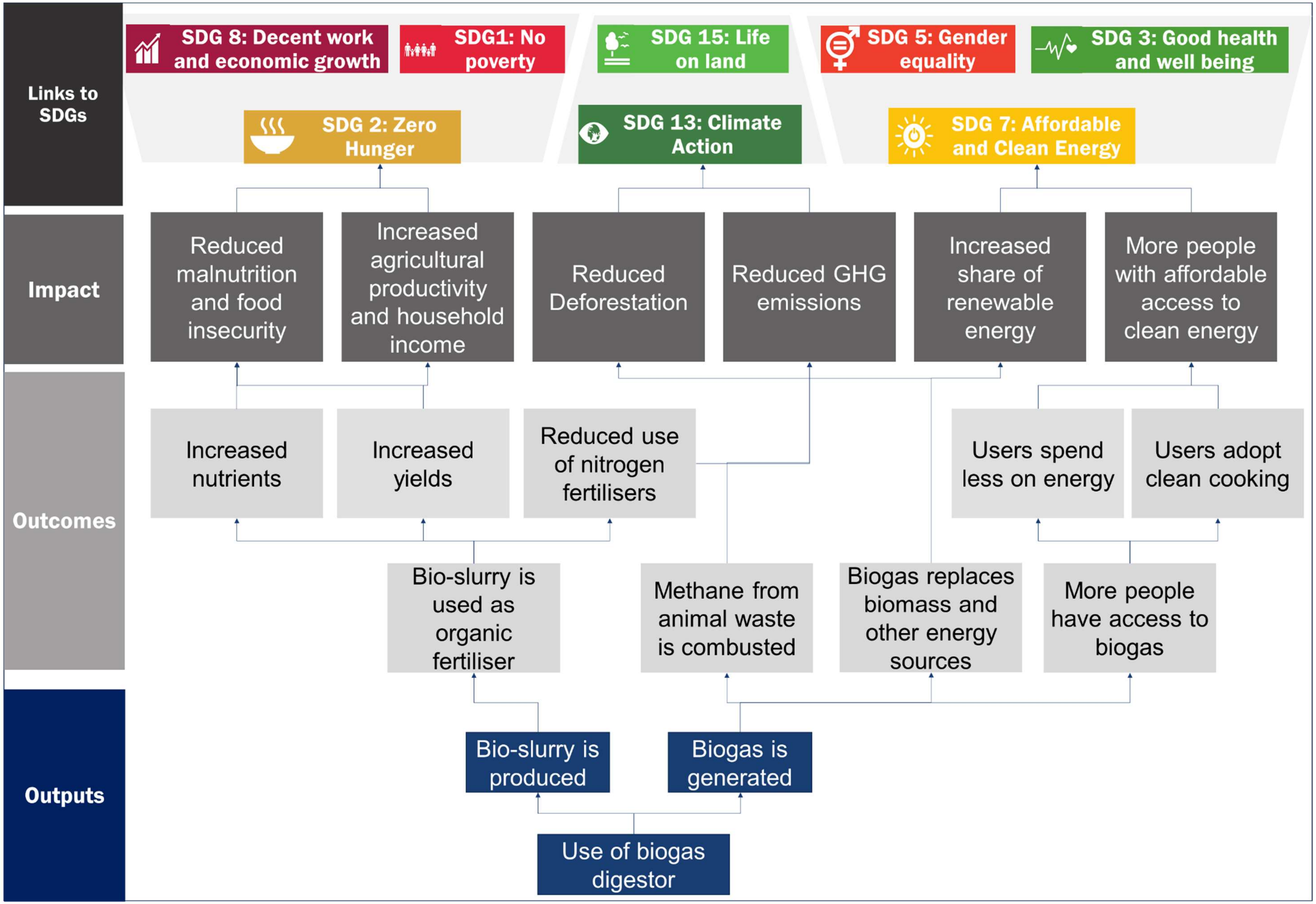
Our approach to answering the first and fourth research questions used Theories of Change to unpack the relationship between biogas and the sustainable development goals, and provide a framework for assessing the strength of evidence for contribution within each impact pathway and for understanding how impact varied by different market segments.

The development of the Theories of Change followed an iterative process. A first draft was produced based on literature review, and a workshop was held with the Sistema.bio and Shell Foundation teams to stress test it and to ensure that it reflected their experience and perspective. The focus of our analysis was on SDGs 2, 7 and 13, although we have also highlighted where there are strong indirect relationships to other SDGs.

We have built a simplified, overarching Theory of Change (overleaf), which sets out at a high level what our research suggests are the most important impact pathways that link the adoption of biogas to SDGs 2, 7, and 13. For the purpose of the strength of evidence assessment, we also developed more detailed, bespoke Theories of Change for each SDG, which we used to structure our analysis.

As the Theory of Change demonstrates, the two key outputs from a bio-digester are biogas and bio-slurry. Biogas provides low-income households with access to a clean, affordable energy source, thus contributing to SDG 7, and displaces other GHG-emitting energy sources (SDG 13). It also reduces methane emissions from the decomposition of animal manure, and addresses deforestation. Bio-slurry increases agricultural yields, displaces nitrogen fertilisers, and increases the nutrients within agricultural produce. In doing so, it primarily contributes towards SDG 2, Zero Hunger.

For each of the three SDGs that this report focuses on, we provide an initial overview of the context and key global targets of the SDGs, before setting out the impact pathways for biogas. These are mapped out using a more detailed SDG-level Theory of Change, which also describes the key underlying assumptions for each output and outcome. Finally, we assess the strength of evidence for each impact pathway, with a focus on also determining how impact varies by market segment.



Demonstrating the potential of biogas to contribute towards the SDG

4.1 SDG 2: No Hunger

SDG 2 aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. This reflects the ongoing global challenge to feed the world's growing population; 2 billion people worldwide do not have regular access to safe, nutritious and sufficient food, and 750 million people face severe food insecurity[29].

Specific targets under SDG2 by 2030 include:

- Doubling the agricultural productivity and incomes of small-scale food producers
- Ending food insecurity
- Ending all forms of malnutrition
- Ensuring sustainable food production systems and the implementation of resilient agricultural practices

As shown in Figure 3, we have identified the three main impact pathways through which biogas is contributing to SDG 2 targets on Zero Hunger. These pathways can be summarised as:

1. **Increasing smallholder farmers' productivity and household incomes** through using bio-slurry produced by the bio-digester as a by-product, and by generating additional income earning opportunities. Bio-slurry is an effective organic fertiliser which increases both the productivity of smallholder farmers as well as the quality of agricultural produce. It also creates additional income earning opportunities through increases in agricultural product sales as well as the sale of bio-slurry. Increasing the productivity and incomes of smallholder farmers helps to address wider food insecurity within rural communities.

Box 2: The relationship between agricultural productivity and food insecurity

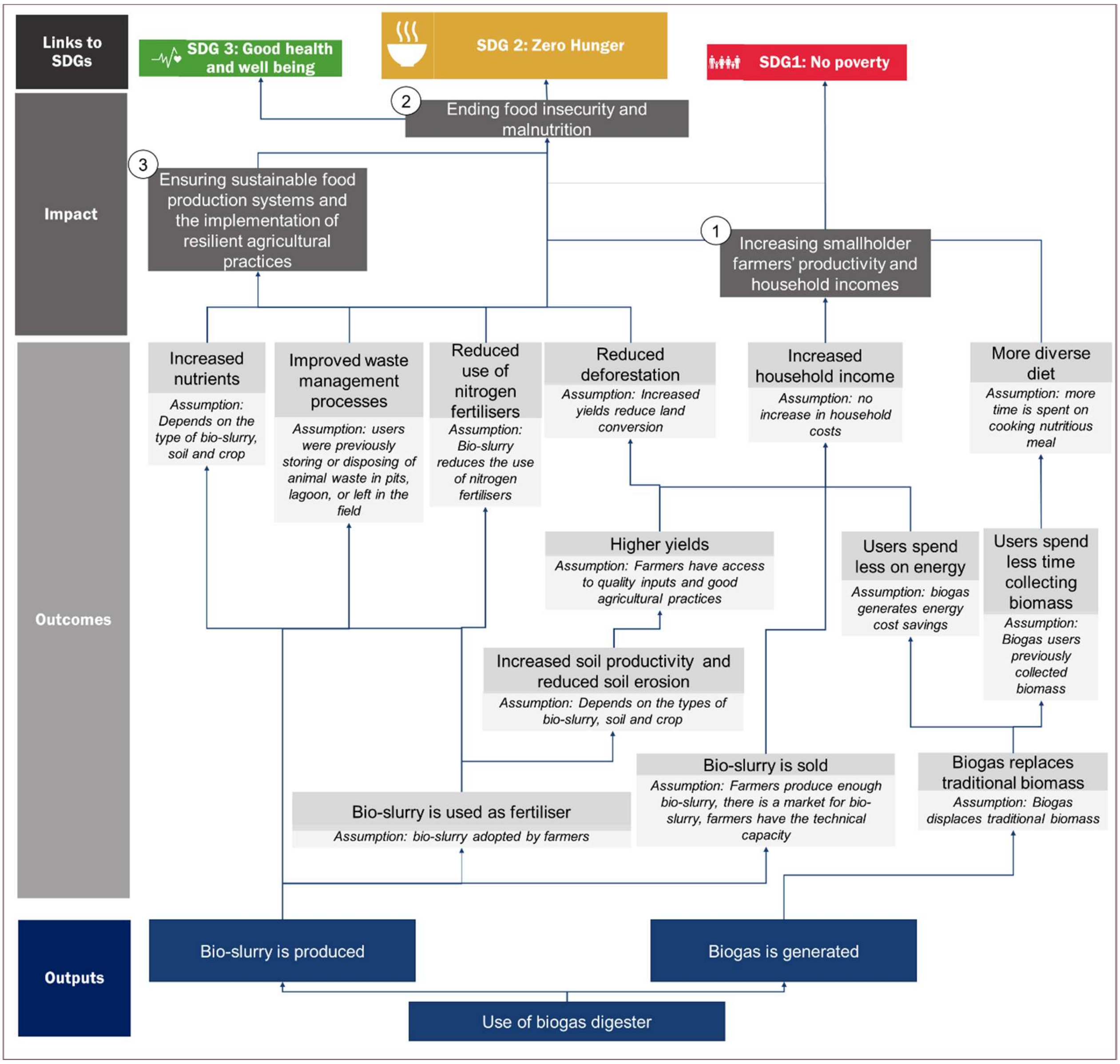
There is a significant body of research which emphasizes the importance of (i) increasing smallholder productivity and (ii) the supply of agricultural produce in local markets to address food insecurity and hence contribute to SDG 2. This recognises both that smallholder farmers themselves can be food-insecure, and that other food-insecure groups (e.g. the rural landless poor) rely predominantly on agricultural produce grown locally by smallholder farmers. The UN has explicitly recognised the importance of this mechanism in target 2.3 of SDG 2, which is centered around increasing the agricultural productivity of smallholder farmers.

2. **Ending food insecurity and malnutrition within households owning bio-digesters** through the use of bio-slurry to increase agricultural yields and increasing the disposable purchasing power of households. As noted above, bio-slurry can increase both the yields and the nutritional quality of produce, helping to address food security and malnutrition for households growing crops for their own consumption. Biogas can also increase disposable household incomes, including through increased crop sales, creating new livelihood opportunities, and generating cost savings through displacing other forms of energy. An increase in disposable household income is correlated with reduced malnutrition and improved food security.

3. **Ensuring sustainable food production systems and the implementation of resilient agricultural practices** by displacing chemical fertiliser with bio-slurry, promoting good waste management practices, and reducing deforestation. There is a clear link between the development of more sustainable and resilient agricultural systems, and addressing the systemic, root issues of food insecurity and zero hunger.

The overall relationship between biogas and SDG 2 is centred on the production of bio-slurry as a by-product and the creation of additional income opportunities. Through these mechanisms, there is also a relationship with SDG 1, No Poverty, as over a longer time period biogas can have a significant impact on the disposable household income and the socio-economic characteristics of adopters, through increasing agricultural yields and generating savings on energy. There is also an indirect link to SDG 8 on Decent Work and Economic Growth, as biogas can also create rural livelihood opportunities, both in more formal roles in the sales, maintenance, and repair of bio-digesters, and in casual on-farm labour in day-to-day management of bio-digesters.

Figure 3. Impact pathways to SDG 2



Each of the three key impact pathways are unpacked in more detail below, with a focus on assessing the strength of evidence and testing the robustness of the underlying assumptions. Whilst the Theory of Change provides a visual demonstration of the causal linkages that we expect between biogas and SDG 2, it does not reveal the evidentiary base for each linkage. The strength of evidence assessment provides the more rigorous analytical framework for assessing that empirical foundation.

4.1.1 Increased smallholder farmers' productivity and household incomes

There is a robust empirical foundation for the impact of bio-slurry on the productivity and household incomes of smallholder farmers, which is a specific target under SDG 2. This reflects the importance of increasing the productivity of smallholder farmers in addressing some of the root causes of food insecurity.

There is considerable evidence that bio-slurry is adopted as fertiliser by smallholder farmers. As well as sources within the wider literature[30] and evidence from development projects[31], there is also robust data from Sistema.bio's own customer base; a survey of Sistema.bio customers in Kenya conducted by 60 Decibels found that 87% of respondents used bio-slurry as fertiliser[32]. The assumption that bio-slurry is adopted by fertilisers is therefore robust with a strong empirical foundation.

However, it is less clear that it is always applied optimally[33]. Some research highlights that farmers do not have access to equipment to compost bio-slurry for optimal usage, or training on effective application[34]. This point was also made in interviews with Sistema.bio staff, who commented that the "the potential of biofertilizer is typically underutilised - it is labour intensive and if you want to do it right you need to compost it"[35]. This suggests that the assumption that farmers are knowledgeable about good agricultural practices does not always hold.

Bio-slurry has a significant impact on agricultural yield, and this result is robust across different crops and different geographic contexts[36]. It compares well to manure and has similar effects to commercial synthetic fertilisers[37]. However, quantifying yield improvements is challenging given that the effect of bio-slurry will vary on the type of digestate, the soil characteristics, and the crop requirements[38]. There is also some evidence that bio-slurry might lead to better yield when combined with synthetic fertilisers than on its own, which complicates isolating the impact of bio-slurry on yield[39]. As an additional benefit, using bio-slurry rather than manure reduces the risk of transmission of pathogens to farmers, improving their health outcomes[40].

There is limited research on the extent to which bio-slurry displaces chemical fertiliser, or on whether biogas adopters used chemical fertiliser prior to purchasing a bio-digester. This is important because whilst displacing chemical fertiliser with bio-slurry would lead to cost savings, it is unlikely to have a dramatic impact on yields. In comparison, if biogas adopters did not use fertiliser prior to purchase of the bio-digester, we would expect to see a very significant increase in yields after application of bio-slurry. There is some data available within Sistema.bio's own customer base; data collected at point of sale suggests that 61% of customers were previously using chemical fertiliser. This varies significantly by geography, with chemical fertiliser use at 78% amongst new customers in India, and 56% in East Africa. More widely, research on smallholder farmers demonstrates that prevailing fertiliser use varies significantly by crop[41] and by region[42], which makes it difficult to generalise on whether farmers were using fertiliser before. The assumption that bio-slurry reduces the use of nitrogen fertilisers is likely to hold at a global level across the wider portfolio of biogas adopters, but there is not enough evidence to quantify the size of this effect.

Table 5: Fertiliser use prior to biogas adoption for Sistema.bio customers

Region	Fertiliser use prior to adoption of biogas
East Africa	56%
South Asia	78%
Central/South America	72%

Most of the impact on income is likely to come from increased yields. For example, bio-slurry has been shown to increase maize yields by 38% compared to using no fertiliser at all[43]. For a Kenyan smallholder farmer with one hectare of maize, assuming typical productivity of 0.91 tons of maize per year[44] prior to biogas, that implies an increase in yield of 348kg, which if sold would generate an additional $104 of income. A survey of Sistema.bio's customers in Kenya found that 64% reported an increase in income from their farms as a result of the biogas digester, and 54% said the primary reason was through an increase in the volume of agricultural produce sold.

In addition, there are examples of farmers generating additional income through the sale of bio-slurry[45]. However, it is not clear if this practice is widespread and there appear to be critical barriers towards smallholder farmers adopting this practice more extensively, as bio-slurry in its raw form is liquid and difficult to transport and sell. Composting and packaging it requires equipment and techniques which are likely to be beyond the reach of most smallholder farmers. This conclusion is reinforced by insights from Sistema.bio's own customer data; a survey conducted by 60 Decibels on their Kenyan customer base found that just 2% sold on bio-slurry to other farmers. This suggests that there is a significant assumption around farmers having the right technology, capacity, and market access to sell on bio-slurry, and that in reality there is limited evidence for this pathway.

4.1.2 Ending food insecurity and malnutrition directly within biogas adopter households

Biogas digesters can increase agricultural yields, the nutritional value of agricultural produce, and disposable household income, thus enabling customers to purchase more food to meet their needs. Increases in disposable household income are correlated with increasing food security and the nutritional value of food consumed. However, households which adopt biogas may be less likely to be food insecure prior to adoption compared to the wider rural population.

As outlined in section 4.1.1, the use of bio-slurry can have a significant impact on yields. Evidence from the wider literature is also reinforced by data from Sistema.bio customers; 94% reported an increase in their agricultural production because of the Sistema.bio bio-digester, and 59% reported that production had "very much increased". This seems likely to have resulted because of increases in productivity, with 91% of farmers who reported an increase in total production farming on the same amount of land as before.

In addition to its potential to increase food production, there is strong evidence that bio-slurry can improve the nutritional content of agricultural produce. Crops treated with bio-slurry tend to have higher levels of nutrients and protein than compared to organic fertiliser[46]. However, the magnitude of this effect depends on the crop and the input material used in the digester[47]. This suggests that the assumptions underpinning increased nutrients in agricultural produce broadly hold, with the caveat that there will be some variation in the size of the effect.

Biogas can generate cost savings both by replacing fertilisers and reducing energy expenditure, but the extent of cost savings varies significantly depending on region and individual-specific circumstances. Key variables include chemical fertiliser use, pre-existing energy sources, and the role of government subsidies. For farmers which do use chemical fertiliser, expenditure on fertiliser is typically a significant component of their annual investment in their farms[48]. This is reinforced by data from Sistema.bio collected at the point of sale, which shows that customers spend on average $271 on chemical fertiliser annually prior to purchase of a biogas digester. However fertiliser use, expenditure and displacement does not only vary between crops and geographies, but also between households at the community level.[49] In some low-income countries, fertiliser is also subsidised by the government implying that replacement of fertiliser may not always generate significant cost savings.

Similarly, cost savings through reduced energy expenditure depends on prior energy use, and the extent to which biogas displaces other sources of energy. Across Sub-Saharan Africa, over 70% of the population still depend on wood-fuel as their primary source of energy[50]. Whilst there is significant evidence that whilst biogas adoption leads to a decline in energy from other sources, it is not clear if it is a complete replacement. Studies in Ethiopia have found that biogas users use 33% less charcoal and 36% less firewood[51], whilst research in China found a similar degree of substitution[52]. However, a similar study in India found that biogas households used 91% less firewood than a comparable sample[53]. Whilst there is some variation, there is robust data that underpins assumptions around biogas displacing other forms of energy (including biogas) and generating cost savings.

Data from Sistema.bio also suggests that there are also significant regional variations in pre-existing energy sources, as demonstrated in the table below. As an energy source, LP gas tends to be more expensive than wood, implying that biogas adopters in Central and South America are likely to generate more significant cost savings.

Table 6: LPG and wood consumption by region for Sistema.bio customers

Region	LP Gas Consumption (litres per month)	Wood Consumption (kg per month)
East Africa	16	658
South Asia	45	318
Central/South America	78	220

There is also clear anecdotal evidence that biogas can help stimulate the creation of additional livelihood opportunities in rural areas. However, this has not been studied systematically, and there is limited robust data on a) the extent to which biogas does generate work opportunities and b) the socio-economic characteristics of people benefiting from them. It is also possible that whilst biogas may create livelihood opportunities, it may negatively affect others (e.g. in collection of firewood, or small-scale production and sale of charcoal). More research on the wider systematic impact of biogas adoption in rural communities would enable a more comprehensive assessment of how important this impact mechanism is. As a comparator, the PAYGO solar industry has estimated that every 100 household solar systems supports one job in sales, maintenance, and repair.

Time and cost savings can have a positive impact on the time spent preparing food and on nutritional diversity. A study of biogas users in Southern India, for example, found that households spent 40 minutes less time cooking and 70 minutes less time collecting firewood per day after adoption of biogas stove, and that households with biogas cook stoves demonstrated greater diet and nutritional diversity[54]. There is a wider body of research on time savings through clean cookstoves, which even if not biogas, are comparable. This suggests that assumptions based on time savings are robust and well-evidenced.

Additional income and cost savings are likely to translate into additional expenditure on food, with considerable evidence that increased income increases both the quantity, the nutritional value and the diversity of food[55].

There is a significant assumption that households with biogas digesters are food insecure in the first place. Research has highlighted that biogas users are unlikely to be the poorest in rural communities, and this finding is consistent across different geographic regions[56]. This finding is also reinforced by research on Sistema.bio's own customers; 60 Decibels found that the income profile of Sistema.bio's customers was significantly wealthier than both the Kenyan national average and the Kenyan rural average. As an example, their data suggests that 65% of the Kenyan rural population live on less than $3.20 per person per day, compared to 24% of Sistema.bio's customers. This finding is not overly surprising; even when available on credit, bio-digesters are expensive relative to household income, and to realise the full potential of biogas, households need to have enclosed livestock, access to water, and access to arable land. Although there is no research on the extent to which biogas users are food-insecure, given that they are unlikely to be bottom-of-the pyramid consumers it seems probable that incidences of food insecurity are much lower in households with bio-digesters even prior to adoption.

4.1.3 Ensuring sustainable food production systems and the implementation of resilient agricultural practices

There is robust, scientific evidence which demonstrates the beneficial impact of bio-slurry on soil fertility, compared to both organic manure and chemical fertilisers[57]. Assessed against chemical fertilisers, there are also benefits with respect to sustainability, as long-term usage of chemical fertilisers without appropriate mitigation measures can have negative long-term repercussions on soil health. Supporting soil health and sustainability is a critical step towards building resilient agricultural systems.

Another key benefit of biogas is the promotion of sustainable waste management practices for animal manure. Untreated animal manure can leach into soils, rivers, and water systems, causing environmental degradation as well as having a negative impact on public health[58]. Whilst disposal of animal waste is typically considered more of an issue for industrial farmers[59], interviews with Sistema.bio staff did highlight that particularly for smallholder pig farmers efficient and safe waste disposal was challenging before the adoption of a biogas digester. More widely, smallholder farmers rarely have efficient and sustainable systems for disposal of animal waste, suggesting that the assumptions that underpin improved waste management are robust.

4.1.4 Assessing impact of SDG 2 by market segment

Many of the impact pathways between biogas and SDG 2 are robust in different contexts, to the extent that to a significant degree we can generalise about the *direction* and *pathways* of impact. However, the magnitude of impact will vary by customer and market segment, as detailed in the strength of evidence assessments above. Table 7 presents a summary of what the evidence suggests in terms of impact variance by pathway.

Table 7: Impact of SDG 2 by Market Segment

	Impact pathway	Evidence of impact variation by market segment
1	Increasing smallholder farmers' productivity and household incomes	- Impact on productivity likely to be greatest for poorer farmers who were not previously using fertiliser - Within Sistema.bio's own customer portfolio, fertiliser use is much lower in East Africa – suggesting that farmers there will see the greatest increases in productivity - However, impact on household incomes potentially more significant for larger farmers – as biogas and bio-slurry displaces more expensive energy and fertiliser sources
2	Ending food insecurity and malnutrition	- Food insecurity unlikely to be a critical challenge except for the poorest biogas adopters. As a reasonable proxy, these are likely to be users of the smallest and cheapest bio-digesters
3	Ensuring sustainable food production systems and the implementation of resilient agricultural practices	- Strong evidence that this is finding will hold across market segments.

4.1.5 Conclusion

Biogas has a strong relationship with SDG 2, with particularly robust evidence for its contribution to the target around increasing smallholder farmer productivity and household incomes and thereby strengthening food security in local rural communities. This is primarily due to the use of bio-slurry as an organic fertiliser, which has a proven significant impact on yields. Importantly, this relationship holds across different contexts and crops, and is supported by scientific studies predicated on optimal usage as well as insights from farmers using bio-slurry. The impact on yields will be greatest for farmers who were not previously using (or were under-using) fertiliser. Given that farmers who were not previously using fertiliser are likely to be poorer, there is an argument that the proportionate increase in yield is likely to be largest towards the bottom of the pyramid. Increasing the yield of smallholder farmers is a critical in addressing food insecurity and progressing towards SDG 2. Not only are some smallholder farmers themselves food insecure, but they also sell their produce through local value chains and through that mechanism support the wider food security of rural communities.

There is also strong evidence for biogas' contribution to ensuring sustainable and resilient food production systems. The relationship between agricultural system resilience and food insecurity is critical, as demonstrated in target 2.4 of SDG 2, and by supporting the development of more sustainable and resilient agriculture biogas makes an important contribution towards the target of zero hunger and addressing food insecurity.

Where there is weaker evidence is on biogas' role in addressing food insecurity and malnutrition directly within the households of biogas adopters. Whilst the impact of bio-slurry on yields and the nutritional content of food is not in doubt, there is also significant evidence both from the wider literature as well as Sistema.bio's own customer base that biogas adopters, even if in rural areas, are not bottom of the pyramid consumers. Although there is no direct research on the extent to which biogas households are food-insecure, given their income profile it seems plausible to conclude that this would be unlikely.

However, one important distinction is that this research reflects data on *current* biogas adopters. Given the impact of bio-slurry on agricultural yields, bio-digesters could still be an effective tool address food insecurity and malnutrition in poorer households – if they were given the means or support to access the technology. With the right support, biodigesters could deliver even more benefits with respect to food security if appropriate financing mechanisms were developed to support their reach into lower-income populations.

Table 8: Strength of evidence assessment summary for SDG 2

	Impact pathway	Strength of evidence summary
1	Increasing smallholder farmers' productivity and household incomes	Strong evidence for positive impact on yield and on household income
2	Ending food insecurity and malnutrition directly within biogas adopter households	Strong evidence for positive impact on yield and nutritional content, but weak evidence that current biogas adopters are food insecure prior to adoption.
3	Ensuring sustainable food production systems and the implementation of resilient agricultural practices	Strong evidence that bio-slurry is healthier for soils, and that bio-digesters improve waste management

4.2 SDG 7: Affordable and Clean Energy

SDG 7 aims to ensure access to affordable, reliable, sustainable, and modern energy for all. Worldwide, 789 million people lack access to electricity, and 2.8bn people do not have reliable access to clean and safe cooking fuels. This has negative effects at the household, community, and global levels. At the household level, indoor air pollution from combustible fuels is the cause of over 4mn deaths annually, whilst globally energy is the dominant contributor to climate change, accounting for approximately 60% of total global greenhouse gas emissions[60].

As shown in Figure 4, we have identified three pathways through which biogas is contributing to progress on SDG 7. These can be summarised as:

1. **Increased access to clean energy (including clean cooking)** through displacing biomass and other fuel sources with the biogas generated through the digester. Traditional fuel sources not only contribute to global warming through the release of GHG emissions, they also generate harmful pollutants and particles which can have a dramatic impact on health and quality of life outcomes. Biogas combustion does not release harmful pollutants, even when used indoors, and through the conversion of methane into carbon dioxide have a positive effect on GHG emissions.

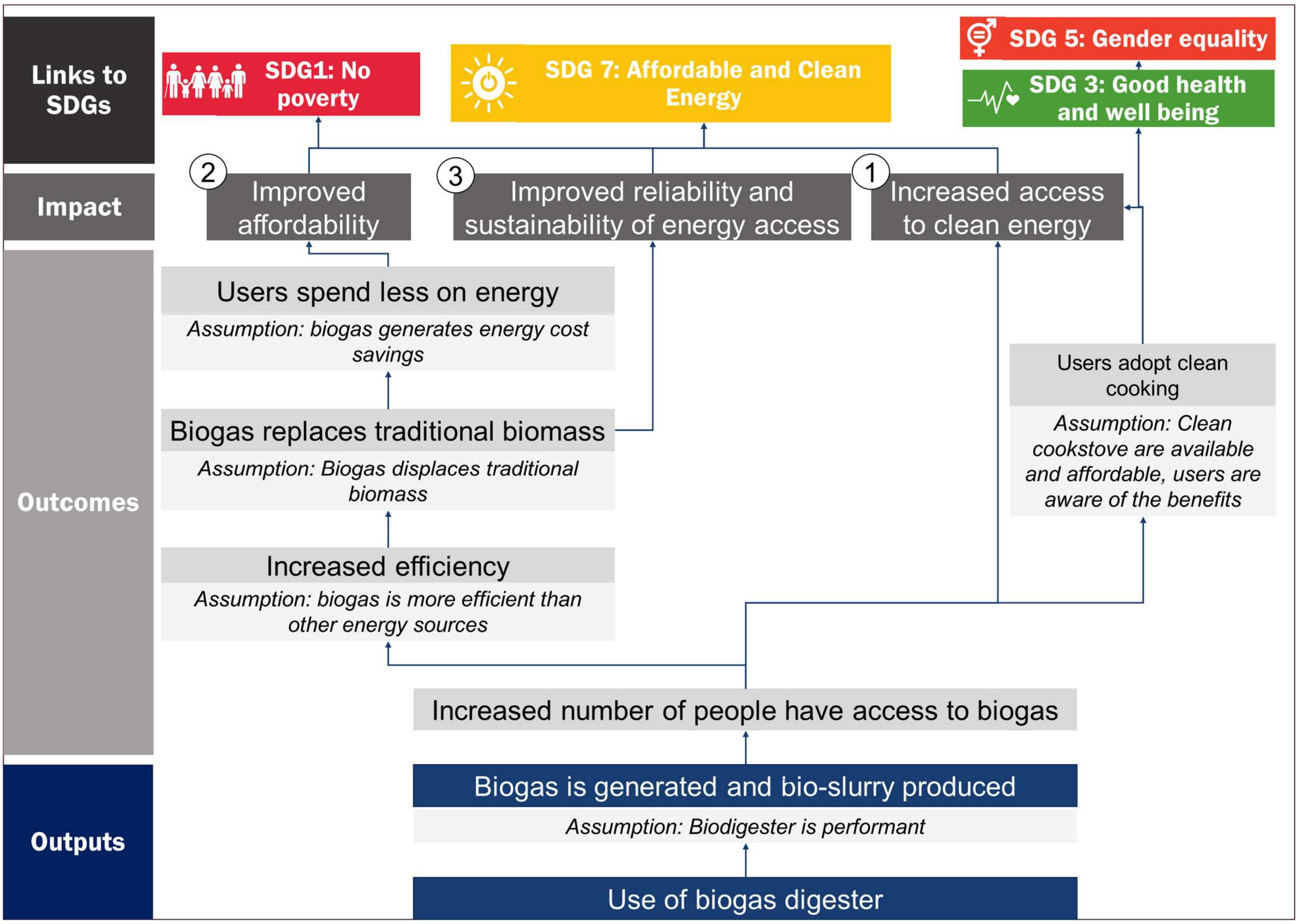
2. **Increased affordability of energy** by creating a new energy source from the waste manure of livestock. Energy costs can be a significant proportion of costs for low-income households, and the prohibitive prices of fuels such as LPG help to ensure continued reliance upon traditional biomass energy sources, which whilst monetarily cheaper often entail significant time and household labour investments. After the purchase cost, biogas requires limited ongoing expenditure. Whilst estimates vary, bio-digesters will typically pay-back the cost of purchase purely through energy savings after 3-6 years. Given their lifespan of 10-20 years, this leaves a significant 'surplus' for the consumer, in addition to which there are the other significant benefits of the technology (e.g. access to bio-slurry).

3. **Improving reliability and sustainability of energy access** by supporting an on-site source of energy which uses readily available raw inputs, rather than having to rely upon energy sources which require extensive physical infrastructure or which are drawn from non-sustainable sources. However, biogas can also have reliability issues, particularly if poorly constructed.

There is significant potential for biogas to play a key role in addressing energy poverty and ensuring reliable and sustainable access to clean energy. In Sub-Saharan Africa, estimates suggest that biogas is a feasible solution for 18.5mn households covering over 90mn people, but currently less than 100,000 digesters have been installed[61]. China, despite an aggressive national programme, has accessed only 5% of its biogas potential by some estimates[62], whilst in Bangladesh research suggests only 1% of biogas potential is being utilised[63].

There are also clear links towards other related SDGs through these mechanisms. Perhaps most significant is SDG 3 on Good Health and Wellbeing (see Box 5), which reflects the significant health benefits of providing access to clean energy for cooking. This impact is also highly gendered, mirroring the disparity in the time spent collecting firewood and cooking between men and women. Addressing a gender-based health inequality also generates a link towards SDG 5 on Gender Equality.

Figure 4. Impact pathways SDG 7



4.2.1 Increasing access to clean energy

Biogas displaces other energy sources, which tend not to provide clean energy. These include traditional biomass (wood, dry dung fuel, and charcoal) as well as petroleum-based products such as kerosene and LPG. There is significant evidence that biogas does displace other energy sources, but the substitution effect is not 100%. The extent to which biogas itself is a clean energy is also dependent on how well the bio-digester and associating stove set-up is managed.

40% of the world's population lack access to clean cooking fuels[64]. The proportions are even higher in the regions in which biogas is a scalable technology; 70% of the population in Sub-Saharan Africa still rely on traditional biomass as a cooking fuel[65]. This is also reinforced by the data collected by Sistema.bio at the point of sale, which demonstrates that even larger farmers are still heavily reliant on both wood and LPG as a fuel source.

Table 9: Energy source by customer type

Customer farm-type	% using wood as a fuel source	Wood usage (kg / month)	% using LPG as a fuel source	LPG usage (litres / month)
Productive	66%	1,316	32%	279
Small	79%	629	21%	24
Subsistence	91%	427	8%	18

Biogas has considerably lower emissions and higher efficiencies than traditional three-stone fires using biomass for cooking[66], and the thermal efficiency of biogas from dung compares well with petroleum-based energy sources[67]. Whilst this is partly dependent on the stove technology used, which varies between different markets, there is strong evidence for the assumption that biogas is an efficient source of energy compared to available alternatives.

Other forms of energy are both significant contributors towards greenhouse gas emissions and harmful pollutants when used in indoor cooking. Biomass burning cookstoves generate over 1bn tonnes of CO_2 annually[68], and, in addition, produce "black carbon", which the Clean Cooking Alliance describes as "by far the most significant short-lived climate pollutant emitted during cooking…[which] is estimated to be second only to CO_2 in its warming impact on the climate"[69]. Cooking inside using biomass also generates harmful pollutants which can cause a myriad of health problems (see Box 5).

However, the extent to which biogas displaces other forms of energy is unclear and is likely to vary significantly by region. The prevalence of "stove-stacking" (the practice of using both a clean fuel stove for biogas and a traditional biomass stove) varies widely, depending on cultural preferences, stove efficiency, and the availability of other fuel sources[70]. This is reflected in the wider research on the extent to which biogas displaces other forms of energy; as noted in section 4.1.2, different studies in different contexts have found that the adoption of biogas results in a fall in wood consumption of between 36% to 91%[71,72,73]. Whilst there is reasonable evidence for the assumption that biogas users do adopt clean cooking practices, it is likely that in some cases households use biogas stoves in addition to traditional cooking methods.

Box 5: Biogas and the relationship to SDG 3 (Good Health and Wellbeing)[74]

Indoor pollution from cooking using biogas is a major source of harmful pollutants and is the cause of approximately 4mn deaths per year as well as a range of health problems. Women and children are particularly affected by household air pollution, due to their higher levels of exposure and greater time spent inside the household. The obvious way to avoid indoor air pollution from solid fuel burning is to cook in the open or for households to transition from traditional ways of cooking and heating towards more modern, cleaner methods such as biogas. Through displacing traditional biomass as a cooking source, biogas adoption makes a significant contribution towards attainment of SDG 3.

Whilst biogas is a clean fuel which contributes to reductions in emissions of greenhouse gases (see section 4.3), if managed or implemented poorly then these benefits will be significantly reduced. In particular, leakages from the bio-digester and in pipes can be an ongoing contributor of methane to the atmosphere. Cooking with biogas using inefficient stoves can also result in incomplete combustion, which also can lead to methane emissions. This is heavily dependent upon the type of system employed, how well it is managed, and the availability of a local repair and maintenance network.

4.2.2 Increased affordability of energy

Biogas can lead to significant reductions in household expenditure on energy, thereby promoting the increased affordability of energy. However, even though over the course of the life-time of the bio-digester it is likely to generate significant cost savings, the high up-front cost and the limited liquidity available to smallholder farmers means that price is a continuing deterrent to more widespread adoption.

Household energy costs are a significant outlay for smallholder farmers. This is reflected in the data collected by Sistema.bio at point of sale, which shows that their customers spent an average of slightly over $30 per month *prior* to the adoption of biogas.

Table 10: Energy expenditure by region

Region	Monthly energy expenditure (USD)
East Africa	34
India	33
Central/South America	31

The displacement of other energy sources generates significant cost savings for households. As noted in section 4.2.1, biogas is an effective substitute for a range of other energy sources. Prior studies using cost-benefit analysis at the household level estimated that energy savings averaged $289 annually in Uganda and $328 in Ethiopia after biogas adoption[75,76]. It is likely that cost savings will vary significantly by region depending on prevailing energy usage, but broadly there is clear evidence for the assumption that adoption of biogas generates energy cost savings.

Whilst energy savings are significant, they do not generate enough cashflow to finance the cost of a biogas digester on a typical 12-18 month credit purchase. Estimates suggest that energy cost savings typically take over 5 years to fund the cost of a biogas digester[77]. That analysis does not include the monetary benefits from using bio-slurry, or the other significant advantages from biogas adoption, and given that bio-digesters have a life-span of between 10-20 years energy cost savings will still generate a significant surplus for consumers in the longer-run. However, given a major barrier towards biogas adoption is the price of the bio-digester, it is worth noting that during the repayment period there is likely to be a negative impact on household cashflow.

4.2.3 Improved reliability and sustainability of energy access

Although the reliability of biogas digesters varies, other energy sources in use in rural farming communities also have significant reliability issues. It is likely that some biogas digesters offer more reliable access to energy than alternative sources, but that this is strongly dependent on the type of bio-digester, the effectiveness of a local maintenance network and local weather conditions.

The energy sources that biogas displaces tend not to be sustainable. LPG is a fossil fuel, whilst a high proportion of biomass consumption is classified as non-renewable. For example, the Clean Development Mechanism, a programme run by the UN Climate Change agency, estimates that 92% of biomass consumed in Kenya, 82% in Uganda, and 98% in Rwanda is non-renewable[78]. Increased pressure on woodland resources can lead to deforestation, emphasising that biomass is not a sustainable energy resource and reducing reliability of access at the local level.

Comparable energy sources also have access issues. The development of LPG as a clean fuel for cooking requires significant investment in developing a nationwide distribution network to enable convenient and reliable access to refill cylinders[79]. Unlike biogas, LGP users have to visit fuelling stations to refill their cylinders. LPG fuelling stations require some limited infrastructure to ensure their safety, implying that LPG cannot be sold in informal village shops. A report by the Ministry of Energy and the Clean Cooking Association of Kenya found that Kenyan households using LPG have to travel 5.3km on average to refill[80].

However, historically bio-digesters have also suffered from reliability issues. The reliability of bio-digesters to generate biogas relates to the biosubstrate, the technology used in the digester, management, and environmental conditions such as soil temperatures. Some studies, typically based on older versions of the technology, found that up to 60% of biogas digesters were not in use after 5 years of operation, primarily due to maintenance issues[81]. Sistema.bio customers interviewed by 60 Decibels reported that their bio-digesters did occasionally need maintenance or a basic repair, but that Sistema.bio's support teams were able to quickly address any issues. This highlights that bio-digesters require ongoing support and maintenance, and without the type of support infrastructure developed by enterprises such as Sistema.bio, there are likely to be long-term reliability issues.

4.2.4 Assessing the impact of SDG 7 by market segment

The relationship between biogas and SDG 7 is clear, and broadly speaking it holds in different contexts for different market segments. However, there are some critical differences, primarily between different geographic markets. This is clear both from Sistema.bio's internal data as well as the wider literature.

Table 11: Impact of SDG 7 by Market Segment

	Impact pathway	Evidence of impact variation by market segment
1	Increasing access to clean energy	- *Income:* Smaller farmers are significantly more likely to use wood as an energy source prior to biogas adoption - *Geography*: According to Sistema.bio's data, farmers in East Africa are significantly more likely to use wood than farmers in India or in Central/South America. In particular, the data suggests the overwhelming majority of larger farmers in East Africa continue to use wood, whilst less than half of larger farmers in India and Central/South America use wood. - *Geography*: The prevalence of stove-stacking varies significantly by both national and local contexts, and is influenced both by cultural cooking practices and awareness around the negative health effects of cooking with biomass
2	Improved affordability of energy	- *Income:* Whilst bio-digesters will make energy more affordable over the life-span of the digester, the initial cost is still a significant barrier towards adoption for low-income farmers - *Geography:* Monthly energy expenditure *prior* to biogas adoption is highest in East Africa for Sistema.bio customers
3	Improved reliability and sustainability of energy access	- *Product:* The reliability of the bio-digester is heavily dependent upon the type of bio-digester used - *Geography:* The reliability and sustainability of alternative energy sources are dependent upon the national and local context (e.g. the prevailing supportive infrastructure for other forms of energy).

4.2.5 Conclusion

There is a clear relationship between biogas and SG7. This is best demonstrated by assessing the link with the target around increasing access to clean energy. Biogas is a clean energy, which does not generate harmful pollutants and has a positive contribution towards GHG emissions. There is strong evidence that it tends to displace more harmful sources of energy, including biomass fuels which when used for cooking produce health-damaging pollutants, and LPG, which generates GHG emissions. The degree to which biogas displaces wood versus LPG is strongly dependent on household income; poorer households are significantly more likely to rely on wood rather than LPG, as Table 9 demonstrated.

Purchase of a bio-digester generates significant energy cost savings for consumers, to the extent that the bio-digester should pay for itself purely though energy savings over a timespan of 3-6 years. Over the lifespan of the bio-digester, this significantly reduces energy costs and improves affordability. However, despite that quick pay-back period, the initial cost of the bio-digester is still a significant barrier to adoption for many consumers. Bio-digesters are typically sold on credit periods extending from 6-24 months (see Figure 7), which means that the impact on customers' cashflow is negative during that period – the energy cost savings cannot fund the cost of credit repayments during the repayment period. Furthermore, energy cost savings are likely to be more significant for wealthier rather than poorer consumers, as the former are more likely to use more expensive LPG gas rather than biomass.

Biogas' comparators have significant reliability and sustainability issues. However, the historical evidence for biogas' reliability and sustainability is mixed, which reflects both weaknesses in older versions of bio-digesters and the under-development of the supporting infrastructure in repair and maintenance. The type of bio-digestor produced by Sistema.bio has a longer lifespan than some of the older models. Although Sistema.bio bio-digesters do occasionally need basic maintenance, Sistema.bio has addressed this by ensuring that the infrastructure is in place to support their customer portfolio. However, it is unclear if in this case the experience of Sistema.bio is generalisable to the wider industry.

Table 12: Summary of strength of evidence assessment for SDG 7

	Impact pathways	Strength of evidence summary
1	Increasing access to clean energy	Strong evidence for increased access to clean energy
2	Improved affordability of energy	Strong evidence for increased energy affordability for users that are able to afford the initial purchase price. However, there is also robust evidence that cost is still a significant challenge for many potential customers, given the short credit periods.
3	Improved reliability and sustainability of energy access	Mixed evidence for the reliability and sustainability of biogas, although noting that evidence is stronger for more recent models and for companies like Sistema.bio which have prioritised an ongoing support network

4.3 SDG 13: Climate action

SDG 13 calls for a global effort to "combat climate change and its impacts." Changes in weather patterns, driven by the global warming resulting from greenhouse gases (GHG) emissions, are responsible for significant human, biological, and economic losses, and without action there is an increasingly likelihood of environmental changes and catastrophic weather events going forward.

The main GHG are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The Intergovernmental Panel on Climate Change (IPCC) estimates that in order to avoid irreversible consequences, in particular for vulnerable regions, global temperature increases need to be limited to 1.5 Celsius over the long-term average.

While specific targets under SDG 13 are policy oriented, the use of bio-digesters can contribute to several different impact-level objectives which align with the overall goal of combating climate change and its impacts. As shown in Figure 6, we have identified the following impacts pathways which we have used to structure our strength of evidence assessment:

1. **Reduced methane emissions from improved manure management:** Manure releases methane via anaerobic decomposition. Capturing methane via a bio-digester and using it as an energy source for cooking reduces methane emissions into the atmosphere. The process of combustion converts methane into the heat used for cooking as well as carbon dioxide, which is far less environmentally damaging and has a much smaller impact on global warming.

2. **Reduced N_2O emissions from fertilisers**: Bio-digesters also produce bio-slurry, which is an effective organic fertiliser. Bio-slurry can reduce reliance on nitrogen fertilisers, which are a major contributor to N_2O emissions via their production process. N_2O is 265-298 times more powerful than CO_2 in terms of its impact on global warming.

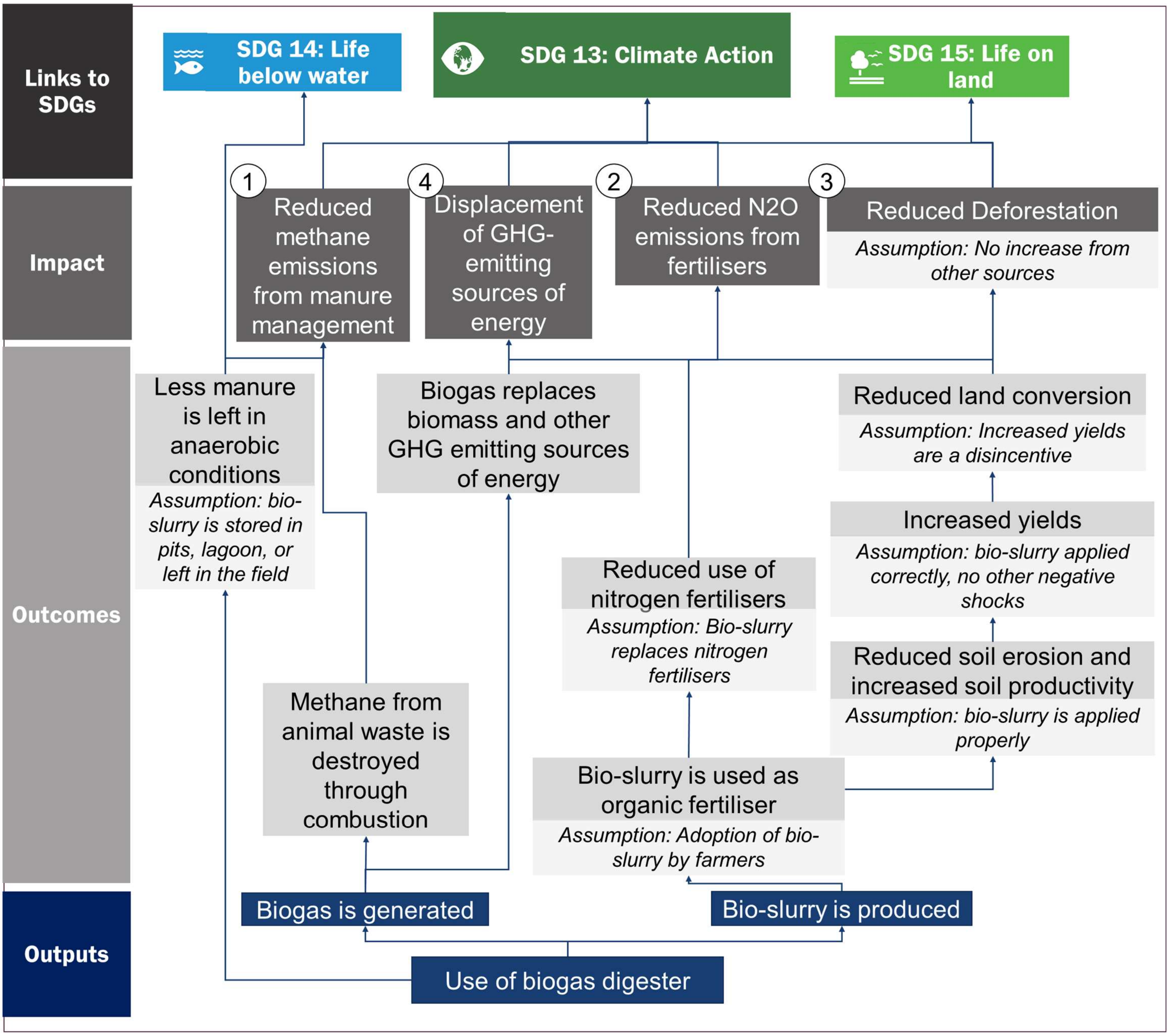
3. **Reduced deforestation linked to energy transitions and land-use changes:** By supporting the transition away from biomass fuel sources, biogas can reduce deforestation. A significant proportion of biomass is drawn from non-renewable sources, and the use of biomass as an energy source is a major contributor to deforestation. There may also be an additional mechanism via increasing soil fertility and yields and reducing the need for slash and burn practices and land conversion. Deforestation is a significant contributor to climate change. Trees absorb and store carbon dioxide, but in the process of deforestation either through combustion or decomposition that carbon is released back into the atmosphere as carbon dioxide. Deforestation is also linked to soil erosion, which amplifies the negative impact of changing weather patterns.

4. **Displacement of GHG-emitting sources of energy:** Biogas can reduce emissions by providing an alternative to GHG-emitting fuels such as biomass, charcoal, kerosene, LPG and natural gas. Replacing these energy sources reduces household emissions, in particular from cooking, and reduces demand for non-renewable fuels.

Bio-digesters have the potential to reduce global GHG emissions by 3,290 to 4,360 Mt CO_2 eq., or 10-13% of the world's current greenhouse gas emissions, if utilised and rolled-out on a global scale across livestock agriculture and human waste systems[82]. At a household level, the results are similarly impressive; research suggests that a small-scale bio-digester generates between 5 to 11 tons of CO_2E savings annually, which is similar to the average carbon footprint of someone from the UK.

These mechanisms also contribute towards the achievement of other SDGs. In particular, reducing deforestation and improving manure management contributes towards SDG 14, Life on Water, as well as SDG 15, Life on Land.

Figure 6. Impact Pathways to SDG 13



4.3.1 Reduced methane emissions from manure management

Poor manure management is a key contributor to agriculture-related GHG emissions. Animal waste accounts for 1.8Gt of CO_2 emissions.[83] Manure storage and processing can directly and indirectly contribute to GHG emissions through two of its components: organic matter and nitrogen. In the absence of oxygen, organic matter is decomposed by bacteria, producing methane. The amount of methane produced through manure varies by animal type, weight and feed intake, as well as the context in which it is stored. Manure is also more likely to lead to GHG emissions when it is stored and processed in liquid form, for instance in lagoons, pits or holding tanks, or left unmanaged on pastures.

Capturing biogas through anaerobic digesters and using it to generate energy via combustion can eliminate methane emissions. Methane combustion converts methane into carbon dioxide at a one-to-one ratio. Methane emissions are 34 times more powerful than CO_2, and therefore converting methane into carbon dioxide via combustion has a significant positive impact on the atmosphere.

Whilst biogas digesters do not capture all of the methane produced via manure, they do have a large impact. The extent that biogas digesters mitigate methane emissions varies depending on the type and quantity of livestock raised, type of feed and manure management, the type of bio-digester, and climate. However, as an illustrative example, a meta-analysis of 30 studies on dairy farms found that methane emissions from manure storage were reduced by 43.2% following adoption of biogas digesters.

The potential to reduce methane emissions from manure via bio-digesters is significant. If all livestock manure from cattle, buffaloes and chicken were collected and processed through bio-digesters, it is estimated that GHG emissions could be reduced by 930 to 1,260 Mt of CO_2 equivalent[84] per year, or 13 to 18% of the current emissions related to livestock.

4.3.2 Reduced N_2O emissions from fertilisers

A substantial proportion of GHG emissions from agriculture is also attributable to the use of fertilisers, both organic (manure) and inorganic (synthetic). Synthetic fertilizers are responsible for 0.6 $GtCO_2$-eq, two third of which is attributable its manufacturing method, the Haber-Bosch process, whilst organic fertiliser generates nitrous oxide via the nitrification-densification process.[85] Transportation of both synthetic and organic fertilisers is another significant source of GHG emissions. In 2017, emissions from synthetic fertilisers amounted amount to 411,606 $GgCO_2$-eq. for Asia, 52,852 Gg CO_2-eq. for Latin America, and 26,479 Gg CO_2-eq. for Africa. It is estimated that if all sewage was collected and all sludge digested, it would be possible to provide fertilisers for 30 million hectares and replace 0.4 to 3% of global synthetic fertiliser used.[86]

Farmers replacing both organic and inorganic fertiliser with bio-slurry produced by the bio-digester can reduce GHG emissions. This depends on the extent that farmers are using chemical fertiliser prior to biogas adoption, the type of fertiliser used, and how much of a displacement effect there is. Although there is limited comprehensive evidence on these variables (as discussed in section 0), Sistema.bio's internal data does offer some pointers. Their point-of-sale data collection indicates that their farmers spend $271 on average on chemical fertiliser *prior* to biogas adoption, whilst the survey conducted by 60 Decibels found that 87% of Sistema.bio's customers used bio-slurry as fertiliser. However, there is still uncertainty as to the displacement effect, and with limited data available on what fertilisers are being replaced it is difficult to quantify or measure the extent of impact here.

4.3.3 Reduced deforestation linked to land-use changes

By reducing the reliance on biomass and the need for forest conversion, bio-digesters could slow down deforestation. With an estimated 5.2$GtCO_2$-eq., Forestry and land-use change, the expansion of pasture and feed crops into forests is the second main contributor to GHG emissions related to agriculture.[87] Deforestation contributes to climate change in two ways. First, it reduces the number of trees that can capture GHGs. Second, when trees are felled, the carbon that they have been storing is released into the atmosphere either via combustion or decomposition.

With a net loss in forest area of 2.60 million hectares per year between 2010 and 2020, Africa is the region that would benefit the most from bio-digesters' potential mitigation effect on deforestation. The second most affect region is South America, with an average of 2.60 million hectares per year. In comparison, deforestation is less prominent in Asia, which showed a net gain in forest area. Both subsistence and commercial farmers significantly contribute to deforestation. According to the FAO, subsistence agriculture accounted for a third of tropical deforestation between 2000 and 2010, while large-scale commercial agriculture (primarily cattle, soya and palm oil) was responsible for 40%.[88]

The biggest driver of deforestation is conversion of forests into cropland , driven by the growing demand for food and fuel.[89] As detailed in section 4.2, biogas can facilitate the transition away from use of biomass to biogas. Multiple studies have highlighted that biogas adopters reduce wood usage. This is also reflected in Sistema.bio's internal data, which demonstrates that customers rely heavily on wood prior to biogas adoption, and that after adoption of biogas farmers report decreased dependence on charcoal and firewood. A significant proportion of biomass derives from non-renewable resources, which contributes to deforestation.

Since the use of bio-slurry as an organic fertiliser has the potential to increase yields, it could reduce the need for expansion by enabling farmers to grow more on the same surface. However, while increased productivity is necessary in order to meet the demand, better yields could also encourage deforestation by making farming more profitable.[90] There is a debate in the literature on whether increased yields are more likely to reduce land-use changes (the "Borlaugh hypothesis") or incentivise it (the "Jevons" hypothesis). The evidence is mixed, and is likely to vary by context according to access to cash, cost of labour, market size, the scale of adoption of the productivity-increasing technology or practice, the location and the regulatory framework.[91]

4.3.3 Displacement of GHG-emitting sources of energy

As detailed in section 4.2.1, biogas displaces GHG-emitting sources of energy, and thereby reduces greenhouse gas emissions. Studies consistently highlight that biogas does facilitate a transition away from other energy sources, including LPG, biomass, and charcoal. Research in Nepal and Indonesia, for example, found that firewood consumption fell by 50% after biogas adoption, whilst in East Java adoption of biogas contributed to a decline in usage of liquified petroleum gas by 7kg per month[92][93].

Estimates of the greenhouse gas mitigation of biogas digesters vary, which given the wide range of contexts that they are employed is not surprising. As illustrative examples, the Cambodia bio-digester programme described in Box 10 used an estimate of 5.5 tonnes CO_2E reduced per digester per year, whilst other studies have suggested savings of 11 tonnes of CO_2E annually. Biogas digesters typically have 10-20 year lifespans, depending on the build model, generating estimates of between 55 to 220 tonnes of CO_2E saved over their lifespan. These figures will depend on a range of factors, including the prevailing sources of energy, the extent of displacement, the size and build quality of the bio-digester, and its lifespan.

4.3.5 Assessing impact on SDG 13 by market segment

Table 9 summarises how the impact of biogas in relation to SDG 13 varies by market segment.

Table 13: Impact of SDG 13 by Market Segment

	Impact pathway	Evidence of impact variation by market segment
1	Reduced methane emissions from manure management	- Strong evidence in different geographic contexts and customer segments. - *Product:* Some types of bio-digesters may be less effective at capturing methane from manure, or more prone to leakage from the digester and stove system.
2	Reduced N_2O emissions from fertilisers	- *Income:* Poorer farmers are less likely to use fertiliser

3	Reduced deforestation	- *Geography:* The extent to which wood use translates into deforestation is highly dependent upon both national and local contexts - *Income*: As described previously, low-income biogas users are more likely to use wood as a fuel source - *Geography*: As set out in Table 10, farmers in East Africa are more likely to rely upon wood as an energy source.
4	Displacement of GHG-emitting sources of energy	- Strong evidence across all contexts and market segments. Research was unable to highlight incidents where biogas-adopters relied upon non-GHG emitting sources of energy for cooking prior to biogas adoption.

4.3.6 Conclusion

Biogas clearly contributes towards SDG 13. This is primarily through the impact on reducing GHG emissions, which occurs through two mechanisms. By capturing and combusting methane from animal waste, bio-digester and cook stove systems reduce a significant source of methane emissions. Biogas also displaces other GHG-emitting sources of energy, such as biomass and LPG, thereby further contributing to mitigating global warming. These mechanisms hold across all of biogas' customer segments, although there is likely to be some variability depending on manure type and pre-existing energy use.

There is also some evidence that biogas will contribute to reduced GHG emissions through reduced N_2O emissions, as a result of transitioning away from chemical fertilisers to bio-slurry. However, not all biogas adopters use chemical fertilisers, and more widely smallholder farmers typically under-use fertiliser. It is also not clear the extent to which bio-slurry displaces (rather than is additive to) chemical fertiliser. It is likely that this mechanism will become weaker towards the poorer end of the market, as fertiliser use becomes less prevalent.

There is strong evidence that biogas reduces wood consumption, and a clear relationship between wood consumption and deforestation. However, there is very little research on the direct link between biogas adoption and reduced deforestation, either at a local or national level.

Table 14: Summary of strength of evidence assessment for SDG 13

	Impact pathways	Strength of evidence summary
1	Reduced methane emissions from manure management	Strong evidence that bio-digesters reduce methane emissions and that this is a significant impact
2	Reduced N_2O emissions from fertilisers	Evidence that some (but not all) biogas adopters used chemical fertiliser prior to biogas adoption. Limited research on the extent to which bio-slurry displaces chemical fertiliser.
3	Reduced deforestation	Strong evidence that biogas reduces wood consumption, and a clear relationship between wood consumption and deforestation. However, no *direct* research or evidence on a relationship between biogas use and reduced deforestation.

4	Displacement of GHG-emitting sources of energy	Strong evidence that biogas displaces other sources of energy which emit GHG

5 Using impact to scale

RQ 2: What are the best mechanisms (including but not limited to climate financing, pay-for-success models and other impact monetisation) to expand the use of this technology based on its impact?

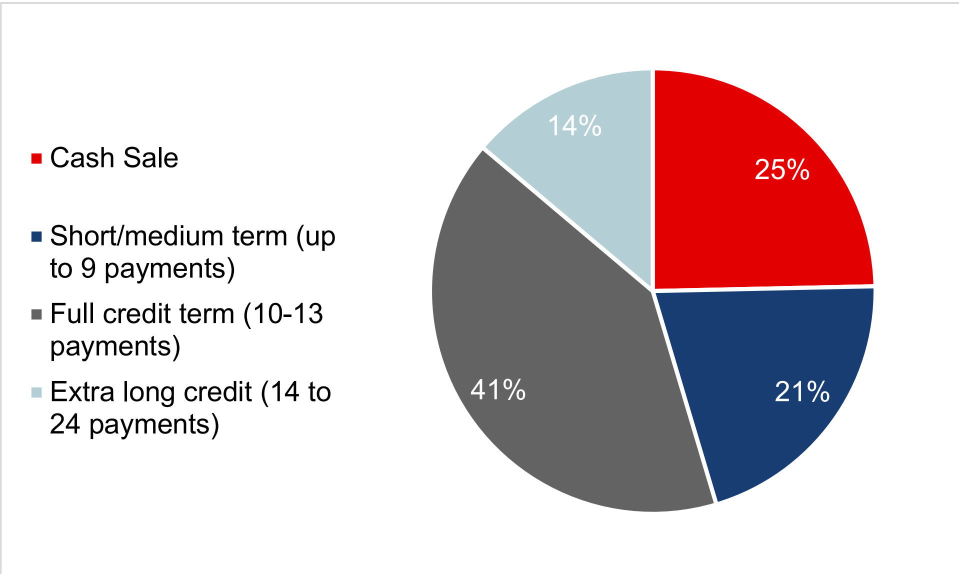
As Section 4 demonstrates, there is robust evidence that biogas generates a significant amount of impact, particularly towards SDGs 2, 7, and 13. Although the technology faces challenges in scaling, there are options which leverage that impact that biogas catalyses to raise finance. Monetising impact helps to capture the wider benefits of bio-digesters whilst enabling companies to sustainably service low-income communities. This section presents an overview of the financial barriers to scale, before identifying impact-based monetisation mechanisms which are relevant and appropriate to the technology.

5.1 Financial barriers to expansion for biogas digesters

Biogas is an expensive technology for low-income households, with devices often costing a minimum of several hundred dollars depending on size and context. For low-income, rural households, the cost of biogas digesters is often the critical constraint towards utilising the technology, despite the economic benefits[94].

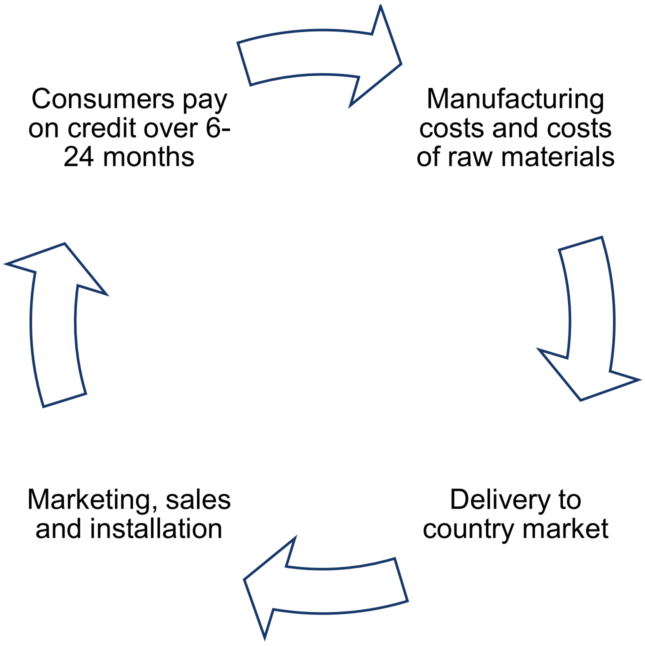
To enable households to purchase the technology, offering products on credit is critical; according to Sistema.bio's internal sales data, 75% of their products are sold on credit (see Figure 7). However, this creates significant working capital pressure for biogas companies operating in this space, who are having to prefinance sales on terms routinely extending over a year.

Figure 7: Sistema.bio Sales by length of credit extended[95]



This means that the cash realisation of sales can extend for up to 3 years after the initial purchase, as highlighted in Figure 8. This creates significant problems for companies operating in the biogas sector with respect to managing their cash cycle and balancing high up-front costs with significant account receivables.

Figure 8: Cash-flow cycle



As outlined above, the sale of biogas digesters to low-income households requires offering products on credit. Not only does this entail significant financing requirements, it also requires the managerial capacity to accurately access the credit-worthiness of consumers, often in businesses environments where reliable third-party credit monitoring agencies are not widespread, particularly amongst poor, rural communities, and additional data on potential customers is limited. Making the 'wrong' credit decisions and lending to consumers who do not have the disposable income to repay can exacerbate the illiquidity challenges of offering products on credit and affect profitability. Prior research conducted by IPE Triple Line found that one biogas company only managed an average repayment rate of 84%, highlighting the challenges of conducting credit assessments by companies with limited specialist expertise in that area[96]. Whilst Sistema.bio have been more successful, there is still a default risk, which ultimately raises the overall price of the bio-digester and further limits affordability.

The business model, as currently structured, is cash intensive. Operational costs are a significant component, and interviews with the Sistema team suggest that per bio-digester the cost of sales, installation and maintenance is roughly equivalent to the cost of goods sold.

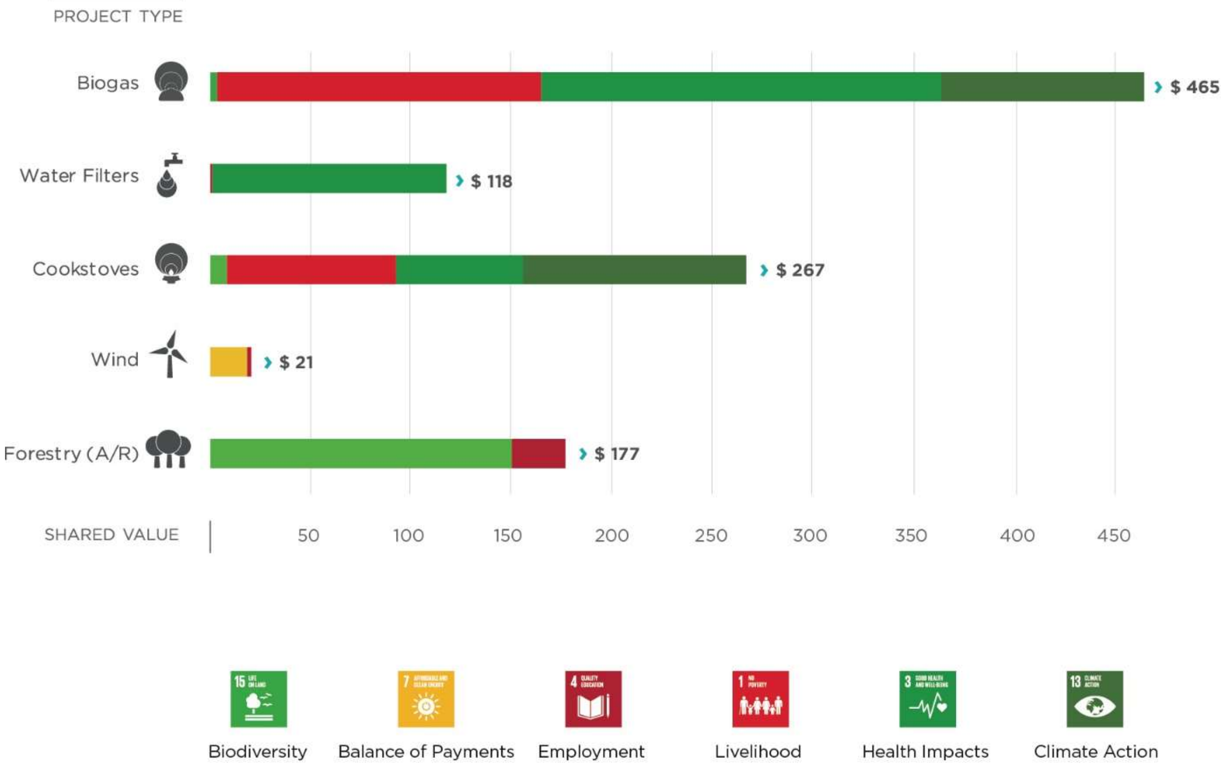
5.2 Understanding the role of impact-based scaling mechanisms

The second part of our review encompassed impact-based scaling mechanisms which are suitable and relevant towards addressing some of the constraints outlined above, and which are aligned with the impact thematic areas and SDGs with which biogas has the strongest relationships. As a technology which has a robust relationship with several different impact objectives, and which is applicable in a range of different geographic contexts, biogas is well positioned to take advantage of impact-based scaling mechanisms.

Our research highlighted three clear take-aways, both of which suggest that biogas enterprises should have a wide degree of flexibility when approaching impact investors and funders:

- Biogas enterprises looking to scale require both significant working capital to enable the 'products on credit' model, and long-term investment capital to invest in marketing, building networks, and manufacturing.
- Unlike technology-based start-ups, biogas businesses are "asset-heavy", and require significant capital to pre-finance the purchase of household bio-digesters. Given that the revenue streams from customer sales should be significant and predictable, debt-based financing may be more appropriate than raising equity.
- As demonstrated in section 4, biogas has strong and robust relationships with several different SDGs. Importantly, impact investors and other stakeholders also broadly recognise the multiple different dimensions of impact catalysed by biogas. Stakeholders we interviewed as part of our research highlighted the economic, health, and environmental benefits of the technology, and we did not find evidence that perceptions of the impact of biogas are limited to a particular thematic area or SDG. As a further example, the Gold Standard has conducted some analysis which suggests that biogas and cook stoves are the only project types on their platform which generate meaningful and significant impact in three areas (see Figure 9).

Figure 9: Gold Standard assessment of monetary benefits of one tonne reduction in CO_2 emissions[97]



Impact-based scaling mechanisms is a broad area, encompassing impact investment, carbon financing, payment by results, impact financing, ODA-funded grant programmes, and governmental programmes and subsidies. Table 15 sets out a summary of these different mechanisms.

Table 15: Summary of impact monetisation mechanisms

Impact monetisation mechanism	Description	Biogas experience	Investors and funders
Grants	Grants to incentivize risk or to enable greater inclusion are a common developmental tool. The size, thematic focus, and use of grants can vary significantly, as can the selection process.	Sistema.bio have received grants from Shell Foundation and AlphaMundi Foundation, whilst other companies have had grants from the Africa Enterprise Challenge Fund.	Bilateral and multi-lateral donors, foundations, NGOs
Equity impact investment	Impact investors seek to generate a commercial return whilst also catalysing impact. The market is varied with different financing mechanisms, ticket sizes, thematic areas, and expectations of a commercial return.	Both equity and debt investment into biogas companies	Impact investors
Debt impact investment			
Carbon financing	Carbon financing is a mechanism by which polluting entities finance activities which mitigate and offset the impact of their pollution. Funders include both individuals and organisations. Schemes are normally financed via platforms who screen and approve project concepts.	Sistema.bio achieved Gold Standard certification in 2020, as have other biogas projects in China and Cambodia.	Companies, NGOs, governments, and individuals
Crowd-sourced financing	Using online platforms to raise finance through small amounts from individuals who are seeking to make a financial return whilst generating impact. These tend to be shorter tenor loans for on-lending, reflecting the risk profile of individual investors and the need to link funding towards outcomes for individual households to provide an impact story.	Sistema.bio has raised finances via the *lendahand* platform, most recently as a two-year loan in August 2020. Other biogas companies have also raised funds through these platforms	Individuals
Securitisation	The sale of account receivables from customers (loan repayments) to a third party, normally a development finance institution or an impact investment vehicle, at a discount to reflect both the risk of non-repayment and the cost of capital. This frees up working capital and greatly reduces the cashflow cycle	Sistema.bio has provisional partnerships in place with institutional investors and are exploring the possibility of setting-up an off balance-sheet vehicle	Institutional impact investors, local financial institutions
Development impact bonds	Impact bonds are a performance-based, pay-by-results model in which initial funding is provided by private investors, who are repaid by a third-party if impact objectives are achieved. This effectively ensures that donors only fund projects which generate impact, and that the risk is carried by private sector investors.	N/A	Institutional impact investors, donors, impact investors
Government subsidy programmes	Government subsidy can support scale up and expansion. Programmes can use price subsidies, loans, direct support to biogas companies, and marketing the benefits via state infrastructure	Government subsidy programmes operate in China, Indonesia, India, and Mexico	Government and multi-lateral donors

At different stages of maturity, distributors of bio-digesters need different types of financing of support to growth. This means that there is a role for different stakeholders with different risk appetites and different expectations of a financial return. To help identify the right way to support biodigesters, each financial instrument was mapped onto 4 key phases of growth for bio-digestor companies to illustrate where as an instrument they are most . However, on caveat to this framework is that within each financial mechanism there is significant diversity, and we would expect to see exceptions to this framework.

Table 16: Identifying the right way to support bio-digesters

Impact monetisation mechanism	Product development phase	Piloting phase	Transitions to scale	Scale up and expansion
Grants	Targeted	Targeted	Targeted	Partially targeted
Equity impact investment	Targeted	Targeted	Partially targeted	Partially targeted
Debt impact investment			Targeted	Targeted
Carbon financing			Targeted	Partially targeted
Crowd-sourced financing		Targeted	Targeted	
Securitisation			Partially targeted	Targeted
Development impact bonds		Partially targeted	Targeted	Partially targeted
Government subsidy programmes	Partially targeted	Partially targeted	Partially targeted	Targeted

Key

- (green) Mechanism is targeted towards supporting this stage of growth
- (orange) Mechanism is partially targeted towards supporting

Each financing mechanism is set out in more detail below.

5.2.1 Grant funding

The size and range of the grant funding sector makes it difficult to draw clear conclusions. Grants range in size from less than $5,000 to multi-million, and are available in a wide range of different thematic areas to serve different impact objectives. Biogas companies have been the recipient of grant funding; several, for example, have received funding from the Africa Enterprise Challenge Fund, and Sistema.bio has received grant funding from the Shell Foundation. Grants are an inherently flexible tool and can be deployed to cover a wide range of different costs, including but not limited to R&D, product development, market scoping, operational costs, and customer subsidies.

However, common across nearly all grants is that they are a one-off tool – and many grant programmes aimed at private sector enterprises have an explicit objective around 'graduating' companies onto non-grant funding. This means that grants tend not to be a sustainable mechanism for long-term scaling and expansion – there has to be other sources of financing which eventually displaces grants.

5.2.2 Equity and debt impact investment

Impact investors use conventional financial instruments such as equity investments and credit with the objective both of making a financial return and generating pre-defined development impact. The impact investment market is by far the most significant impact-orientated financing mechanism, with a total market size of $715bn. This figure includes asset managers seeking market-rate returns whilst investing in an asset class with a development thesis, as well as investors targeting below-market rate returns and taking a proactive approach towards identifying impact opportunities. The market is very varied, with a significant range of different ticket sizes, financial instruments, and thematic areas. Given this diversity, it is difficult to generalise about this mechanism. However, for the purpose of identifying the right funding sources for bio-digesters, there is a clear distinction between the suitability of equity impact investment and debt impact investment at different stages of a company's growth trajectory. Whilst equity impact investment can be targeted towards each phase, it is best suited towards the initial high-risk product development and pilot phase. In contrast, debt impact investment should be targeted once bio-digestors have an initial customer and a stable revenue stream through repayments.

5.2.3 Carbon financing

Carbon financing, or carbon offsetting, places a monetary value on reducing emissions of GHG and enables polluting companies to pay to offset their own emissions. In the European Union, there is a mandatory carbon offsetting scheme to incentivize companies to cut their emissions or offset them. There is also a significant voluntary market which in 2018 had a market value of almost $300mn[98]. The European Union's scheme is not suited for biogas, with the focus on funding emission reductions within larger, industrial installations, primarily located within the European Union. However, voluntary carbon financing markets, which often have a smaller, community focus with "co-benefits" (e.g. positive health or economic outcomes) beyond reductions in GHG emissions, are adaptable to the biogas model.

The voluntary market primarily works through certification platforms, of which the two most significant are the VCS+CCB standard managed by VERRA, and the Gold Standard. Together, these two platforms account for 88% of the market. The platforms solicit applications from project developers, review and certify the expected benefits, and once confirmed market the opportunity to companies and individuals who plan to offset their emissions. Renewable energy, the category which biogas falls under, accounted for $31.5mn in 2017 and $40.9mn in 2018[99]. The average carbon 'price' for renewable energy products was $1.7 per tonne of CO_2E in 2018, although that figure masks considerable variation; as demonstrated in Box 10, the price of Carbon offsets for biogas projects on the Gold Standard platform is $19 per tonne of CO_2E.

Our analysis reviewed carbon financing from two separate angles; the commercial viability for biogas, and the suitability of biogas in terms of meeting the restrictions set by the two major certification platforms. With the public information available, it is difficult to estimate the potential benefits for biogas companies of certification in a carbon offset scheme against the additional costs of monitoring and compliance. Biogas as a technology is very well suited to the certification schemes and is recognised by Gold Standard as a mechanism which generates significant impact in different dimensions. However, biogas projects previously certified on carbon offset platforms have tended to be managed by development aid organisations in partnership with government (see Box 10). This perhaps suggests that the Gold Standard Platform has some preconceptions around what biogas projects should look like and how they should be managed, emphasising the role of the state as well as NGOs.

Box 10: Examples of biogas within carbon offset schemes

The Gold Standard platform currently has three biogas projects in Kenya, Cambodia and China for financing, with 'selling' prices of $19 per tonne of CO_2E. The projects in Kenya and Cambodia are managed by Hivos, a Dutch aid organization with a long history of pioneering the technology. In Cambodia, the carbon offset funds an "investment subsidy" of $150 per biogas digestor, whilst in Kenya sales of carbon offsets helps to fund "after-sales support, bio-slurry training, and other useful services". The Cambodian project is implemented jointly with the Cambodian Ministry of Agriculture, Forestry, and Fisheries, whilst the Kenya project coordinates with Kenya's National Biogas programme.

The project in China is implemented by UPM, a German environmental company which specializes in supporting climate adaption and carbon offsetting programmes in China, in partnership with the Governmental Sichuan Rural Energy Office. Funding via the Gold Standard Platform is used to support a free maintenance, repair, and advisory service via the local offices of the Sichuan Rural Energy agency as well as the costs of installation.

These examples provide four clear takeaways:

- Projects are normally developed and managed by development aid organisations in partnership with state entities. There appears to be a limited role for private sector biodigester distributors/manufacturers, although there is no technical restriction on their input. Other Gold Standard projects are managed by private sector entities (e.g. a Cambodian manufacturer producing ceramic water filters, or a plastics recycling company in Romania).
- There is significant flexibility in what funds can be used for. Projects used the proceeds from carbon offsets as a price subsidy, to support offering products on credit, and to fund post-sales services including maintenance and extension services.
- There is also a wide range in terms of the size of the projects. The project in China reached 400,00 households, whilst in Cambodia and Kenya the figures were much lower at 27,231 and 15,140 bio digestors installed respectively.
- All 3 projects emphasized the non-environmental advantages of biogas, reflecting the 'co-benefit' approach. All the projects highlighted the use of bio-slurry to increase crop yields, as well as the health benefits of transitioning to smoke-free kitchens.

In addition, Sistema.bio have recently received approval from the Gold Standard platform for a project in partnership with Good Farmland Management Kenya and Swiss Carbon Value. The project aims to support the installation of 84,266 bio-digestors in Kenya by 2023.

Neither the Gold Standard nor the VERRA platform set prices for carbon themselves, leaving it up to project developers to do so. Unfortunately, there is limited public information available on a) how they have calculated their prices (although Gold Standard have launched a process to encourage greater price transparency, b) how reductions in carbon emissions are calculated, and c) the amount spent on carbon offsets under each project. This makes judging the commercial potential of Gold Standard Certification challenging in the absence of these benchmarks.

However, there are some data points which highlight the potential commercial feasibility of certification. In 2019, the Gold Standard platform issued 5.4mn carbon certificates for biogas, and 'sold' 3.4mn. This ratio effectively equates to demand, implying that of the 5.4mn certificates available, 3.4mn were purchased[100]. The ratio for biogas was slighter higher than the portfolio average even though the average price for biogas carbon credits was higher, suggesting that carbon offset purchasers recognise the multi-dimensional impact that biogas generates[101].

The Gold Standard platform supports biogas via their "Community Services" category. The relevant document explains that that "Methane recovery project activities shall be eligible for emission reductions from both methane avoidance (including from the flared biogas fraction) and non-renewable fuel substitution as long as evidence is provided on time for validation to demonstrate that the system was designed in a way to at least make use of some of the biogas recovered for the delivery of energy services (e.g. electricity, heat)". This clearly covers the standard biogas operating model used by Sistema as well as other companies in the industry.

Whilst private sector companies are eligible to be project developers in the Gold Standard scheme, a review of the wider portfolio suggested that most projects are developed by aid organisations in partnership with government. This potentially reflects the emphasis on stakeholder engagement in the Gold Standard certification and approval process, as well as the additional monitoring requirements which may be beyond the capacity of private sector companies. There may also be an in-built bias in the Gold Standard model for non-profit organisations.

Carbon offsetting via the Gold Standard platform is a viable option for biogas companies. Biogas projects have been certified before, the Gold Standard have recognised the impact of biogas (see Figure 9), and demand for carbon credits from biogas projects has been robust. There is also significant flexibility in how funding can be used, suggesting that offsets could be deployed both to scale to new areas or to introduce subsidies for poorer consumers. However, to achieve certification platforms require a viable example as a demonstration, implying that carbon financing is not an appropriate funding source for either the product development or initial piloting phase. Furthermore, the market is still relatively small, meaning that there are constraints to the extent to which it can support significant expansion.

5.2.4 Crowd-sourced funding

The crowd-sourced funding market for energy access is small but growing rapidly, with $31mn raised in 2018 compared to under $4mn in 2015. As it has grown, it has pivoted from crowd-sourced financing targeted directly at individual customers to crowd-sourced loans targeted at energy companies; in 2015, 70% of loans were directed at individuals, and 4% at companies, and by 2018 88% of loans went towards companies and only 4% to individuals (with the remainder being the small crowd-sourced equity market)[102].

Given the relative size of the markets, the focus of our analysis has been on loans towards companies. There are a range of platforms which screen potential lending opportunities, market them to investors, and act as financial intermediaries between investors and energy access enterprises, including Lendahand, Energise Africa, TRINE, bettervest, and Kiva. Common across all of the platforms is that there is an impact story, with investors motivated both by the financial return and impact. Investors also tend to be individuals, rather than companies, often working outside the development or energy sectors[103].

There is also significant variation in whether crowd-sourced funding seeks to generate commercial or near-commercial returns, as well as the loan size and tenor. Kiva's business lending projects, for example, tend to be smaller (>$100,000), with shorter maturities, and often do not involve interest repayments. In comparison, bettervest projects have a maturity of up to 8 years, with fixed interest rates of up to 8% and ticket sizes of up to EUR 1mn.

Box 11: Sistema.bio's use of crowd-sourced financing

Sistema.bio have successfully raised finance before via the lendahand platform, most recently in August 2020. Sistema.bio's EUR37,500 two year loan at an annual interest rate of 6.5% was fully funded in less than a day, with the proceeds used to help manufacture and export 125 bio-digestors to Kenya for sale on credit to smallholder farmers. Previous projects include a 12-month EUR150,000 loan, which was also intended to address the working capital gap in manufacturing and exporting products for the Kenyan market.

There is also a transactional cost of raising financing through crowdsourcing. Platforms typically require some form of impact monitoring and verification, although the rigour and cost of this varies. In addition, whilst investments are motivated by impact, they are also financial transactions with significant sums of money. This requires the development of a financial prospectus as well as an understanding of the tax and regulatory issues in raising financing in different jurisdictions.

A further significant hurdle for biogas companies raising money through crowd-sourced platforms is that it can create a currency mismatch between their assets and liabilities[104]. Crowd-sourced platforms raise funds almost wholly through USD, GBP, or EUR, whilst products are sold to customers on credit in local currencies. Local currency depreciations decrease the value of credit repayments from customers compared to repayment of loans. This can be significant; in Kenya, for example, since January 2020 the currency has depreciated by 8% against USD, meaning that when valued in USD the valuation of credit repayments from Kenyan consumers has fallen by 8%. Managing currency risk is a major additional cost for biogas companies which crowd-sourced funding does not mitigate.

Crowd-sourced financing is increasingly a viable option to raise large sums of debt capital over a mutli-year period. However, it is not 'free money' – investors in crowd-sourced financing mechanisms, particularly at the larger end, still expect a significant financial return. This may be lower than commercial financing, but it still implies a significant cost of capital. This suggests that whilst it is an attractive option for working capital financing to fund the cost of extending credit to customers, it is not a good option for expansion into new areas.

5.2.5 Securitisation through off balance-sheet vehicles

A third option for enterprises offering bio-digesters on credit is through securitising accounts receivables through an off-balance sheet vehicle. This enables companies to realise the cash through product sales much more rapidly, shortening the cashflow cycle, whilst for investors it facilitates their input without investing directly into the company (with the greater operational risk that implies).

Whilst there are significant advantages of securitisation, there are also significant barriers towards wider adoption as well. These include:

- Marketing and identifying the investment opportunity to investors
- Demonstrating the track record of repayments from customers
- Achieving sufficient scale to justify the significant start-up costs of securitisation

This suggests that securitisation is only available as an option when businesses have a proven concept and track-record and are able to absorb significant amounts of financing. Persistent Energy, who advised on the first securitisation in the PAYGO solar market in 2015 and have since championed it as a financing mechanism, concluded "securitisations can attract investors with offerings as *small* [author italics added] as $5m million. However, economies of scale won't be realised unless a company raises much more debt this way"[105]. Furthermore, the legal requirements for setting up an SPV means that pooling portfolios of customers from different countries can become more complex, implying that companies need to be in a position to absorb significant amounts of financing at a country level.

Securitisation can also create currency mismatches. Whilst it is potentially feasible to do local currency securitisation, in reality this will depend on the depth of local capital markets and the presence of local institutional investors. Significant financing is likely to be limited to major, non-local currencies.

There are organisations which can act as financial intermediaries to support the securitisation process and to market the opportunity to investors. Unfortunately, these are heavily geared towards the solar sector. Examples include SunFunder and the AfDB Distributed Energy Service Companies Financing Program. Starting a conversation with these organisations to highlight the potential of biogas and the similarities with the PAYGO model could open the doorway to third-party institutional capacity and support.

Whilst securitisation investors are motivated by impact, there is also a clear distinction between their impact incentives compared to investors in crowd-sourced financing mechanisms. Securitisation investments in the PAYGO sector have been dominated by large institutional impact investors, including Oikocredit, CDC, Calvert Impact Capital, and the US Development Finance Corporation. Crowd-sourced investors, as described above, tend to be individuals with limited professional expertise in the sector. This entails a different type of impact monitoring, with more focus on robust, data-led impact frameworks rather than capturing beneficiary stories.

Given the transaction costs involved and the requirement to have a clear track record, securitisation is best suited towards financing scale up and expansion It is not an appropriate financing method for product development or for initial piloting.

5.2.6 Development impact bonds

Development impact bonds are a mechanism of funding developmental programmes from private investors who earn a return funded via a third-party donor or government if the programme is successful. This means that development programmes unlock private sources of capital, and developmental financing is only spent when pre-agreed development impact targets are achieved. The Brooking Global Impact Bonds Database reports that 194 impact bonds have now been launched, encompassing $421mn in upfront investment and $460mn in outcome funding committed by governments and donors. However, the bulk of this funding is in Social Impact Bonds rather than Development Impact Bonds, implemented in high income countries such as the United Kingdom, the United States, and the Netherlands, with just 17 in middle and low-income countries[106].

The development impact bonds which have been launched have been across different sectors, with examples in health, youth employment, livelihoods, and education. Regardless of the sector, however, there needs to be a set-up which enables clear identification of pre-agreed outcomes, and independent verification of these outcomes by third parties. Examples of indicators include number of surgeries conducted, differences in learning outcomes, and increases in household income.

Criticism of development impact bonds have centred on the increased complexity and the accompanying increased costs of design and set-up. An evaluation of four Development Impact Bonds concluded that the median cost of the design and set-up was 10.1% of the total funding (including both the initial capital investment and funding for outcome payments)[107]. In addition to these set-up costs, implementation costs are likely to be higher because of the requirements around external verification of outcomes and results. Participants in development impact bonds also reported reputational risks given the focus and interest in this funding mechanism[108].

However, as a report commissioned by the UK Department for International Development noted, this is also likely to be a consequence of both the limited number of development impact bonds launched, which reduces institutional know-how on how they should be designed and operated, and the relatively small size of current development impact bonds – given that a proportion of costs are likely to be 'fixed' regardless of the total bond size[109]. This suggests that as the market continues to grow, development impact bonds could become significantly cheaper and more feasible as an option.

Surprisingly, there have been few development impact bonds linked to energy access technologies, including biogas and solar. A World Bank report on off-grid solar financing released in 2020 could not find any examples of development impact bonds in the off-grid solar market[110]. On paper, this is unexpected; the impact of the off-grid solar market is well-recognised, and there are clear metrics with which external outcome donors could monitor and verify impact. Given that biogas is a less widespread technology than solar, this could suggest that it would be better to focus on health rather than energy access outcomes when exploring this financing mechanism.

Given the nascent stage of the market, development impact bonds may not be an attractive short-term option. Currently, there are significant transaction costs to setting up a development impact bond, as well as reputational and implementation risks. However, biogas companies should keep a close eye on how the market develops, given that as it scales the costs and risks of development impact bonds are likely to fall significantly.

If development impact bonds do continue to develop, they are likely best placed to support companies seeking to transition to scale. At this stage, private sector investors have the track record of a successful pilot to assess the risk to their investment, whilst for third-party donors there is enough uncertainty to justify outcome-based funding.

5.2.7 Government subsidy programmes

In high-income countries both access to energy and climate change mitigation initiatives are heavily subsided by government, particularly for poorer, rural consumers. This reflects the social benefits of increasing access to energy and in mitigating climate change, which can be difficult to capture using purely market-based mechanisms. Given the significant benefits demonstrated by biogas, there is a strong policy argument for governmental subsidies. In two of the countries in which biogas adoption is highest – China and Indonesia – government-backed subsidy programmes have been critical to wider expansion of the technology. Government subsidies could also play a significant role in enabling market access for poorer customers, including food-insecure bottom of the pyramid consumers who fulfil the technical criteria for biogas (access to livestock and running water) but cannot currently afford the technology.

However, there are two issues which act as significant barriers towards more widespread use of governmental subsidies programme. First, in many of the countries with significant biogas potential, such as Kenya, Ethiopia, Tanzania, and Nigeria (for a full list, please see Table 4), the tax base for government spending and government expenditure as a proportion of GDP is still very low – often, below 15%. This compares to an average of 34% in high-income OECD countries. There is limited financial capacity to support wider government subsidy programmes, despite the significant societal advantages. Secondly, looking at the same pool of countries, whilst potential biogas adopters are poor when assessed on a global scale, they are not amongst the poorest segments of society on a national level. Recent research by 60 Decibels on Sistema.bio's customer base in Kenya demonstrated that clearly; Sistema.bio's customers tend to be wealthier than the national average, and significantly wealthier than the average for rural communities. This potentially makes it more difficult for governments to justify subsidy programmes which do not impact bottom of the pyramid consumers.

This suggests that there is likely to be more scope for governmental programmes in the short-run in middle-income and lower-middle-income countries which still have extensive biogas potential in poorer sections of the population. In these countries, the tax base is higher – typically 15-25% - and potential biogas adopters are more likely to be poorer than the national average. Examples of countries in this pool include Mexico, China, and Indonesia.

Although government subsidies are an inherently flexible tool, the framework suggests that they are best targeted at scaling up and expansion. This is because governments have the financial resources and institutional presence to continue to support expansion and growth even at a significant scale, beyond what other donors can provide.

5.3 Conclusion

There is significant potential for biogas to attract greater funding from alternative impact-based sources. However, there are some barriers towards adoption. Carbon offsets require a lengthy and expensive certification process, as well as on-going monitoring. Once set up, however, the funding does not create any balance sheet liabilities and can be used flexibly – either as a purchase subsidy, or to fund ongoing operational costs. Crowd-sourced financing is an effective way of raising small-medium sums of working capital, but it comes at a financial cost; interest rates are typically between 6-8%, and loans are denominated in international rather than local currencies, creating a currency mismatch on the balance sheet and exposing biogas companies to currency risk. Securitisation can enable biogas companies to access large pools of institutional impact-related funding, but it is not clear if the transaction costs justify the process except when raising larger sources of financing once companies have already achieved scale. The smaller size of the entire biogas sector (compared to similar technologies such as solar) also impedes securitisation because there are fewer organisations in the supporting markets advising and acting as financial intermediaries.

Whilst development impact bonds appear well-suited to the biogas sector, where impact metrics can be track and verified and financial income streams are predictable, it is still a very new finance-raising mechanism, and few institutions have the institutional know-how and capacity to participate in a DIB without entailing significant transaction and start-up costs. Surprisingly, despite the success of PAYGO more widely in raising finance, there are also no examples of DIBs in the energy access sector. Whilst DIBs are an option for biogas, companies should be aware that there will be additional costs to being a 'first-mover' in this sector.

Government subsidy programmes are another attractive mechanism for securing ongoing financial support. However, there are clear difficulties in securing significant financial support in many of the countries with the highest biogas potential. In the short-run, advocacy should be focused on middle-income and lower-middle income countries which have more financial leeway with respect to public expenditure, and where biogas adopters are more likely to be amongst the poorer segments of society.

6 Measuring and tracking contributions towards the SDGs

RQ 3: How can the impact of biogas be better tracked, measured, and understood?

As noted above, impact based monetisation does normally require some form of impact measurement and verification, both to attract investors and stakeholders to the technology, and to demonstrate to investors post the financial commitment that their investment has had an impact. The focus and rigour of impact measurement will vary depending upon the impact mechanism involved – ODA-funded grants for example, typically require more rigorous assessment than crowd-sourcing financing.

Measuring the impact of biogas is challenging. As described above in section 4, biogas contributes towards several different SDGs, which means that there is no single, universal indicator which adequately captures the impact of the technology. Biogas is also used in very varied geographic contexts, which demonstrates the flexibility and adaptability of the model, but also makes data collection using the same set of indicators more difficult because the indicators have to continue to be relevant and applicable in different environments.

Our proposed solution is to combine a top-down approach which uses simple, cost-effective indicators which draw from globally used and recognised frameworks with a participatory methodology using beneficiary insights to help illuminate and demonstrate impact. Global indicators serve to track, measure, and communicate impact, whilst customer perspectives can help demonstrate through stories the impact of the technology at the household and community level.

6.1 Using global indicators to measure and track impact

To select indicators, we have developed the following criteria:

- **Cost-effective**: indicators should be cost-effective to collect data against. This recognises that both biogas enterprises and impact investors rarely have the resources to invest in significant third-party data collection. ODA private sector grant programmes typically invest up 5-10% of the total grant amount in monitoring and evaluation; given the imperative to make a commercial return and guarantee sustainability for social enterprises and impact investors, a comparative level of investment is not possible. This means that indicators should, where possible, rely upon data already collected by companies as part of their normal business processes.

- **Simple to implement:** similarly, we have to be aware that monitoring and data collection will not always be carried out by firms with significant capacity in these areas. Proposing data collection tools which require significant additional expertise, either in terms of technical expertise or monitoring and data collection expertise, is unlikely to lead to wide-spread adoption.

- **Robust relationship with impact objective**: simple and cost-effective indicators will rarely directly measure the attainment of an impact objective. Impact level indicators are typically more complex and take significantly longer to demonstrate progress when compared to output and outcome indicators. This is clear from analysis of some of the indicators suggested by the UN to measure the SDGs. Indicators for SDG 2, 'No Hunger', include measurement of the prevalence of stunting among children under 5 years of age, and the prevalence of anaemia in women between the ages of 15-49. These indicators are difficult and expensive to measure, and the effect of a biogas digester will take a significant amount time to influence the data. Instead, we have identified indicators lower down the causality mechanism, where it is cheaper and simpler to collect, but which still have a *robust* relationship with the impact objective. We have drawn upon the research conducted as part of the strength of evidence assessment to ensure that there is a clear empirical foundation between the indicators we selected and the impact objective and focused on identifying outcome level indicators.

6.2 Suggested measurement approach and indicators

To identify indicators, we reviewed a series of global impact frameworks. These included the measurement frameworks provide by the UN to track progress towards the SDGs, the IRIS+ framework, and energy-access specific frameworks developed by GOGLA.

Using these frameworks as well as leveraging our experience in impact measurement, we identified indicators to collect evidence against the outcomes identified through the TOC, as demonstrated in Figure 12. Based on Sistema's experience in data collection, we have also assessed the ease of collection for these indicators by a biogas company. The choice of indicators on which to report will be determined by the companies' ambition in terms of evidence generation, the resources available for data collection, and potential donor or investor requirements. The ease of collection was classified as follows:

Table 17: Framework for assessing indicators

High	Data is likely to already be collected by the company or can easily be integrated into normal business operations
Good	Data is not directly linked to business operations and is unlikely to be already collected by the company, but can potentially be integrated into normal business operations
Medium	Data is not directly linked to business operations and may not easily be integrated into normal business operations
Low	Data is complicated to collect

As shown in Figure 12, three outcomes have indicators that are likely to be collected as part of normal business operations, and four can easily be measured. Increase in yields is challenging to assess because the outcome will often take more time to become observable and might need to be measured differently across crops. Finally, data on the increase in nutrients cannot be easily collected by biogas companies. Scientific studies would be better suited to collected evidence against this outcome.

Figure 12. Mapping indicators onto the Theory of Change

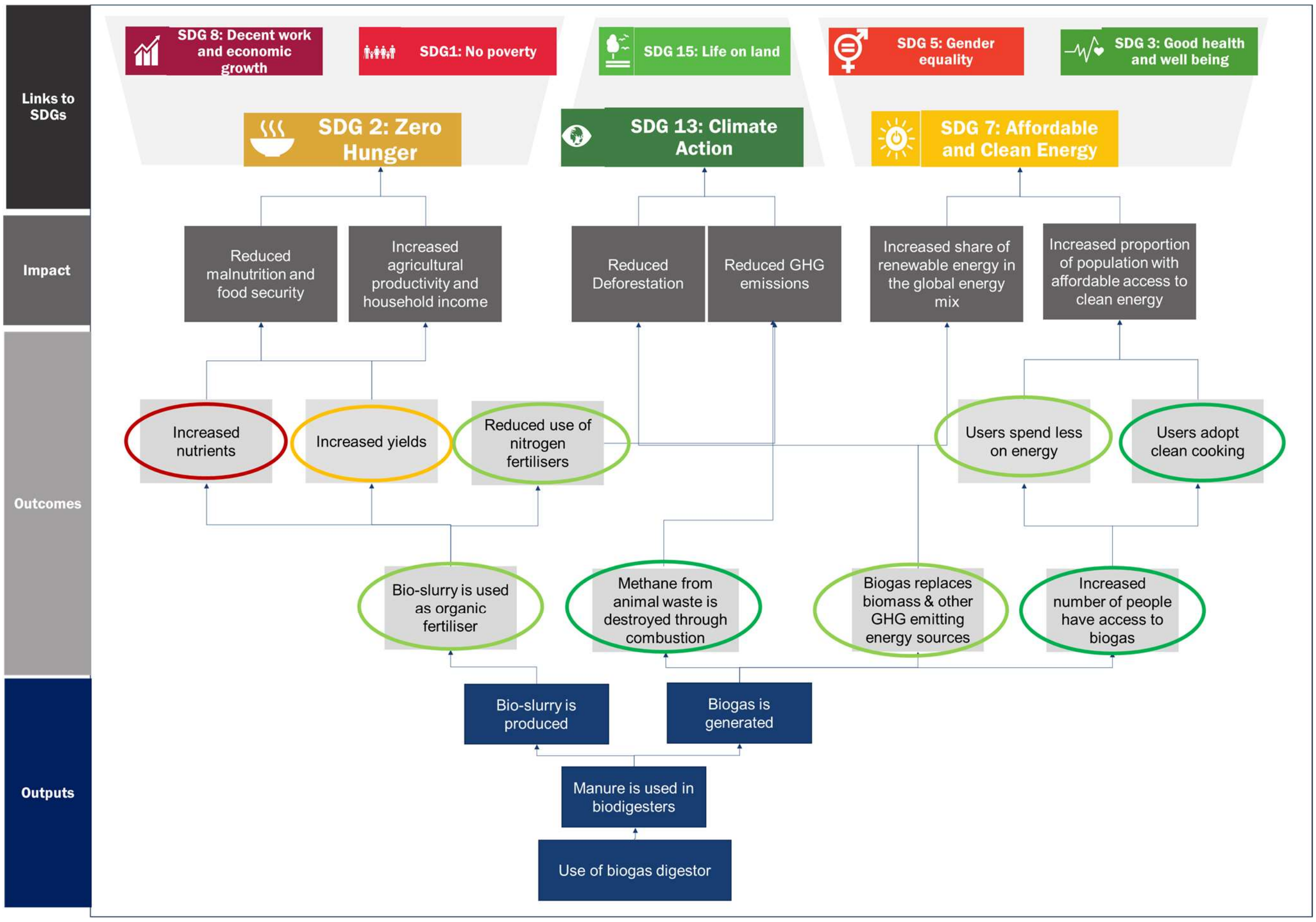


Table 18. Suggested indicators

TOC hypothesis	#	Indicator	SDG 2	SDG 7	SDG 13	Ease of collection
Increased number of people have access to biogas	1	**Number of new people with access to biogas** *This corresponds to the total number of new people that have accessed biogas for the first time thanks to Sistema's product over the reporting period. This is calculated by multiplying the number of new households with access to biogas by the average household size. This can be aggregated to provide the total number of people reached to date.*		X		Operational/financial data on the number of new sales should already be collected. Data on household size and previous use could easily be collected as part of the diagnostic.
	1.1	**Number of new households with access to biogas** *This refers to the number of customers who have gained access to biogas during the period (new customers who are also first-time users) This indicator corresponds to IRIS indicator PI2845, and can be aggregated to provide the total number of households reached to date.*				
	1.2	**Number of people per new household with access to biogas** *This should be measured in terms of individuals directly benefitting from energy generated by the bio-digester. This indicator corresponds to IRIS indicator PI4548 and can be aggregated to provide the total number of people reached to date.*				
Methane from animal waste is destroyed through combustion	2	**Amount of manure used in bio-digester over the reporting period** *This refers to the total amount of manure (in kg) used by customers in Sistema's digesters over the reporting period. This is calculated by multiplying the number of current customers by the average bio-digester consumption over the reporting period. This can be aggregated to provide the total amount of manure used to date.*	X		X	The amount of manure collected (e.g. per day) will often be part of the diagnostic to estimate if a client will have sufficient inputs and determine which product will be suitable. For instance, as part of its diagnostic, Sistema collects data on liters of manure collected per day, as well as the number of animals owned, disaggregated by type of livestock. There will be some assumptions used in calculating this indicator (e.g. that all manure

						will be used in the bio-digester). Companies should also know their products' capacity and use that to triangulate and ensure that none of the produced is unfeasible.
Bio-slurry is used as organic fertiliser	**3**	**Number of customers using bio-slurry as organic fertilisers for the first time.**				Prior fertiliser usage is collected through the marketing/diagnostic process, but will rarely be formally collected as it is not directly useful to the company. Clients can often be assumed to be first-time users, and to use bio-slurry. This information is also more difficult to collect as it will need to be collected after the point of sale. It could easily be collected during monitoring visits, or through an impact study.
		This refers to the number of customers reporting having used bio-slurry over the reporting period. This only includes customers who have applied bio-slurry for the first time (e.g. customers who have already reported using bio-slurry should not be counted). This can be aggregated to provide the total number of customers reached to date.				
	3.1	**Number of customers applying fertilisers properly**				This is unlikely to be collected by the company unless technical support is provided by the company or a partner (e.g. via extension agents or an NGO). It could also be collected through a specific impact study.
		This refers to the number of customers applying bio-slurry according to best practices for the first time, over the reporting period. This can be aggregated to provide the total number of customers reached to date.				
Increased yields	**4**	**Number of customers reporting increased yields following the use of bio-slurry as fertiliser for the first time**	X		X	This information needs to be collected after the point of sale, and potentially quite some time after the sale (at least one season should have passed). Depending on the business model and relationship with the client, it might be possible to collect it as part of a monitoring visit or via an SMS. It could easily be collected through an impact study. Data could be useful for marketing purposes.
		This corresponds to the number of customers who have applied bio-slurry to their crops and observed an increase in yields over the reporting period. This only includes customers who have observed an increase for the first time (e.g. customers who have already reported an increase in the past should not be counted).				
	5.1	**Average percentage yield increase**				This information is not directly useful to companies and very complicated to collect, considering differences between crops etc. Quantitative information about yield increases would be best assessed through a specific, in-depth case study.
		This correspond to the average yield increase per customer following the application of bio-slurry. This should ideally be disaggregated by crop, region, type and quantity of bio-slurry applied, etc.				

Reduced use of nitrogen fertilisers	6	**Number of customers reporting reduced use of nitrogen fertilisers for the first time**	X		X	Prior usage is likely to be known through the marketing/diagnostic process, but will rarely be formally collected as it is not directly useful to the company. Clients can often be assumed to be first-time users.
		This corresponds to the number of customers who have applied bio-slurry to their crops and report having decreased their use of nitrogen fertilisers during the reporting period. This only includes customers who have reported a reduction in their nitrogen fertiliser use for the first time (e.g. customers who have already reported a decrease in the past should not be counted).				This information is also more difficult to collect as it will need to be collected after the point of sale. It could easily be collected during monitoring visits, or through an impact study.
	6.1	**Total decrease in nitrogen fertiliser consumption over the reporting period**				Prior usage likely to be know through the marketing/diagnostic process, but will rarely be formally collected as it is not directly useful to the company. Clients can often be assumed to be first-time users.
		This corresponds to the average difference in nitrogen fertiliser use (in kg) before and after the bio-digester purchase over a specific time period (e.g. month), multiplied by the number of customers				This information is also more difficult to collect as it will need to be collected after the point of sale. It could easily be collected during monitoring visits. This requires some calculation.
Users spend less on energy	7	**Number of customers reporting energy savings for the first time**	X	X		Prior energy spending is likely to be known through the marketing/diagnostic process. For instance, Sistema bio collects on baseline energy spending, disaggregated by type of energy source.
		This corresponds to the number of customers who report spending less on energy than before purchasing a bio-digester. This only includes customers who report a decrease in expenditure for the first time (e.g. customers who have already reported a decrease in the past should not be counted).				Change in energy spending is more difficult to collect as it will need to be collected after the point of sale. It could be easily collected during monitoring visits, or impact studies. For instance, Sistema bio collects data on energy related savings as part of monitoring visits.
	7.1	**Average decreased in spending on energy**				Prior energy spending is likely to be known through the marketing/diagnostic process. For instance, Sistema bio collects on baseline energy spending, disaggregated by type of energy source.
		This can refer to the difference in energy spending before and after purchase of the bio-digester, over a specified reporting period. This could be disaggregated by energy source (e.g. Wood, charcoal, organic waste, LP Gas, Gasoline/diesel, Kerosene). This should be reported over a specific time period (e.g. month)				Change in energy spending is more difficult to collect as it will need to be collected after the

						point of sale. It could be easily collected during monitoring visits, or impact studies. For instance, Sistema bio collects data on savings as part of monitoring visits. Quantitative data provides more information about the extent of the impact, but can be more challenging to collect as there is a risk of recall bias, and might require more calculations (e.g. currency conversions).
Biogas replaces biomass and other GHG emitting sources of energy	**8**	**Number of households reporting reduced consumption of biomass and other GHG emitting sources of energy for the first time.** *This corresponds to the number of households who report having reduced or stopped their consumptions of other sources of energy after purchasing a bio-digester. This can be disaggregated by energy source (e.g. Wood, charcoal, organic waste, LP Gas, Gasoline/diesel, Kerosene).*		X	X	While baseline energy consumption may be recorded as part of the marketing/diagnostic process, changes in consumption is also more difficult to collect as it will need to be collected after the point of sale. For example, Sistema bio collects data on how much wood and LP gas prospective customers are consuming per months, but does not collect data on energy consumption past the point of sale. It could be easily collected during monitoring visits, or impact studies.
	8.1	**Average reduction in GHG emitting sources of energy** *This refers to the average amount of GHG emitting sources of energy displaced by biogas, in kg, over a set time period (e.g. month) per customer. This can be disaggregated by energy source (e.g. Wood, charcoal, organic waste, LP Gas, Gasoline/diesel, Kerosene).*				Baseline energy sources are likely to be known through the marketing/diagnostic process, but may not necessarily be recorded. Sistema bio records whether prospective clients consume wood, charcoal, organic waste, LP Gas, Gasoline/Diesel or kerosene as part of its diagnostic.
Users adopt clean cooking	**9**	**Number of customers using clean cookstoves for the first time** *This refers to the number of customers that purchase a clean cookstove other the reporting period, and did not have access to a clean cookstove before (first-time users).*		X		Data on products sold should be readily available.
Increased nutrients	**10**	**N/A**	X			This outcome cannot be easily measured.

6.3 Drawing on beneficiary perspectives to understand impact

In addition to quantitative indicators, to *understand* impact our strong recommendation is to build systems and tools which enable biogas customers and beneficiaries to explain from their perspective, in their own words, why biogas is important to them and what benefits it has brought. This recognises that in different contexts, perceptions of what the most important advantage of biogas is will vary significantly. It also reflects that relying solely on universal indicators to track and measure impact does raise the risk of 'missing' outcomes which are not captured in that framework. Finally, capturing customer stories and beneficiary perspectives can create material that can easily be repurposed for communication and marketing, helping to demonstrate the impact of biogas to a wider range of stakeholders and attract more funding.

Whilst drawing on customer perspectives appears straightforward, in reality collecting information and giving customers the space to respond without introducing bias is complex. We outline two tools which use a participatory, open-ended approach that gives customers the flexibility to express their opinions:

- **Outcome harvesting** is a participatory methodology which gives customers and beneficiaries the space to define outcomes themselves, rather than pre-defining them. In the case of this paper, for example, we have started by looking at predetermined objectives and outcomes – the SDGs – and assessed progress towards them. Using outcome harvesting as an approach, we would have instead started by conducting open-ended field work with biogas customers and defined outcomes based on their perspective. This may have generated a different analytical lens – focusing, for example, more on the time savings of a bio-digester, or on the increased social status from bio-digester ownership – than on the impact objectives of the SDGs. Periodically conducting outcome harvesting assessments, particularly with new groups of customers, can help ensure that we have a comprehensive picture of impact which is not determined by pre-set objectives or frameworks.

- **Most significant change** involves collecting stories of change from customers and using their insight to understand from their perspective what the most important changes were. Stories are collected using an open-ended approach (e.g. "what is the most significant change for your household since purchase of a bio-digester?"), rather than aligned with a specific impact objective. The methodology also involves asking beneficiaries and stakeholders to justify *why* they their answer is the most significant change, from their perspective. This helps to ensure that as well as capturing impact and progress towards global frameworks like the SDGs, we are also understanding what changes customers prioritise and value, and why. Most significant change also readily adapts itself to producing compelling communication material which can demonstrate to a wide range of stakeholders why this technology is having such an impact.

Whilst the primary tool for measuring impact should be quantitative indicators, and we would only advocate using these tools in combination with a quantitative framework, there are significant advantages to incorporating these participatory and qualitative methods. Understanding impact from the perspective of customers and beneficiaries generates a more holistic and comprehensive view of impact, and also provides powerful material for communication and for demonstrating to a wider range of stakeholders why biogas is such an impactful technology.

6.4 Conclusion

The Theory of Change provides a clear framework for identifying indicators which are simple, cost-effective, and have a robust relationship with the impact objective. The indicators we have selected and mapped onto the Theory of Change provide a clear gauge of impact, and can be easily communicated to a wide range of non-technical stakeholders to demonstrate the impact of biogas. Throughout our approach, we have focused on the cost and feasibility of data collection, and also assessed indicators by how straightforward data collection is.

In addition to the quantitative indicators, we have also proposed two methodological approaches for collecting qualitative information. This helps to ensure that impact measurement provides a holistic view of the impact of biogas, and ensures that we understand impact from the customer and beneficiary perspective.

7 Conclusions

This report aimed to map out the key impact pathways between biogas and SDGs 2 (Zero Hunger), 7 (Clean and Affordable Energy), and 13 (Climate Action), and provide a rigorous strength of evidence assessment of these linkages drawing upon both secondary research and data provided by Sistema.bio. This process demonstrated that there is a robust empirical foundation for the impact generated by biogas in relation to SDGs 2, 7 and 13 – and importantly, to a large extent the key impact pathways hold true in a range of different contexts, geographies, and market segments. This makes biogas an almost uniquely impactful technology with the potential to be deployed in variety of different contexts.

However, leveraging that impact is critical to support biogas reaching scale. Whilst there is a clear sustainable business model for biogas, it is capital intensive, and reaching the poorest consumers is challenging without some form of subsidy. In the only markets where biogas has reached significant scale (primarily China and other countries in South-East Asia), government subsidies have played a pivotal role, highlighting the difficulties of expanding without attracting additional support and investment from impact-orientated stakeholders.

Biogas is well-suited towards impact monetisation mechanisms. It generates impact across multiple SDGs, and as demonstrated by the Strength of Evidence assessment the empirical foundation for impact is robust. No single impact monetisation mechanism is perfect, and in reality biogas companies seeking to scale should take a multi-faceted approach towards attracting funding. Grant funding is suitable for initial product development, start-up costs, price subsidies, and expansion to new territories. However, it is not a sustainable mechanism, and there tends to be a ceiling on how far companies can scale using grant funding. Crowd-sourced lending is an effective way of raising working capital finance both for small and medium amounts, but due to the financial terms and the currency risk its use should be limited to pre-financing purchases, rather than financing the operational costs of expansion. Carbon offsets can be used flexibly to fund a range of costs including price subsidies, operational costs, and pre-financing. However, projects need to go through a certification process, which can be onerous and restrictive. Securitisation is an option to raise large amounts of working capital, but is only suitable for larger firms who have already developed significant customer portfolios. Development impact bonds are a promising mechanism, but currently the market is not yet developed enough.

Impact-based monetisation mechanisms also require a clear and robust framework for measuring, tracking, and demonstrating impact to third-party stakeholders. This is critical in persuading impact-orientated investors that biogas is a technology worth funding. Again, there is no single perfect framework, and the rigour of impact measurement will also depend on the type of financing – different stakeholders will have different expectations around the strength of accountability and the attribution of results to their funding. However, we can identify indicators which map onto the impact Theory of Change for biogas, and which are within the capabilities of biogas companies to collect, either on a one-off basis or as part of their normal business operations. This report also proposes qualitative tools – outcome harvesting and most significant change – for capturing insights. Using these tools helps to develop a holistic view of impact and understand the advantages from the customer perspective.

Annex 1. Endnotes

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