Ministry of Foreign Affairs

Bio-slurry's Contribution to Food Security

Integrating Biodigester Impacts into the Voluntary Gold Standard's SDG 2 Framework

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Integrating Biodigester Impacts into the Voluntary Gold Standard's SDG 2 Framework

A Systematic Review and Proposed Methodology for Assessing and Quantifying the Impact of Bio-slurry on SDG 2 (food security)

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List of acronyms

ABC: Africa Biodigester Component

AGR: Agriculture projects (under the Gold Standard)

BEC: Bio-slurry enriched compost

CEC: Cation Exchange Capacity

CSA: Community service activities (under the Gold Standard)

FAO: Food and Agriculture Organization

FYM: Farmyard manure

GS: Gold Standard

HIVOS: Humanist Institute for Co-operation with Developing Countries

NARC: Nepal Agricultural Research Council

NGO: Non-governmental organization

NPK: Nitrogen, Phosphorus, Potassium

OFVI: Organic Fertilizer Valorisation Implementer under ABC

OM: Organic matter

SDG: Sustainable Development Goal

VGS: Voluntary Gold Standard

WWF:

Executive summary

This study investigates the potential of bio-slurry, an important product of anaerobic digestion in biodigesters, to enhance food security, particularly in the context of achieving Sustainable Development Goal 2 (Zero Hunger). The research systematically reviews existing literature and project findings to understand the complex relationship between bio-slurry, agriculture, and food security.

The study found that bio-slurry, in both liquid and composted forms, is a valuable organic fertilizer that improves soil health, increase crop yields, and reduces reliance on chemical fertilizers. The study also proposes the inclusion of an existing food security SDG 2 indicator, currently used for agriculture projects under the Voluntary Gold Standard (VGS), to be applied to community service activities (CSA) biodigester projects. This indicator, focused on crop yield improvement, would enable biodigester projects to credibly claim contributions to SDG 2, potentially attracting higher-valued carbon credits and further incentivizing efforts to combat food insecurity.

This study has significant implications for promoting sustainable agriculture and enhancing food security, particularly in regions with high levels of food insecurity and harsh conditions to conduct agriculture. The findings provide a compelling case for the wider adoption and integration of bio-slurry and BEC in agricultural practices. By demonstrating the potential of these organic fertilizers to improve soil health, increase crop yields, and contribute to SDG 2, this research paves the way for a more resilient and sustainable agricultural system that can effectively address the challenges of food insecurity and promote a food-secure future for all.

1 Introduction

Ensuring food security for a growing global population is a pressing challenge, especially in the face of climate change and resource scarcity. The United Nations defines food security as the state where all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. However, millions of people, particularly in Sub-Saharan Africa, lack consistent access to adequate food, threatening their health and livelihoods. This report explores the potential of bio-slurry, a byproduct of anaerobic digestion in biodigesters, to enhance food security and contribute to achieving Sustainable Development Goal 2 (Zero Hunger).

Biodigesters offer a sustainable solution for managing organic waste such as animal manure, utilizing a process called anaerobic digestion to break down organic matter and produce biogas, a clean energy source for cooking and heating. Another valuable product of this process is bio-slurry, a nutrient-rich effluent that can be used as a liquid fertilizer or composted to create bio-slurry enriched compost (BEC). This study systematically reviews existing research and project findings to understand the complex relationship between bio-slurry, agriculture, and food security, focusing on the actual use and potential of bio-slurry to enhance crop yields and soil health.

The Voluntary Gold Standard (VGS), a globally recognized certification standard for carbon offset projects, mandates that projects demonstrate positive impacts on at least three Sustainable Development Goals (SDGs).

The VGS has developed the SDG Impact Tool to assess and report these impacts. This study aims to establish a robust methodology to quantify the impact of bio-slurry and/or BEC on SDG 2, enabling biodigester projects to credibly claim contributions to food security and potentially attract higher-valued carbon credits.

2 Methodology

To establish a robust evidence base for understanding the link between bio-slurry and food security, this study employs a systematic literature review methodology. This approach is well-suited for synthesizing existing knowledge, identifying research gaps, and providing a comprehensive overview of the topic. The review process includes a thorough assessment of current bio-slurry practices, an evaluation of its potential for enhancing food security, and an analysis of best practices for its production and application.

The literature search strategy involves utilizing a combination of targeted and broad search approaches. Initially, the study leverages reports and relevant materials from the Organic Fertilizer Valorization Implementer (OFVI) project, which is part of the Africa Biodigester Component program. The OFVI project focuses on demonstrating the value and business potential of bio-slurry and BEC. It provides valuable insights into practical applications and challenges and it estimates the response of various crops to bio-slurry and BEC fertilization and its economic potential for the biodigester's business case. To complement these targeted resources and ensure a broader perspective, the study incorporates a comprehensive literature search using diverse search engines. This expanded search encompasses peer-reviewed scientific articles, reports from reputable organizations like the FAO and Wageningen University, and other relevant publications.

The selection of studies for inclusion in the review is guided by specific criteria to ensure that only relevant and high-quality research is considered. Studies are included if they focus on the use of bio-slurry as a fertilizer, its impact on crop production and soil health, and its potential for enhancing food security. Data extraction from the selected studies involves recording key variables and outcomes, including the type of bio-slurry used (e.g.: liquid, dried, BEC), the crops and soil types studied, the application methods employed, and the observed impacts on crop yields, soil health indicators, and food security outcomes.

The study's theoretical framework posits that properly managed, stored, and applied bio-slurry can lead to higher-quality and -quantity organic fertilizer:

Figure 1: Result chain: Bio-slurry's Pathway to Food Security

This, in turn, can result in improved soil health, increased crop yields, , improved income and enhanced food security. The framework recognizes the complex interactions between bio-slurry, agricultural practices, and food security outcomes, acknowledging the influence of factors such as soil type, climate, and crop type.

3 Bio-slurry and food security

3.1 Food security

Food security is a complex and multifaceted concept, encompassing not only the availability of food but also access to it, its utilization, and the stability of food systems. The United Nations' Committee on World Food Security defines food security as the state where all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. This definition encompasses four key dimensions:

- **Availability:** Sufficient quantities of food, either through domestic production or imports, must be consistently available.
- **Access:** Access to food implies that individuals have the economic resources to purchase food or the physical means to produce it, ensuring that they can acquire adequate food for themselves and their families.
- **Utilization:** Utilization focuses on the nutritional aspect of food security, ensuring that the food consumed is safe, nutritious, and prepared and consumed in a way that promotes health and well-being.
- **Stability:** Stability refers to the resilience of food systems to shocks and disruptions, such as droughts, economic crises, or conflicts, ensuring that access to food remains reliable and consistent even during challenging times.

Food insecurity can range in severity from moderate, where individuals experience uncertainty about their ability to obtain food, to severe, where food consumption is reduced to the point of causing significant health consequences. The prevalence of food insecurity varies across regions, with sub-Saharan Africa facing the most severe challenges (figure 2).

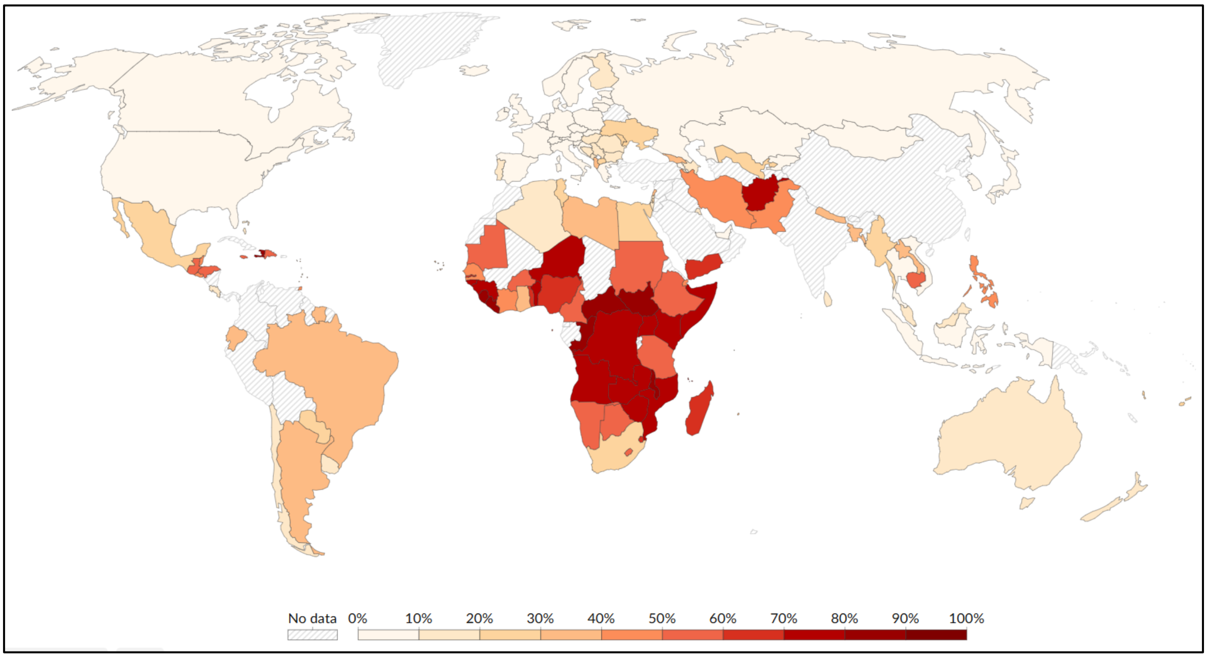

Figure 2: Share of population with moderate severe food-insecurity[1]

[1] https://ourworldindata.org/sdgs/zero-hunger *Food insecurity is defined by the Food Insecurity experience scale (FIES). Moderate food insecurity is associated with the inability to regularly eat healthy nutritious diets. Severe food insecurity is more related to insufficient quantity of food energy*

The number of severely food-insecure people in Africa has been increasing in absolute numbers, highlighting the urgent need for sustainable solutions to enhance food security on the continent (figure 3).

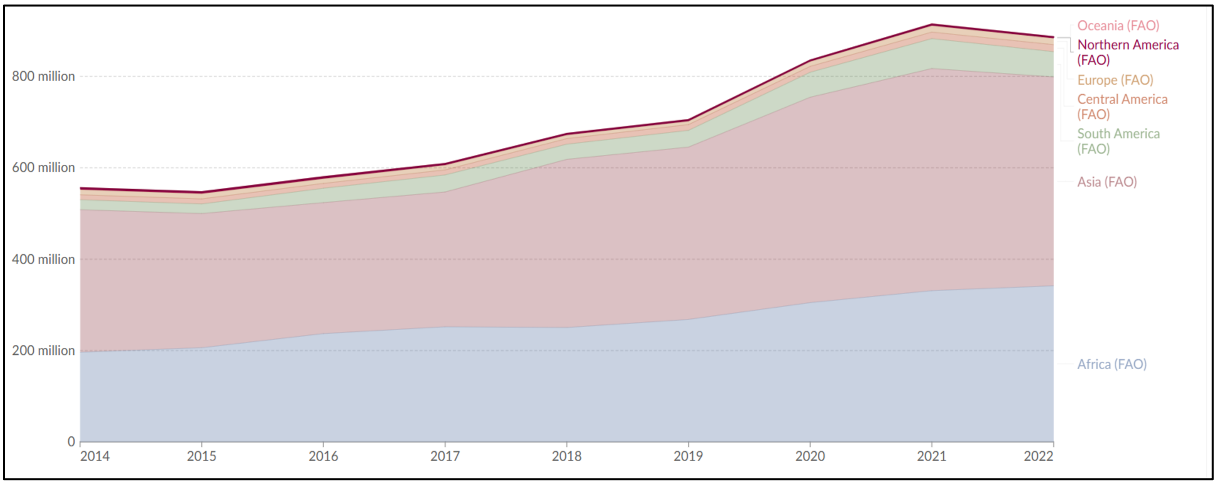

Figure 3: Number of food insecure people by continent [1]

3.2 Introduction on bio-slurry

Bio-slurry is a product of the anaerobic digestion process that occurs when organic waste is broken down in a biodigester. On a domestic scale, biodigesters are typically small, ranging in size from 4 to 10 m^3 digester volume. The feeding ranges between 20 and 100 kg of animal waste per day. These systems are generally “fed” a mixture, composed of pig and/or cattle manure, urine, and water that becomes a thick liquid. This organic mix undergoes anaerobic digestion within the biodigester, producing biogas and bio-slurry, which is rich in nutrients and can be used as an effective organic fertilizer for crops. During the anaerobic digestion process, about half of the volatile solids in the feeding materials are converted into gas which reduces mainly the carbon and hydrogen content. Elements like nitrogen, phosphorus, and potassium as well as numerous micro-nutrients remain in the slurry. In figure 4 the functioning of a biodigester system, and bio-slurry production is illustrated:

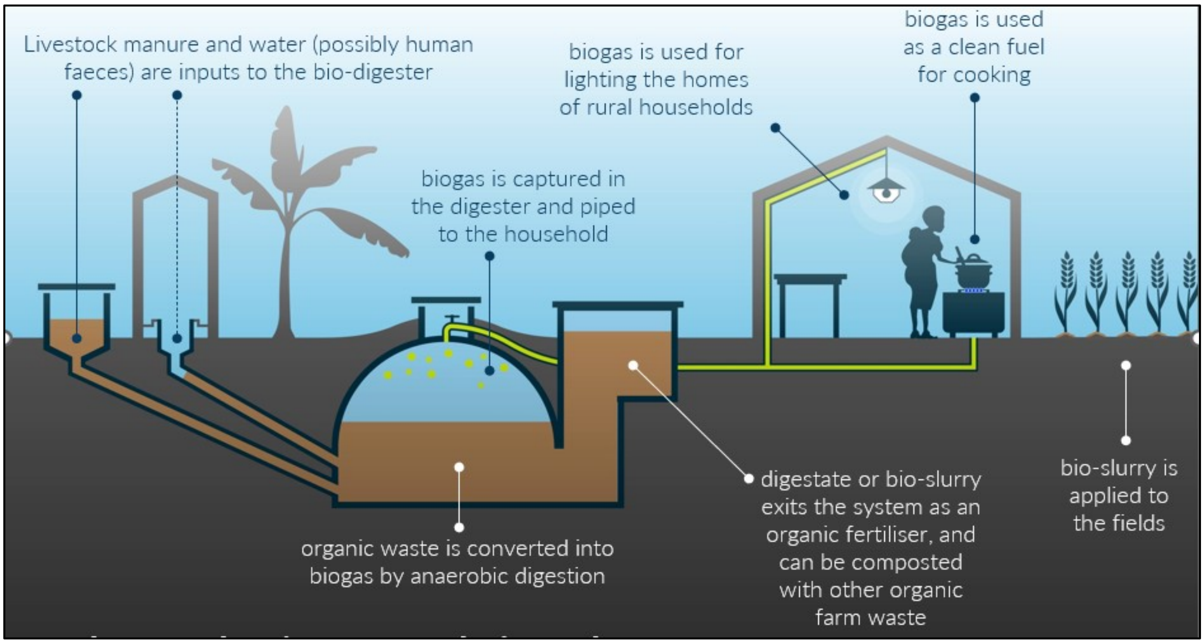

Figure 4: diagram showing the functioning of a biodigester and its outcomes: biogas and bio-slurry (Krauese A., 2020)

At a larger scale, biodigesters can utilize a wider range of feedstocks, including crop residues, vegetable and fruit waste, and even slaughterhouse waste, thanks to advancements in pre-processing technologies. The resulting bio-slurry, a nutrient-rich liquid material, is readily absorbed by plants and positively impacts soil structure due to its high organic matter content. In this respect, bio-slurry is comparable to other organic fertilizers like manure or compost, offering a sustainable alternative for enhancing soil fertility and crop production.

3.3 Bio-slurry and BEC nutrient composition

The nutrient composition of bio-slurry varies significantly depending on factors such as the type of feedstock used, the biodigester design, and the anaerobic digestion process. However, bio-slurry is generally rich in essential macro-nutrients, including Nitrogen (N), Phosphorus (P), and Potassium (K), as well as other beneficial elements like Calcium (Ca), Magnesium (Mg), Iron (Fe), Manganese (Mn), organic matter (OM), amino acids, and trace metals like copper and zinc. In general, there seems to be a good match between soil nitrogen supply and plant nitrogen demand of liquid bio-slurry[2].

The table below presents an analysis of the nutrient content of different types of bio-slurry, comparing them to traditional fertilizers like compost and farmyard manure. The data highlights the variability in nutrient composition depending on the type of slurry and its processing.

Table 1: Nutrient Content of Bio-slurry and Other Organic Fertilizers[3]

Kinds of slurry/manure	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Author
Bio-slurry	1.5 to 2.0	1	1	Khandewal et al., 1986

[2] *Möller and Stinner, 2009, p. 11*
[3] *Bio-Slurry a Super Fertilizer, Oppenoorth and Warnars 2014.*

Bio-slurry	1.03 to 1.8	0.8-1.2	0.8 to 1.0	Gupta 1991
Sun-dried slurry	1.4 to 1.8	1.1 to 2.0	0.8 to 1.2	
Bio-slurry	3.6	1.8	3.6	Wim J. van Nes undated
Bio-slurry enriched compost (BEC)	0.57 to 2.23	0.072 to 2.11	0.0 to 5.1	Average value of 100 slurry compost samples analysed by Soil section NARC Khumaltar. 1996
Ordinary compost	0.5 to 1.0	0.1 to 0.3	0.5 to 0.7	Maskey. Dept. Of Agriculture
Farmyard manure (FYM)	0.3 to 0.5	0.1 to 0.2	0.5 to 0.7	
Bio-slurry	0.03 to 0.08	0.02 to 0.06	0.5 to 0.10	APRBRTC, 1983: 155
Bio-slurry	0.8 to 1.5	0.4 to 0.6	0.6 to 0.12	
Composted slurry	1.31	1.18	0.88	Wet basis ATC 1997
	3.75	3.37	2.52	Dry basis
Sun-dried slurry	1.73	0.69	0.68	Dry basis
	2.92	1.17	1.15	
bio-slurry	0.06	0.04	0.06	Dry basis
	0.87	0.58	0.87	
Bio-slurry without toilet attached	0.05	0.04	0.07	Dry basis
	0.87	0.65	1.07	
Bio-slurry with toilet attached	0.06	0.04	0.06	Dry basis
	0.85	0.51	0.83	
Bio-slurry enriched compost (BEC)	2	1	2	Jumba et al, 2024[4]

Generally, bio-slurry, the direct output from a biodigester, typically contains 1-2% nitrogen, 0.8-1.2% phosphorus, and around 1% potassium[5]. Drying the bio-slurry, such as through sun drying, can concentrate these nutrients, but could also lead to N volatilization (NH3) and nutrient loss when drying happens in uncontrolled environments. Therefore, in order to retain nutrients in bio-slurry it is important to store bio-slurry in shaded conditions and to keep it moist. Generally, for long-term storage it is recommended to compost bio-slurry with other organic materials. This process of co-composting stabilizes nutrients, and it generally referred to as bio-slurry enriched compost (BEC).

[4] OFVI project
[5] Jumba et al., 2024

Composting bio-slurry with organic materials has the advantage of increasing the nutrient levels of the final organic fertilizer, as the organic materials provide additional nutrients. The final nutrient composition of BEC shows high variability for N that can range between 0.57-2.23% while P 1% and K 2%. The high N variability is mainly due to the composition of the organic materials used for composting, to the quality of the bio-slurry and to the proper handling of the composting process and the afterwards storage.

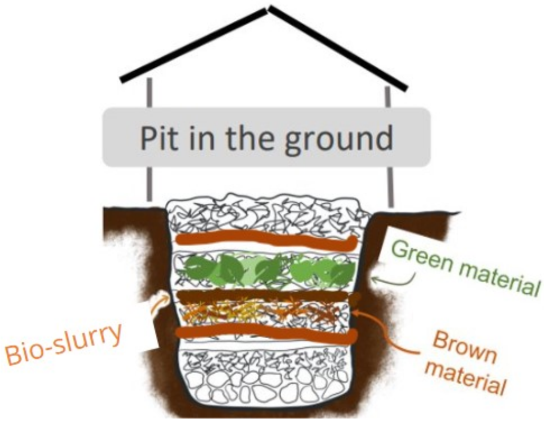

Figure 5: Co-composting Bio-slurry with Organic Materials (OFVI 2025)

Figure 5 shows an ideal situation, where a bio-slurry is composted with layers of other materials, where green materials are a source of nitrogen (grass, fruit, vegetable scraps etc.) and brown materials (dry leaves, branches) a source of carbon and fibers to improve the soil structure.

The OFVI project also highlights additional benefits of enriching compost with bio-slurry (BEC) such as the easiness to store, transport and applying compost rather than liquid fertilizer. Unlike liquid bio-slurry, BEC can be easily stored, packaged, transported, and applied to fields, making it more suitable for trading among farmers or selling in local markets[6].

3.4 Bio-slurry and soil health

A particularly significant finding is the cumulative positive impact of bio-slurry and BEC applications on soil quality and health in the long-term. Regularly adding organic matter (OM) and nutrients, whether annually or multiple times a year, leads to numerous advantages that contribute to a more productive and resilient agroecosystem. Specifically, increased OM content positively influences the following[7],[8]:

- **Readily Available Nutrients:** Organic matter provides immediate nutrients for plant growth, ensuring optimal development.
- **Soil Acidity Reduction:** Organic matter has been shown to reduce soil acidity, creating a more neutral pH. The optimal pH range of 5.5 to 7.5 facilitates the conversion of micro- and macronutrients into forms accessible for plant uptake.
- **Enhanced Cation Exchange Capacity (CEC):** Bio-slurry and BEC improve soil CEC over time, enabling better retention and gradual release of nutrients. This ensures a sustained, balanced supply of both macro- and micronutrients for plants.
- **Erosion Prevention:** Organic matter binds soil particles, protecting the topsoil—rich in nutrients like nitrogen—from erosion caused by wind and rain. Reduced soil erosion enhances nutrient availability over time, diminishing the need for additional fertilization.

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[7] *(OFVI, implementation report 4: Assess which crops benefit most from bio-slurry and BEC application, 2024).*

[8] *Groot & Bogdanski (2013) _Bioslurry = Brown Gold, A review of scientific literature on the co-product of biogas production*

- **Improved Soil Life:** High OM levels boost the activity of beneficial soil organisms, including insects, worms, bacteria, and fungi. These organisms improve nutrient mobility and contribute to healthier soil structures.
- **Enhanced Water-Holding Capacity:** Organic matter improves soil structure, allowing better water absorption and infiltration during heavy rains. This reduces erosion and ensures that crops have access to stored water over longer periods.
- **Anecdotal Benefits:** Evidence suggests that bio-slurry and BEC application can accelerate fruit production (e.g., bananas), increase germination rates, and enhance pest resistance.
- **Carbon sequestration.** OM can increase Soil Organic carbon content and therewith sequester carbon[9].

Furthermore, healthier plants are more resilient to pests, diseases, and climatic shocks. This resilience fosters more reliable production, lowers the need for pesticides, enhances income-generating opportunities for farmers, strengthens their food security and contributes to climate change adaptation and mitigation.

3.5 Bio-slurry versus chemical fertilizers and other fertilizers

The table below (figure 6) summarizes the short- and long-term effects of various fertilizers on nutrient availability (chemical), soil structure (physical), and soil life (biological).

Effect	Chemical fertilizer	Farmyard manure	Bio-slurry fresh	Bio-slurry dried	Compost	BEC
Immediate – chemical	Highly positive	Slightly positive	Positive	Slightly positive	Slightly positive	Positive
Long term - chemical	Negative	Slightly positive	Slightly positive	Slightly positive	Slightly positive	Slightly positive
Long term - physical	Moderate negative	Positive	Slightly positive	Slightly positive	Highly positive	Highly positive
Long term - biological	Negative	Positive	Positive	Positive	Highly positive	Highly positive

Figure 6: short- and long-term impact of different types of fertilizers[10]

The choice of fertilizer can significantly impact both immediate nutrient availability and long-term soil health.

Chemical fertilizers, while offering a quick nutrient boost, often come with environmental and economic drawbacks[11]. Their production is energy-intensive, contributing to greenhouse gas emissions and fossil fuel dependency[12]. Overuse can lead to nutrient pollution in water bodies,

[9] Tang et al (2021)- Changes in soil organic carbon status and microbial community structure following biogas slurry application in a wheat-rice rotation

[10] Langeveld, J.W.A., P.M.F. Quist-Wessel, E. Möller, G. Ghaffari and L. Laroche (2023) Literature review of best practices regarding bioslurry and bio-slurry enriched compost (BEC) application. Wageningen: Biomass Research, 15pp. + Annexes

[11] Postma, R., Zhang, X., Ndegwa, S. W., Mwangi, J. K., & Karanja, A. (2016). Towards general guidelines for the management of bioslurry in Kenya. NMI, Nutrient Management Institute

[12] Groot & Bogdanski (2013) _Bioslurry = Brown Gold, A review of scientific literature on the co-product of biogas production

soil acidification, and adverse effects on soil life. The rising cost and fluctuating prices of chemical fertilizers also pose challenges for farmers, particularly smallholders[13]. In addition, chemical fertilizer application has an acidifying effect on soil pH, which is detrimental for crop production that performs better in pH ranges between 5.5 and 7.5. Chemical fertilizers do not contain organic matter (OM), essential for soil life and structure, affecting root growth, plant development, water retention capacity, etc. An additional drawback of chemical fertilizer is that when the importation and distribution are centralized, it is not always available for all farmers when needed at the start of the ploughing season.

In contrast, **organic fertilizers** like bio-slurry, BEC, manure, and compost offer a more sustainable and cost-effective alternative. While their effects on nutrient availability may be slower in the short term, they excel in improving soil structure and enhancing soil life, contributing to long-term soil health and productivity. Compost and manure have a positive effect on soil structure and microbiology, as they retain up to 50% of the organic matter as persistent humus, which slowly releases nutrients into the soil and positively influences microbial activity.

Bio-slurry and BEC, in particular, have shown promising results as effective replacements for chemical fertilizers. The slow-release nature of nutrients in bio-slurry can improve nutrient uptake efficiency and reduce environmental losses. Studies have demonstrated that bio-slurry can effectively replace chemical fertilizers in various crops, leading to comparable or even higher yields while improving soil health and promoting sustainable farming practices[14]. Furthermore, they both increase soil pH, counteracting acidification and stabilizing the soil pH to ideal levels for plant growth (agricultural crops).

To optimize yields, Integrated Soil Fertility Management often recommends combining bio-slurry with reduced amounts of chemical fertilizers, especially in the initial years of transition to organic practices. This approach can help maintain productivity while gradually improving soil health and reducing reliance on chemical inputs over time.

3.6 From Potential to Impact: Linking Bio-slurry to Crop Production

This systematic review of prior research and project findings underscores the potential of bio-slurry and BEC to serve as sustainable and effective alternatives to conventional fertilizers, including chemical fertilizers and farmyard manure, for smallholder farmers. The evidence presented in this chapter highlights the considerable nutritional value of bio-slurry and BEC, suggesting their capacity to improve soil health and promote crop growth.

However, the central question remains: does this nutritional potential translate into increased crop yields and enhanced food security? This critical inquiry will be addressed in the subsequent chapter, which delves into the direct impacts of bio-slurry and BEC on crop production and their capacity to contribute to a more sustainable and food-secure agricultural model. Moreover, the chapter will explore the potential of bio-slurry and BEC to improve the nutritional value of crops, further contributing to food security and improved nutrition. By examining these multifaceted impacts, the study aims to provide a comprehensive understanding of how bio-slurry can contribute to achieving SDG 2 and promoting sustainable agriculture for a food-secure future.

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[13] Bonten, L., Zwart, K., Rietra, R., Postma, R., & de Haas, M. (2014). Bio-slurry as fertilizer. Alterra Wageningen UR
[14] Fotseu (2015) bio-slurry PPRE Oldenburg University presentation

4 Bio-slurry's Impact on Crop Production and Food Security

Both liquid bio-slurry and BEC are versatile and can be used on a wide variety of crops at different growth stages. These include serving as a seedbed substrate for germination, providing additional nutrients to seedlings during transplanting, and regular fertilization for perennial and annual crops. Since nutrient uptake during early growth stages is relatively low, fertilization is most effective during active growth phases[15].

4.1 State of the art review of bio-slurry usage and effectiveness in biogas programs

The table below presents an overview of bio-slurry usage across different regions based on data collected through ABC program. The findings reveal that bio-slurry is widely used as an organic fertilizer among farmers owning biodigesters (Table 2).

Table 2: Overview of bio-slurry usage in selected countries[1].

Country	Bio-slurry/Bio-compost Usage (%)	Storage Method	Application Method	Crop Quality/Quantity Improvement
Kenya	94-100	Primarily liquid; some composting	Direct application to various crops (maize, vegetables, bananas, coffee, tea)	97-100% improvement in crop quality
Uganda	84-100	Primarily liquid; some composting	Direct application to various crops (bananas, coffee, maize, vegetables)	92-97% improvement in both crop quality and quantity
Burkina Faso	Up to 93 (for BEC production)	Composting in double compost pits	BEC applied to various crops (maize, sorghum, millet, rice, vegetables, cotton)	79-94% of farmers consider BEC effective
Nepal	Data lacking	Storage in pits	Foliar spray or direct application	10-30% increase in cereal crop yields
Vietnam	Data lacking	Storage in tanks or pits	Direct application or fertigation	25-70% increase in maize yields,

[15] OFVI: Implementation report 3: Guidelines for bio-slurry and BEC production and application, 2025

				depending on the variety
Honduras	Data lacking	Data lacking	Data lacking	Increased resistance to coffee rust disease
Ethiopia	Data lacking	Storage in tanks or pits	Direct application or fertigation	20-30% increase in banana yields
Tanzania	Data lacking	Storage in tanks or pits	Direct application or fertigation	25% increase in crop yields

While the exact percentage of farmers actively using bio-slurry and/or BEC as their preferred fertilizer is not available, the evidence suggests that bio-slurry adoption is high in Kenya and Uganda, and BEC is widely used in Burkina Faso, Nepal and Ethiopia. The positive impact on crop yields in other countries further supports the notion that bio-slurry is being actively used by farmers in these regions. The crop quality/quantity improvement also varies across countries. In Kenya, there is a 97-100% improvement in crop quality, while in Uganda, there is a 92-97% improvement in both crop quality and quantity. In Burkina Faso, 79-94% of farmers consider BEC effective. In Nepal, there is a 10-30% increase in cereal crop yields. In Vietnam, maize yields increase by 25-70% depending on the variety.

4.2 Scientific literature analysis

This section aims to systematically review the existing body of scientific literature to identify the available knowledge regarding the effects of bio-slurry and BEC application on crop yield, soil health, and crop nutritional value.

Table 3: Scientific Literature Analysis: Effects of Bio-slurry and BEC Fertilization on Crop Production, Soil Health, and Nutritional Value

Scientific paper	Bio-slurry types	Crop	Yield increase	Application rate	Other improvements mentioned
Effects of different forms of bio-slurry on performance of crops in western Uganda, Laban F.T. et al., 2017	BEC	Maize	70%	10t/ha	+ 65% revenue on the crop considering money-saving not buying NPK
	BEC	Cabbage	59%	10t/ha	Improved N content in the soil
	BEC	Coffee	65%	10t/ha	BEC is found a safest product than liquid bio-slurry
Evaluation of bio-fertilizer application to ameliorate the environment and crop production, Nasir, A., Khalid, M. U., Anwar, S., Arslan, C., Akhtar, M. J., & Sultan, M. (2012).	Dried bio-slurry	Cabbage	20%	10t/ha	Positive effects on yield, soil Ph, CEC, OM%, nutrient mobilization, reduction of soil salinity, easy to use in dry form. Good plant development

Effect of different rates of poultry manure and bio-slurry on the yield of Solanum antiopium, Nanyanzi M., et al., 2018	Bio-slurry	Potato variety Solanum antiopium	81%	10t/ha	Improved growth due to higher leaves production. NPK however, resulted with a growth of 189%
Performance of poultry bio-slurry as a source of organic manure on potato production, Rahman et al., 2011	Poultry bio-slurry	Potato	38%	3t/ha	N/A
Use of digestate as alternative to mineral fertilizer: effects on growth and crop quality, Panuccio, M. R., Papalia, T., Attinà, E., Giuffrè, A., & Muscolo, A. (2019).	Bio-slurry	Cucumber	NA	25% of the total amount of soil (in pots)	50% increase of phenols, ascorbate and antioxidant capacity16
Bio-slurry as fertilizer: Bonten et al (2014)	Cattle bio-slurry	Maize	No significant difference compared to other fertilizers	N/A	Increased soil pH and reduced or eliminated liming requirements
	Pig bio-slurry	Maize	No significant difference compared to other fertilizers	N/A	

Table 4: Analysis of key studies

Report	Key Findings on Fertilizer Value of Bio-slurry	Impact on Crop Yields Compared to Other Fertilizers	Key Recommendations on Best Practices
Bio-slurry as fertilizer Alterra Wageningen UR L.T.C. Bonten, K.B. Zwart, R.P.J.J. Rietra, R. Postma, & M.J.G. de Haas (2014)	Nutrients in bio-slurry, especially nitrogen, are more readily available than in manure, leading to a larger short-term fertilization effect.	In some studies, bio-slurry performed equally well compared to other fertilizers.	National biogas programmes should continue to promote the use of bio-slurry as fertilizer and soil improver.
	However, risks for N losses through volatilization and leaching are larger for bio-slurry than for manure during storage, handling, and application.	In a number of studies, the N uptake after application of bio-slurries was lower than that after application with the same amount of N via mineral fertilizer.	The programmes in each country are advised to critically review and where possible improve the various ways of its storage, handing and application to minimise nutrient losses.

[16] *This result suggested that the addition of digestate, rich in carbon and phenols, stimulated plant-resource reallocation from primary metabolism to secondary metabolite production, driving the synthesis of important health-promoting phytochemicals*

Bioslurry = Brown Gold? A review of scientific literature on the co-product of biogas production FAO Lennart de Groot and Anne Bogdanski (2013)	Bioslurry has proven to have positive effects on yields of grains, vegetables, and fruit compared to not using any soil amendments and fertilizers at all.	The comparison with other organic fertilizers such as undigested farmyard manure or compost, and with synthetic fertilizers like urea, remains very ambiguous.	Further efforts are needed to determine the ideal quantity and interval between bioslurry applications.
		In some cases, bioslurry outperforms synthetic or other organic fertilizers, in others it is the other way round.	Standardized field trials are needed to determine how bioslurry should be applied, what the correct dose is, and what the rate of application is.
Bioslurry: A Supreme Fertiliser HIVOS Lavinia Warnars and Harrie Oppenoorth (2014)	Bioslurry is a more readily available form of compost than traditional compost.	Not directly compared, but bioslurry can increase cereal crop productions by 10 to 30% compared to farmyard manure	The composted form of bioslurry is the best way to overcome the transportation issue related to liquid bioslurry and the nutrient loss of the dried form.
	Bioslurry contains readily available plant nutrients, and it contains higher amounts of nutrients and micronutrients than FYM and composted manure do.		
Valorization of Biogas Slurry for Smallholders Fair Climate Fund Marton Levente (2024)	Bio-slurry is a cost-effective, readily available, and environmentally friendly alternative to chemical fertilizers, if used adequately.	Not studied	BGS must be fully digested before use.

The table below, reproduced from the HIVOS report (Warnars and Oppenoorth, 2014), shows the percentage increase in crop yields for various crops when using bioslurry as fertilizer in Nepal in 1998, compared to a control plot with no fertilizer. The data were collected in Nepal, and the control plots were not fertilized in order to isolate the benefit of bio-slurry (table 5).

Table 5: Crop increase in yields compared to control plot, Gurung 1998.

Crop	% Increase in yield over control plot
Rice	46%
Tomato	108% and 33%
Chillies	No impact
Rice	40%, 23% and 14%
Eggplant	33% and 77%
Maize	92%
Cabbage	20%
Potato	34%

The data show a significant increase in yields for most crops, with variations depending on the specific crop and the form of bio-slurry used. For example, tomato yields increased by 108% and 33% in different trials, while maize yields increased by 92%. Chillies showed no improvement with bio-slurry.

Overall

The findings from these studies consistently show the positive effects of bio-slurry and BEC on various aspects of agricultural sustainability, including enhanced crop production and improved soil health.

The storage and application methods for bio-slurry vary across countries, and the crop quality/quantity improvement also varies. In the addendum of this report, best practices of bio-slurry/BEC storage and application are elaborated upon.

4.3 Conclusion on bio-slurry usage and its potential in improving food security

Globally, there is a growing dependence on inorganic fertilizers in agriculture, leading to a heavy reliance on imports and external market trends. This over-reliance can have negative consequences, as seen in the recent surge in fertilizer prices and the subsequent decline in fertilizer consumption, impacting crop production.

However, recent years have seen a shift towards sustainable soil health management practices, driven by the pressures of climate change and the need for adaptation. Initiatives like the Africa Fertilizer and Soil Health Summit in 2024 highlight this shift, emphasizing the importance of multi-stakeholder partnerships, investments, policy reforms, research and development, and capacity building in promoting sustainable soil health[17].

Biodigesters are a valuable investment, managing organic waste, boosting crop production, and reducing fertilizer costs. While scaling up bio-slurry and BEC use faces challenges like initial investment costs and livestock ownership requirements, carbon finance and SDG impact reporting offer solutions.

Currently, mechanisms exist to monitor SDGs like SDG 13 (climate action), poverty reduction (SDG 1) and access to clean energy (SDG 7). This study proposes in the next chapter a new indicator for SDG 2: food security, aiming to increase the value of carbon credits and attract investment from parties specifically interested in improving food security. This is crucial, especially in regions like sub-Saharan Africa, where food insecurity is rampant. By demonstrating contributions to SDG 2 through increased yields and improved soil health, it is hoped that biodigester carbon projects can attract higher-valued credits, further incentivizing the very much needed solutions to combat food insecurity and contributing to a more resilient and sustainable agricultural system.

[17] https://au.int/en/documents/20240509/nairobi-declaration-2024-africa-fertilizer-and-soil-health-summit

5 Introduction of Voluntary Gold Standard

The Voluntary Gold Standard (GS) is a globally recognized standard for certifying carbon offset projects. It was established in 2003 by WWF and other international NGOs to ensure projects credibly reduce carbon emissions and contribute to sustainable development. The GS mandates that projects demonstrate positive effects on at least three Sustainable Development Goals (SDGs). This requirement ensures that projects not only address climate change but also contribute to broader societal benefits.

To facilitate the assessment and reporting of impacts on SDGs, the GS has devised the SDG Impact Tool. This standardized framework enables project developers to gauge and document their project's contributions to various SDGs. The tool offers a set of indicators and methodologies to measure and quantify these impacts, ensuring transparency and credibility. It was developed in collaboration with stakeholders to provide a robust and user-friendly framework for assessing SDG impacts.

5.1 Effectiveness of the Impact Tool

The VGS and its SDG Impact Tool have garnered significant attention in the realm of sustainable development. Studies highlight the role of the GS in driving investment towards projects that generate both climate and sustainable development benefits (Michetti and Espinoza 2021) The SDG Impact Tool has been lauded for its contribution to standardizing impact measurement and promoting greater transparency in reporting (Lehtonen, 2018 and Hajer et al. 2020)

Key benefits and features contributing to its effectiveness include:

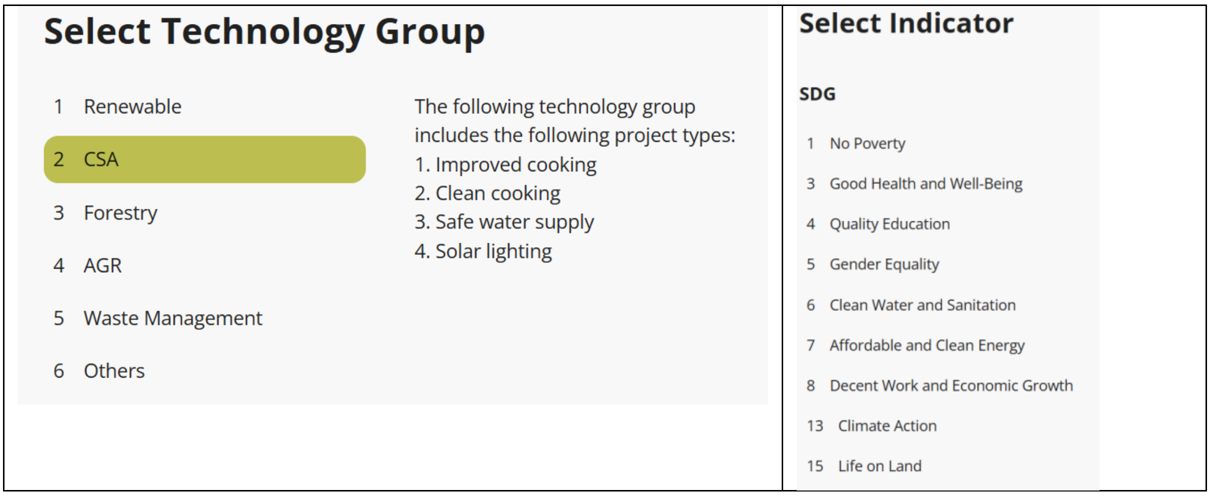
- **Rigorous Standards**: The GS is known for its stringent criteria, ensuring that certified projects deliver genuine and quantifiable contributions to sustainable development. This is reflected in the high level of scrutiny involved in the GS certification process.
- **Holistic Approach**: The SDG Impact Tool promotes a comprehensive evaluation of project impacts, encouraging project developers to consider their contributions across a range of SDGs. This aligns with the growing recognition of the interconnectedness of sustainable development challenges.
- **Transparency and Credibility**: The standardized framework and indicators provided by the SDG Impact Tool enhance transparency and bolster the credibility of impact claims. This is crucial for building trust among stakeholders and ensuring the integrity of carbon markets.
- **Market Value**: Projects certified under the GS, particularly those demonstrating strong contributions to SDGs, are considered premium carbon credits in the market. This incentivizes project developers to prioritize sustainable development co-benefits.

Indeed, the latest "State of the voluntary market (2024)", shows that buyers are prepared to spend more on VGS credits. A premium amounting 140% for end-users sales amount credit standards in 2023, up from 85% in 2022. Moreover, market participants expressed increasing buyer preference for credits from nature-based and community-focused project types, such as domestic biodigesters, that offer environmental and social co-benefits in addition to emissions reductions. This suggests that projects addressing multiple SDGs through co-benefits, like those facilitated by VGS and the SDG Impact Tool, are becoming increasingly attractive to buyers seeking holistic solutions.

5.2 SDG indicators under the VGS

Biogas projects are grouped under community service activities (CSA) under the Gold Standard. The GS website digital SDG impact tool lists the following indicators for CSA indicators for CSA projects (table 6):

Table 6: SDG indicators for CSA project types

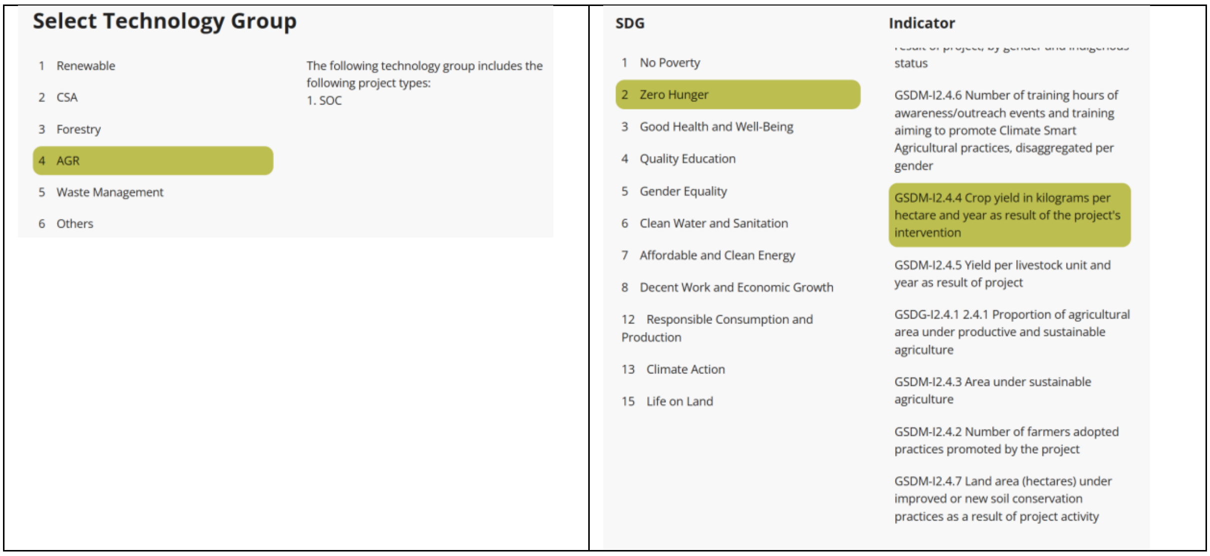


The impact tool contains no indicators related to SDG 2 for CSA projects. Previously, in the non-SDG digital tool, there were 2 indicators related to SDG 2, use of bio-slurry and area on which bio-slurry is applied. Neither, however, is it directly related to food security. A clarification request has been submitted to the Gold Standard on this[18].

The impact tool for Agriculture projects (AGR) under the Gold Standard, however, contain a great number of indicators, including a number that related to food security (SDG indicator 2.4), table 7:

[18] *Email sent to the GS on the 8th of March*

Table 7: SDG indicators for Agriculture projects (AGR)[19]



While these indicators are currently not applicable to CSA projects, it is likely possible to propose their inclusion, supported by a strong evidence base. This report can serve as evidence linking bio-slurry with increased crop yields and enhanced food security.

Proposing new indicators is also an option, but the Gold Standard aims to harmonize indicators to streamline reporting and avoid an excessive number of indicators. A large number of indicators would complicate reporting and make it challenging to track progress at the Gold Standard level.

An assessment of the AGR indicators that could be proposed to CSA biodigester projects is provided in table 8:

Table 8: SDG 2 targets under the Gold Standard[20]

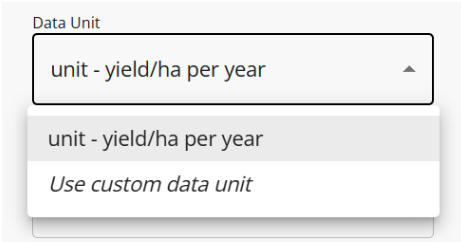
Targets	**Relevant indicators under AGR**	**Assessment for CSA biodigester applicability**
 **Sustainable food production and resilient agricultural practices**	GSDM-I2.4.6 Number of training hours of awareness/outreach events and training aiming to promote Climate Smart Agricultural practices, disaggregated per gender	Bio-slurry training and extension services on effective use of bio-slurry for climate smart agriculture is a common feature of biodigester projects. However, there is no direct link here with food security.
	GSDM-I2.4.4 Crop yield in kilograms per hectare and year as result of the project's intervention	As demonstrated in chapter 3, bioslurry/BSE usages can lead to improved yields, and this links directly to improving food security together with improving

[19] https://sdg-tool.goldstandard.org/
[20] https://www.globalgoals.org/goals/2-zero-hunger/

2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality.		climate resilience related to improved soil health
	GSDM-I2.4.5 Yield per livestock unit and year as result of project	Not applicable
	GSDG-I2.4.1 Proportion of agricultural area under productive and sustainable agriculture	This indicator in the non-digital version is already applicable to CSA projects. However, there is no direct link to food security. Indicators 2.4.1 and 2.4.3 appear related and overlapping
	GSDM-I2.4.3 Area under sustainable agriculture	
	GSDM-I2.4.2 Number of farmers adopted practices promoted by the project	

One indicator stands out, which is GSDM-2.4.4: Crop Yield in kilogram per hectare as a result of the project's interventions which directly improves food security by improving yields. The GS guidance for this indicator is shown below (table 9):

Table 9: GSDG-2.4.4: Crop yield in kilograms per hectare and year as result of the project's intervention

Monitoring Indicator	**Guideline**	**Monitoring indicators**
Crop yield in kilograms per hectare and year as result of the project's intervention	Project should not calculate this indicator using aggregate data across all farmers. Rather, organizations should use farmer-specific data. Project should report yield from the most recent harvest and include details on the unit of measure reporting against (e.g., kilograms, bushels, etc. per hectare). Where applicable, the project should report on the data for small farm holders, income status of farmers and other appropriate levels. It is often difficult to isolate the effect of several factors contributing to yield, e.g. variety of seeds, fertilizer, water and weather. In order to establish if the observed increase in yield was caused by the	 Projects have two options: • Using the data unit yield/ha per year • Custom unit (to be proposed by the project developer)

	improved practices, some type of experimental design for counterfactual comparison must be set. This indicator would refer to a specific project where the beneficiary farmers could be directly asked about their assessment of gain in yield	

This indicator could be applied to biodigester projects. It is proposed here, based on the analysis, to move forward with propose this indicator for CSA biodigester projects with some additional guidance, on how this could most effectively be monitored across all types of biodigester projects in the world. This will be studied in more detail in the stakeholder analysis during the road-testing activity in the next step of assignment. Based on that, a monitoring approach and guidance will be proposed and submitted to the GS based on the existing indicator mentioned in table 9.

6 Conclusion

The study presented in this report underscores the significant potential of bio-slurry and BEC as sustainable and effective alternatives to conventional fertilizers. The evidence presented demonstrates the capacity of bio-slurry and BEC to improve soil health, promote crop growth, and ultimately enhance food security. The positive impacts of bio-slurry and BEC on crop quality and quantity are evident, though the specific storage and application methods, as well as the degree of improvement, vary across different contexts.

The findings of this study have far-reaching implications, particularly in the context of the Voluntary Gold Standard (VGS) and its role in promoting sustainable development through carbon offset projects. By proposing the inclusion of an existing indicator for SDG 2 (food security) for CSA biodigester projects, this study opens up new avenues for incentivizing and valuing contributions to food security within the VGS framework. This is particularly crucial in regions grappling with food insecurity, as it could potentially attract higher-valued credits for biodigester carbon projects, thereby driving further investment and action towards combating food insecurity.

While further work is necessary to refine the proposed indicator and establish effective monitoring approaches across diverse biodigester projects, this study provides a compelling foundation for promoting bio-slurry and BEC as key solutions for enhancing food security and building a more resilient and sustainable agricultural system. The insights presented here pave the way for a more integrated approach to achieving SDG 2, where bio-slurry and BEC play a pivotal role in transforming agricultural practices and ensuring a food-secure future for all.

Annex: Best practices bio-slurry application

Direct application of bio-slurry

While compost is typically used before planting or seeding during soil preparation, liquid bio-slurry is often applied to actively growing crops. For larger plants like bananas or tree-like plants, a ring of soil is created around the base to contain the bio-slurry.

It is common practice to dilute bio-slurry with water at a 1:4 ratio before application. This helps to prevent excessive fertilization, which can lead to nutrient imbalances and reduced yields.

Often, bio-slurry applications are combined with irrigation. However, mixing bio-slurry with irrigation water can have mixed results. If the water flow is uneven, the bio-slurry may be unevenly distributed, in slow moving water there will be more solids deposits. In Kenya, a system has been developed where bio-slurry is mixed with water for drip irrigation, utilizing special nozzles that can be easily cleaned to prevent clogging.

Figure 7: Examples of direct application of liquid bio-slurry for coffee in Uganda (right) and beans in Cambodia.

It's important to note that liquid bio-slurry applications do not contribute to improved soil structure in the same way that BEC does.

Storage and Handling of Bio-slurry

The effectiveness of BEC as an organic fertilizer depends on the quality of the bio-slurry, proper processing and handling during composting, and adequate storage. These factors help to maintain nutrient content and prevent nutrient loss caused by overexposure to sunlight or rainfall.

Farmers with biodigesters are encouraged to construct a bio-slurry pit for passive collection of liquid bio-slurry from the biodigester. The bio-slurry pit should be connected to at least two compost pits for layering liquid bio-slurry with organic materials. Having multiple compost pits allows for rotation, making composting more efficient and less labour-intensive. After 2-3 months, the mature compost can be applied to the land, packaged, or stored.

The combined volume of the compost pits should ideally be equal to or larger than the biodigester volume. Since one pit is typically in use while the other is composting, each pit should have at least half the volume of the biodigester.

Figure 8: BEC hut in Mali, OFVI 2024 and a compost hut in Cambodia

Design and Maintenance of Compost Pits

To minimize nutrient loss and ensure optimal composting conditions, compost pits should adhere to the following guidelines:

- **Roofing:** Compost pits should be roofed to prevent exposure to sunlight and rainfall, which can cause nitrogen volatilization. Suitable roofing materials include leaves, iron sheets, or polythene. The roofing should have a slope of at least 30 cm to prevent rainwater from flowing inside.
- **Impermeable barrier at the bottom of the storage to prevent leaching**[21]
- **Wall Construction:** Bricked or concreted walls can prevent nutrient leaching and groundwater contamination.
- **Safety Measures:** Fences around the biodigester and compost pits can prevent accidental falls by people or animals.

Figure 9: OFVI Implementation report 3: Guidelines for bio-slurry and BEC production, 2024

[21] *Towards general guidelines for the management of bioslurry in Kenya NMI B.V. R. Postma and X. Zhang (2016)*

Composting Process

Once bio-slurry flows into the compost pit, it should be layered with dry organic materials like leaves, crop residues, and kitchen scraps. The layering should follow this order:

1. Dry plant materials (e.g., maize stalks, grass, leaves, wood sticks)
2. Bio-slurry to cover the dry materials.
3. Green plant materials (e.g., food scraps, fresh plant residues, grass clippings)

Aim for a 50/50 ratio of green to brown materials. Turn the compost pile every two weeks to ensure adequate aeration and promote uniform decomposition. Maintain a balanced carbon-to-nitrogen (C: N) ratio between 5 and 20. Avoid adding materials like meat, dairy products, problematic plants, fats, oils, and citrus fruits, as these can disrupt the composting process.

The composting process typically takes around three months, but this can vary depending on the local climate. The finished compost (BEC) is ready when it becomes dark brown with a crumbly texture and an earthy smell.

Application of BEC as Fertilizer

BEC is versatile and can be applied to various crops, including perennials like bananas, coffee, and fruit trees. BEC can also be used as a substrate for seed germination and to provide nutrients to seedlings during transplanting. Regular fertilization with BEC throughout the growing season can enhance crop growth. In some cases, BEC can be diluted with irrigation water for even distribution.

Figure 10: BEC end-product after composting

Application rates vary depending on the crop:

- **Trees:** 2-5 kg per tree twice a year
- **Home gardens and vegetables:** A handful of BEC in the planting hole
- **Larger-scale crops:** 5-10 tons per hectare

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