A Methodological Approach to the Assessment of the Greenhouse Gas Mitigation Potential of Container-Based Sanitation Systems

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A Methodological Approach to the Assessment of the Greenhouse Gas Mitigation Potential of Container-Based Sanitation Systems

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Cover Photo: Contaminated river leading to Lake Atitlán in Guatemala, Mosan 2019

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Abstract

Container-based sanitation (CBS) is a safely managed sanitation service designed for regions with limited sanitation and water infrastructure (WHO/UNICEF, 2018). CBS services replace unsafe sanitation practices in low- and middle-income regions and thus avoid greenhouse gas (GHG) emissions from uncontrolled degradation of excreta in the environment (Harroff et al., 2019). CBS provides waterless toilets with sealable containers that separate human excreta from human contact (= safely managed), regular collection and revalorization of excreta (CBSA, 2018). This service is less costly than conventional sewage systems, but there are recurring operational costs for which long-term revenue streams such as climate financing are needed (Coates & Gray, 2021; Russel et al., 2019; World Bank, 2019).

The objective of this study was to develop a methodology that allows CBS projects to systematically quantify and monitor their GHG savings vis-à-vis unsafe sanitation solutions. The two main goals were 1) to quantify the GHG emissions in sanitation as accurately as possible; and 2) to minimize monitoring efforts for CBS projects that apply the methodology.

A literature review on GHG emission pathways from sanitation systems was supplemented with key informant interviews with experts in sanitation and methodology development. A methodology was drafted, along with an Excel calculator. The methodology provides default values for the quantification of emissions from CBS projects as well as the sanitation systems they replace. An uncertainty analysis revealed that a significant uncertainty of emission savings is pertaining to the variability and categorization of the unsafe sanitation systems that are replaced by CBS.

The methodology was applied to the Mosan social enterprise at Lake Atitlán in rural Guatemala. It was found that about ¾ of the local population use on-site sanitation and ¼ are connected to a sewage system. However, 70% of the sewage system discharges directly to Lake Atitlán. Implementation of one Mosan CBS toilet can mitigate 370 kg CO_2-equivalents per year. Further development and authorization of the draft methodology is needed to consolidate these findings and unlock climate financing for CBS projects.

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Furthermore, I would like to thank Lauren Harroff (Sanergy, Kenya, and CBSA), Claire Remington (SOIL, Haiti), David Crossweller (Sanitation First, India), Jane Wambui (Sanivation, Kenya) and Barbara Evans (University of Leeds) for taking time for me and sharing their expertise.

Content

Glossary

Terms that are frequently used in this report (concepts of the carbon market or terms defined to describe a system or process in the context of the methodology)

Additionality	Concept of the carbon market: A project proponent needs to prove that the project activities are additional i.e., that they guarantee carbon emission savings that are additional to what could have been achieved in absence of the project and the financial revenue of resulting carbon credits (Verra, 2019b). The methodology determines how the project proponent proves this additionality.
Aggregate Baseline (Scenario)	Baseline scenario in which two or more sanitation pathways co-exist. The aggregate baseline is a combination of the sanitation pathways in the project region weighted by the percentage of usage.
Applicability	Concept of standards of the carbon market: It describes the conditions in which a project shall be eligible for registration on the carbon market. It also describes what criteria the project must adhere to, i.e., what activities it must contain.
Baseline Scenario	Existing sanitation pathway to reach the same outcome in the absence of the CBS project. The same outcome for the users is the disposal of excreta.
Baseline Assessment	The project proponent must define (assess) the respective baseline scenario when registering on the carbon market. The methodology determines how the project proponent is to achieve this.
Carbon Credits	Certificate per ton of CO_2-eq emission savings (reduction or avoidance) that could be traded for monetary revenue on a carbon market.
(Carbon) Project	Projects that adhere to the applicability conditions of a methodology and are eligible to register and issue carbon credits on the carbon market.
Carbon Standard	Carbon standards are quality labels which certify that carbon credits arising from carbon projects comply with given environmental and/or social criteria.
Project Activity	Service or process that is executed within the project. The project activities are defined as part of the applicability conditions. E.g. CBS project activities must include provision of toilets, collection and transport of containers and transformation of excreta.
Project Emissions	Greenhouse gas emissions associated with the project activities.
Project Proponent	The entity that registers their project on the carbon market, applying carbon methodologies.
Sanitation Pathways	Term to describe the possible sanitation options for the user and outcomes of the sanitation systems, three main pathways are open defecation, sewerage and on-site sanitation. E.g. sewerage is the option for the user, the outcome is discharge in the environment or at a wastewater treatment plant.
Transformation	Term to describe the CBS project activity that entails the treatment of excreta with generation of a useful and safe end-product. ‘Transformation’ is used to differentiate from wastewater or faecal sludge ‘treatment’ in the baseline scenario.
Carbon Market	Voluntary carbon markets allow emitters of CO_2 (individuals or companies) to offset their unavoidable emissions by purchasing carbon credits generated by carbon projects. These offsets are in contrast to government controlled mandatory carbon markets that regulate emission caps for companies and countries. Overstepping these caps mandates the entities to purchase carbon credits from another company or nation whose emissions are lower than the mandated cap.

1 Introduction

1.1 Background

Worldwide, 54% of people lack access to safe sanitation services (Ritchie & Roser, 2021). Sanitation is safely managed if use of a private sanitation facility separating excreta from human contact is possible and each step of excreta disposal in the service chain is managed appropriately (OECD, 2019). The sanitation service chain includes safe containment, emptying and transportation, treatment, and disposal or end-use (Tilley et al., 2014). Lack of or interruption of such a sanitation service chain leads to the pollution of living spaces. Pollution of water sources and the environment are the cause of illnesses and more than 750’000 deaths per year (Bain et al., 2014; Ritchie & Roser, 2021; WHO/UNICEF, 2021). Unsafe sanitation poses a problem predominantly in low- and middle-income countries (LMIC): Between 2 – 3 billion people use on-site sanitation, such as pit latrines where excreta accumulates as faecal sludge (Strande, 2014). Moreover, 6% of the global population, located in LMICs, still practice open defecation (Ritchie & Roser, 2021).

In response to these issues, sanitation is addressed by the WHO in the 17 Sustainable Development Goals (SDGs). SDG 6.2 is dedicated to providing safe sanitation to everyone and eliminating open defecation until the year 2030 (J. Bartram et al., 2018). Considering the global population growth that is projected prevalently for LMICs, an estimated 5.6 billion people will need to be fitted with safe sanitation solutions within ten years (WHO/UNICEF, 2021). Efforts to develop sanitation solutions that lower risks to human health and development are ongoing (Couder & Kibuthu, 2020; Greene et al., 2021; Jenkins et al., 2014)

The principal goal in safe excreta treatment is to kill off pathogens and reduce organic contents and nutrients (Tchobanoglous et al., 2014). Treatment processes relying on biological degradation produce the greenhouse gas (GHG) emissions carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in different fractions. N_2O is a product of incomplete nitrification and denitrification reactions, i.e. aerobic oxygenation of ammonium and anoxic reduction to nitrogen gas (Kampschreur et al., 2009). Estimated CH_4 emissions from anaerobic degradation in the sanitation sector could amount to 2 – 6% of global anthropogenic CH_4 emissions (Saunois et al., 2020). Pit latrines have been estimated to contribute 1 – 2% to CH_4 emissions globally (Reid et al., 2014). Anthropogenic CH_4 is linked to around a quarter of the 1.1°C temperature increase above pre-industrial levels (IPCC, 2021). GHG emissions could increase substantially following the construction of poorly managed sanitation facilities to meet the rising need globally. This approach to sanitation capacity building in LMICs (SGD 6) opposes the mitigation of climate change (SGD 13) (Water Aid, 2019). The Sixth Assessment Report (AR6) of the IPCC identified the potential in cutting methane emissions to battle climate change.

Container based sanitation (CBS) is a comprehensive service designed for regions where space is limited and infrastructure and investments needed for sewered sanitation and centralized treatment are lacking. CBS provides dry toilets without flush water, safe containment and regular collection of human waste. Excreta are treated and valorised as compost, biogenic fertilizer, biogas for energy or solid biofuels (CBSA, 2018). In 2019, CBS has been recognized by the WHO/UNICEF Joint Monitoring Programme as a safe sanitation solution that mitigates risks to human health (WHO/UNICEF, 2018). In addition to saving water, environmental pollution can be avoided by direct enclosure of excreta and subsequent stabilization and valorisation in the CBS service chain (Smith, 2020; World Bank, 2019). The current state-of-the-art is application in rural areas or densely populated and fast-growing cities in LMICs, where decentralised sanitation is more useful and feasible than sewage systems and centralised wastewater treatment (Coates & Gray, 2021).

CBS can replace other on-site sanitation facilities in LMICs and avoid the disposal of faecal sludge or wastewater in the environment. This also means that the respective GHG emissions from open degradation of excreta in the environment can be avoided. The resulting emission savings should be calculated and attributed to a CBS project (Montgomery et al., 2020). Reporting such GHG savings on the carbon market (see Figure 1) could generate a revenue from carbon crediting. In other sectors, climate financing via the voluntary carbon market that adheres to principles set in the Paris Agreement 2016 is an established method (UNFCCC, 2015). In the water sector, more than USD 4.5 billion in carbon credit revenues have already been generated by sustainable drinking water service projects (Peters-Stanley et al., 2013). The possibility of carbon crediting has not been unlocked for CBS projects, which have not yet established widespread coverage and are not financially self-sustaining (World Bank, 2019). Additional financing tools for sustainable sanitation solutions are needed, so that these sanitation services can become self-sustaining (Dickin et al., 2020). Climate financing could potentially accelerate upscaling of CBS to help provide safe sanitation in LMICs (Russel et al., 2019), and thereby create a positive feedback loop between SDG 6 and SDG 13.

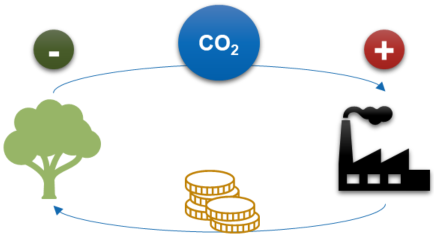

Figure 1: Depiction of trading on the (voluntary) carbon market. A carbon project (left) that causes one ton of CO_2-equivalent emission savings generates one carbon certificate that can be purchased by an emitter of CO_2 (right).

1.2 Scope and Objective

In CBS projects, emission savings are achieved by avoidance of emissions from the baseline scenario, from which the project emissions must be subtracted. To date, no methodology exists that allows CBS projects to systematically estimate their GHG emission savings. The quantification and reporting of the emission savings should be standardized to eventually be eligible for climate financing.

The research objective of this work was to assess and develop a methodology in order to systematically quantify, monitor and report the GHG impact and savings potential of CBS systems, and to apply it to the case of the Mosan social enterprise in Guatemala. To this end, five research questions were defined:

1. What are the GHG sources of relevant baseline sanitation systems for CBS?
2. What are the boundaries for the calculation of GHG emission reduction from the containment phase of CBS systems?
3. How can the GHG emission reduction pertaining to CBS systems be quantified reliably?
4. How can CBS providers in low- and middle-income countries monitor their GHG emission reduction accurately and cost-efficiently?
5. What conclusions can be formulated for the concrete case of the Mosan CBS system?

There are three main sections to this report. Methods: The methods section describes the elements of a carbon methodology and how the information needed to draft the methodology was gathered. Results: The results section clarifies what considerations were made in developing and formulating the methodology – with a focus on the baseline scenario – and how a project proponent would apply the respective steps. A case study on the Mosan social enterprise that operates a pilot project at Lake Atitlán in Guatemala was conducted. Discussion: The discussion section critically assesses the choices that were made in the development of the baseline quantification model and the robustness thereof, and evaluates the potential of GHG emission savings and climate financing for the CBS sector and the Mosan social enterprise in particular.

2 Methods

2.1 Methodology Development

2.1.1 Research Approach

The objective of this work was to develop a methodology for container-based sanitation (CBS) that allows for a quantification of the real emission savings within the context of a carbon methodology, in line with the principles of carbon crediting that are based on the Paris Agreement 2016 (Broekhoff et al., 2019; UNFCCC, 2015). The quantification of emissions (both baseline and project) should rely on a sound scientific assessment of emission generation pathways within the sanitation sector. To ensure adherence to international standards, the ISO 14064-2:2019 guidance for quantification, monitoring and reporting of greenhouse gas emission reductions were considered (DIN, 2019). Different chapters of IPCC Guidelines for National Greenhouse Gas Inventories were used as a basis for quantifications (IPCC, 2019).

The new methodology should be based on existing and approved methodologies. A standard that regulates official international carbon credit trading is the Clean Development Mechanism (CDM) that originates from the Kyoto Protocol (Dufrasne, 2020). To gain an overview of projects on the carbon market, a variety of carbon methodologies developed under the CDM were studied (UNFCCC, 2021a). The technical details of methodologies concerning waste handling and disposal (CDM sectoral scope 13), their format and wording were analysed. Within this analysis, the methodological gap regarding sanitation in low- and middle-income countries (LMIC) was identified. There are two options to fill such a gap: Amend an existing methodology to include the missing elements or create a new methodology. An evaluation revealed that creating a new methodology was the more feasible approach (see paragraph 3.1.2).

The new methodology was drafted based on a template of the Verified Carbon Standard (VCS), an established carbon standard of the voluntary carbon market which is in line with UNFCCC regulations and thus the Paris Agreement 2016. Sebastián del Valle Rosales from the carbon consulting company South Pole was a key informant during the methodology development. The following paragraphs describe how the main elements of the draft methodology were developed. These elements include applicability conditions and boundary setting, additionality, emission savings quantification as well as monitoring thereof.

2.1.2 Applicability and Boundary Setting

As a first step in developing the methodology, the applicability conditions were defined. They delineate responsibilities and requirements a CBS project must fulfil as well as the external conditions that should apply. The boundaries of the baseline and project were set. They define the required project activities and specify processes and greenhouse gas (GHG) emissions to be included. Projects that do not adhere to these applicability conditions would not be able to use the methodology for carbon financing.

Existing CBS projects were assessed and the conditions in which they are operating were clarified based on key informant interviews (KII) and a review of previous work done within the CBS sector. The key informants were Lauren Harroff (Sanergy, Kenya, and CBSA), Claire Remington (SOIL, Haiti), David Crossweller (Sanitation First, India) and Jane Wambui (Sanivation, Kenya).

2.1.3 Additionality

There are several methods to demonstrate additionality of a project when registering on the carbon market. Information on common methods for demonstrating additionality was gathered, specifically on their formulation and application (Cames et al., 2016; del Valle Rosales, 2021; UNFCCC, 2017a, 2021a; Verra, 2019a, 2019b). There are three methods with differing levels of complexity. For the draft methodology, the method to demonstrate additionality was chosen based on feasibility for the CBS project proponent, as presented in paragraph 3.1.4.

2.1.4 Baseline Assessment

In general, the baseline scenario of a carbon project is defined as the system employed to fulfil a specific purpose or reach a certain outcome in the absence of that project. In the case of a CBS project, that common outcome is the disposal of human excreta. Identifying the existing systems of reaching this outcome proved more complex.

Different sanitation systems existing in LMICs were assessed with a literature research. For well managed and innovative sanitation technologies, the "Compendium of Sanitation Systems and Technologies" (Tilley et al., 2014) was consulted as a major source. Further information was retrieved from scientific journal articles and studies. Excreta flow diagrams (SFDs) and the SFD manual provided information on terms and sanitation options used in LMICs (SFD Promotion Initiative, 2018a). Available SFD diagrams and reports for Latin America, Africa and South East Asia (Vietnam, Cambodia) were studied (retrieved from the SuSanA Library (SuSanA, 2021)). To gain an overview, discharge methods and sanitation management practices were compiled.

As the draft methodology requires a pre-defined list of sanitation categories for the quantification of baselines, specific categories had to be selected from the compilation of existing sanitation options. Based on the applicability conditions and boundary setting (see paragraph 3.1.3), systems outside of the boundary were excluded. Degradation and GHG emission pathways of the remaining sanitation categories were investigated in scientific literature. A limited number of categories was then selected based on availability of parameters required for the calculation of direct GHG emissions.

In order for the methodology to be used by project proponents in registration of a CBS project on the carbon market, it needs to specify how the baseline situation will be investigated, i.e. provide guidelines on what the project proponent needs to do, measure and report. The aim is to ensure that the project proponent can aggregate the results of the baseline investigation into the categories defined in the draft methodology. To facilitate the application of the methodology for project proponents with limited expert knowledge a decision tree that guides the categorization of sanitation systems in LMICs was developed.

2.1.5 Quantification of Emission Savings

Baseline Quantification

The baseline quantification is the element of the draft methodology that enables the project proponent to calculate the GHG emission avoidance of the project. Developing the quantification model for direct GHG emissions from sanitation systems in LMICs was a central innovation task in this work. The development of the model resembled an optimization between scientific accuracy of the methodology and simplicity of its application. The following criteria were defined:

1) The quantification model should render results that would correspond to real emissions.
2) Assessment and monitoring efforts of the project proponent should be minimized.
3) The quantification model should be easily adaptable to different sanitation systems and require only few input parameters.
4) Equations and methods should not differ significantly from established quantification methods in the carbon crediting framework, so as to increase the chances of acceptance by a carbon standard.

The baseline quantification model is based on IPCC Guidelines for National Greenhouse Gas Inventories of wastewater (hereafter referred to as IPCC Guidelines), which were adapted to the characteristics of different sanitation pathways (see paragraph 2.1.4) (IPCC, 2019).

To minimize baseline assessment efforts of the project proponent, default parameters were assessed for many equation inputs. To define the default values for these parameters, literature on excreta and sanitation as well as the IPCC Guidelines were consulted. Two constraints determined the choice of default values: 1) the availability of data in the sanitation sector; and 2) the intrinsic variability and uncertainty of sanitation systems' characteristics. In particular, information on direct GHG emission factors from sanitation systems was limited and partly defined the selection of sanitation categories in the draft methodology (see paragraph 2.1.4). Variability of data was observed in the characterisation of human excreta and faecal sludge as well as degradation conditions in sanitation systems. Default characterisation parameters were chosen on the one hand based on median values that had been assessed in previous scientific literature reviews and on the other hand based on values that were found to be replicated within the same range by at least two studies. The accuracy of default parameters and resulting emissions could not be verified with measurements within the scope of this work.

The resulting baseline quantification model was consolidated in an Excel calculator designed to facilitate quantification of direct baseline GHG emissions. The calculator requires a baseline scenario assessed by the project proponent (see paragraph 2.1.4) as input information. To address uncertainties of the baseline quantification, a sensitivity analysis with the Excel calculator was conducted (see section 2.3).

CBS Project Description and Emission Modules

Because collection and transformation of human waste to end-products are integral to CBS services, the draft methodology needs to account for the associated emissions. As the draft methodology is intended to be globally applicable in the CBS sector, all transformation processes that are currently applied by the eight main CBS companies (Clean Team, Loowatt, Sanergy, Sanitation First, Sanivation, SOIL, X-Runner and Mosan) were embedded as project modules. These processes were assessed based on previous work in the CBS sector and key informant interviews with experts from Sanergy, Sanitation First, Sanivation and SOIL (see paragraph 2.1.2.). Processes covered in existing carbon methodologies were identified from an analysis of the CDM carbon methodology framework (UNFCCC, 2021a). Other processes and associated GHG emissions were investigated based on recent scientific journal articles and existing carbon methodologies.

Emission Savings

To enable a comparison between different GHG emissions they are converted to CO_2-equivalents. The methodology uses global warming potentials of 34 kg CO_2-eq per kg CH_4 (methane) and 298 kg CO_2-eq per kg N_2O (nitrous oxide) respectively (Myhre et al., 2013). Emission savings are calculated by subtracting the CO_2-equivalents of project emissions from the baseline emissions.

2.1.6 Monitoring and Measurement

Project proponents must document and report certain parameters of a carbon project for annual auditing that enables authorization by a carbon standard (Verra, 2019b). The parameters to be measured and monitored, i.e. those that do not entail a default value in the baseline and project quantification models, were identified. The draft methodology prescribes how the project proponent should assess these parameters. Parameters needed for the baseline quantification are assessed ex-ante.

2.2 Case Study: Mosan Social Enterprise in Guatemala

As part of this work, the draft methodology was applied to the Mosan social enterprise, a CBS project operating in the Lake Atitlán region in Guatemala. The implementation of the draft methodology entails 1) evaluating the applicability of the methodology and defining Mosan's project activities; 2) demonstrating additionality; 3) assessing the baseline scenario; 4) quantifying the baseline emissions; and 5) quantifying the project emissions. The emission savings potential is obtained by comparing the results of the steps 4 and 5.

A research trip to Guatemala during the course of this work allowed for a field visit of Mosan's project region. The goal was to gain an understanding of the conditions and baseline scenario that the Mosan social enterprise currently operates in as well as insights in the everyday activities of a CBS system.

As the first step in implementing the methodology, applicability was evaluated based on Mosan's project activities and the external conditions in which Mosan is operating. To define the project activities and relevant emissions, the transformation centre where excreta are transformed into end-products was visited.

The external conditions, additionality and the baseline scenario were evaluated based on documents and key informant interviews assessing the social and political situation and the deficiencies around sanitation services. Information about governmental issues regarding sanitation in Guatemala and the Lake Atitlán region were obtained in conversations with key informants from the governmental agency for the sustainable management of the watershed of Lake Atitlán (AMSCLAE) as well as staff from the local wastewater treatment plant (WWTP) in Santa Catarina Palopó. Descriptions of the sanitation status in Guatemala and the Lake Atitlán region were obtained from previous studies and governmental documents issued by AMSCLAE and the National Institute of Statistics (INE) (INE, 2019).

Figure 2: Guided tour of the WWTP in Santa Catarina Palopó, Guatemala (Photo by M. Mijthab, 26.05.2021)

Figure 3: Key informant interview with resident in Santa Catarina Palopó (Photo by M. Gómez, 26.05.2021)

Key informant interviews were conducted with customers of the Mosan social enterprise, local constructors of pit latrines and professionals from water and sanitation companies. A guided tour of the WWTP provided an insight into the state of wastewater treatment in the Lake Atitlán region. These key informant interviews allowed for the classification of the existing sanitation options under the pre-defined categories in the draft methodology, based on the described construction and usage details. Baseline emissions were quantified with the Excel calculator with the assessed baseline scenario as input information. The project emissions were quantified based on the equations drafted in the methodology.

2.3 Sensitivity Analysis and Quality Control

In carbon crediting, quality control of the reported GHG emission savings is paramount for the legitimacy of the prospective carbon credits. Accordingly, several measures were taken within the course of this work to reduce, but also to address uncertainty.

With the help of the developed Excel calculator sensitivity analyses were performed to test the robustness of the drafted baseline quantification model. The tool for "What-if Analysis" with data tables was used. The quantification models were implemented as formulas in the Excel worksheet. Ranges of uncertainty of each parameter were tested to evaluate the sensitivity of the model output. Such analyses were also performed for pairs of correlated parameters, with output values presented in two-dimensional matrices.

The model outputs that were explored are CO_2-equivalents of direct CH_4, N_2O or total GHG emissions of a certain sanitation system. The focus of the sensitivity analysis was on the sanitation baseline emissions. Uncertainty within the quantification of fossil fuel or electricity emissions was outside of the scope of this work and thus not assessed.

The parameters to be varied were chosen once the draft methodology equations had been defined. The uncertainty intervals of the input parameters had to be chosen specifically for each parameter based on reported value ranges identified in the literature study on sanitation systems or from IPCC Guidelines.

3 Results

3.1 Methodology Development

3.1.1 Approach

Appendix E to this report contains the draft methodology. It is based on a template for a new carbon methodology (Verra, 2019b), and is formulated as an extensive procedure and guidance to CBS projects worldwide. The following paragraphs describe what considerations and decisions were made in formulating the elements of the draft methodology.

3.1.2 Methodological Foundation

Existing carbon methodologies were studied (see section 2.1.1) to assess methodological gaps regarding the sanitation sector. The requirements that must be met for a CBS project were identified and existing methodologies were compared vis-à-vis these requirements.

CBS projects cover the entire sanitation service chain, user interface to end-use (CBSA, 2018). Several transformation processes are currently used in the sector (CBSA, 2018). These processes were to be considered in the draft methodology to make it applicable to CBS projects worldwide. The baseline may consist of several decentralized and co-existing sanitation systems in LMICs where no single centralised sanitation system is implemented (see section 3.1.5).

The review of existing methodologies made clear that there is no methodology covering decentralized and co-existing sanitation options (UNFCCC, 2021a). Methodologies were first characterized according to the main type of waste that is treated, resulting in three broad categories: wastewater, organic solid waste and manure. Table 1 shows similarities and differences of exemplary CDM methodologies in the sectoral scope 13 (waste handling and disposal) in comparison to a CBS project. The assessed methodologies do not account for N_2O emissions.

Table 1: Similarities and differences of exemplary methodologies in the sectoral scope 13, evaluated vis-à-vis the requirements of a CBS project. WWT(P) = wastewater treatment (plant).

Methodology	Project	Similarities	Gap
AM0073 (UNFCCC, 2008)	Multi-site manure collection and treatment	Collection of organic waste from multiple sites Avoidance of CH_4 emissions from on-site degradation	Not containing waste from the source No co-existing baseline pathways
AM0080 (UNFCCC, 2009)	Aerobic WWT	Avoidance of CH_4 emissions from degradation in anaerobic treatment	No co-existing baseline pathways
AMS-III.H (UNFCCC, 2019)	Treatment of WWTP sludge	Avoidance of CH_4 emissions from open anaerobic degradation	Considers only 1 treatment (anaerobic digestion)

Some possible transformation processes that can be applied in CBS projects are already covered in existing methodologies of carbon standards. The baselines for these methodologies typically involve two aspects: 1) the decay of wastes in landfills; and 2) more energy-intensive production processes of (fossil fuel-based) alternative products that are to be replaced by the end-products of waste transformation. Amending these existing methodologies separately with the missing sanitation baseline for CBS would not have rendered one consistent methodological solution for CBS projects (del Valle Rosales, 2021).

Consequently, no existing methodology could be feasibly adapted to match the needs of a carbon methodology for the CBS activities of containing and enclosing excreta to replace a baseline consisting of unmanaged or unsafe sanitation systems. Therefore, the development of a new methodology was preferred, including the development of an aggregate baseline methodology, which is the common denominator for CBS projects. A variety of transformation processes was integrated to pre-emptively cover a wide range of CBS projects. The methodologies mentioned above were used as a foundation for formulations and structure and are listed in the draft methodology chapter "Relationship to Approved or Pending Methodologies" (Appendix E).

3.1.3 Applicability and Boundary Setting

Applicability

The general setting and external conditions under which the methodology is applicable are part of the methodology chapter "Project Activities and Applicability Conditions". In the implementation of the draft methodology, the project proponent must ensure that the CBS project adheres to the defined conditions.

The formulation of applicability conditions was guided by the principal goal of CBS solutions in LMICs: To provide a dignified alternative to unsafe and unmanaged sanitation endangering human health and ecologic integrity. Existing CBS projects operate in regions with limited access to safe sanitation (see also Appendix A.1) (CBSA, 2018). This could be due to a lack of infrastructure (user interface structures or sewage/excreta transportation), funding or enforcement of legislative framework (Tayler, 2021; World Bank, 2019). Regions with well-managed sanitation were excluded. Thus, the target region of CBS was defined, which is the geographic operating space of the CBS project, excluding the demographic with access to safely managed sanitation services.

The draft methodology is only applicable if excreta are transformed as part of the CBS project to achieve the requirement of safe sanitation. Furthermore, end-products should not be disposed of or stored downstream of the CBS project. This ensures permanence of emission reductions which is one of the carbon crediting principles (Broekhoff et al., 2019). Similarly, urine should not be discharged to a sewage system if that system is not well managed. If urine is treated at an external treatment site, associated N_2O emissions must be accounted for by the project proponent.

Project Activities and Boundaries

The project boundaries were defined in the draft methodology via included and excluded project activities. Figure 4 shows the boundaries that were chosen for the draft methodology. Project activities include 1) provision of a CBS toilet to customer households alongside cover materials; 2) collection of the containers at least once a week; and 3) transformation of excreta.

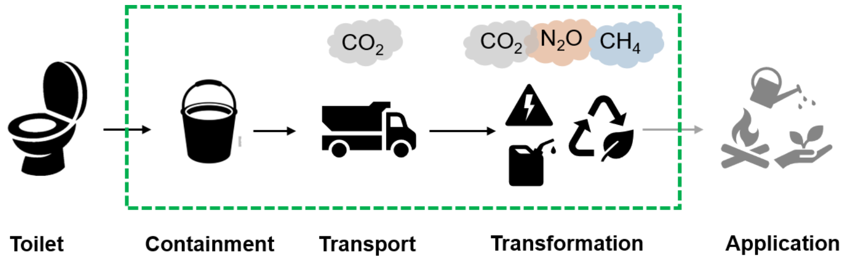

Figure 4: Project activities along the sanitation service chain, with boundary setting and identification of relevant GHG emissions for the purposes of the draft methodology.

From the assessment of sector 13 carbon methodologies (see paragraph 3.1.2), it became evident that a methodology for CBS cannot only account for the avoided emissions from the replacement of inefficient sanitation systems. As transformation of excreta is integral to CBS services, the associated emissions must be accounted for (Verra, 2019a). The transformation is further described in the above paragraph 'applicability conditions'. The methodology includes different applied transformation processes for faecal matter. Subsequent application of the end-products is part of separate carbon projects and is not accounted for with the draft methodology.

Transformation of source-separated urine involves storage or treatment such as struvite precipitation with magnesium oxide in closed containers (World Bank, 2019). Accounting for emissions from storage and transformation of source-separated urine was outside the scope of the draft methodology. Emissions from infiltration of urine to the ground as fertilizer were considered part of the activity "Application" and are thus outside of the boundaries (Figure 4) (Marsden et al., 2018).

Baseline Boundaries

The baseline scenario covers degradation of excreta in on-site sanitation (OSS) containments, and of faecal sludge or wastewater transported to dumping sites or treatment facilities (Figure 5).

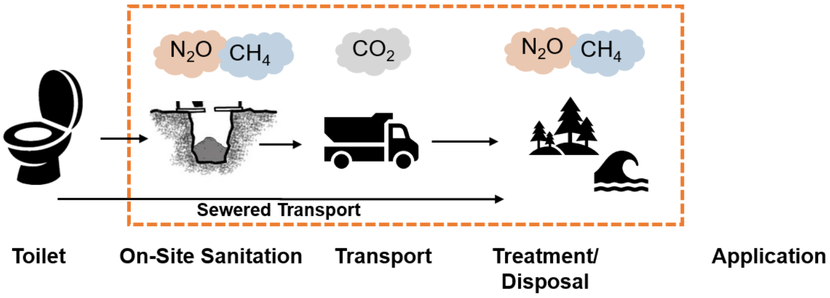

Figure 5: General baseline sanitation pathways along the sanitation service chain, with boundary setting and identification of relevant GHG emissions for the purposes of the draft methodology: direct emissions from on-site sanitation and the disposal site, as well as fuel emissions from transport of faecal sludge. Open defecation is not depicted but equates to direct 'disposal' without any previous infrastructure.

In accordance with applicability conditions, sanitation systems that already provide safe sanitation or render safe end-products were excluded from the baseline scenario definition.

The baseline boundaries also defined which processes and emissions were included in the development of the emission quantification model. Excluded baseline emissions are direct emissions from emptying, transport or intermediate storage of faecal sludge, and from wastewater transport in sewers. It was assumed that residence times in transport processes and intermediate storage are relatively short compared to long-term containment and final disposal (Harroff et al., 2019). The quantification model does not consider a timespan for transport processes: The faecal sludge is modelled to be either in the stage of containment or disposal. This simplification contributed to streamlining the initial efforts for assessment of the baseline situation (see also paragraph 3.1.6).

Boundaries for Greenhouse Gas Emissions

Considered direct emissions are CH_4 and N_2O. Direct CO_2 emissions are not accounted for in the draft methodology as they originate from biogenic sources (= excreta) and are thus excluded as per the IPCC Guidelines (Doorn et al., 2006). N_2O is typically not included in sanitation methodologies (UNFCCC, 2009, 2019). For a more comprehensive emission calculation in adherence with the reality of natural processes, N_2O emissions are included in the draft methodology.

Fossil fuel energy or electricity might be required for motorized transport or other operational activities, in the project as well as the baseline. The latter is mainly pertained to emptying and transport services for faecal sludge and aeration of aerobic wastewater treatment plants (WWTP). Fossil CO_2 emissions are considered in the draft methodology via reference to existing methodological tools that cover the respective processes.

Emissions from manufacture of CBS toilets or auxiliary materials are not considered, since carbon methodologies do not follow Life Cycle Analysis (LCA) guidelines (Zurbrügg et al., 2012).

3.1.4 Additionality

Additionality is one of the key principles of the carbon market to ensure that issued carbon credits correspond to a real decrease of emissions (World Bank, 2016). There are three ways to show additionality: The project method, the performance method or the activity method (Verra, 2019a). This section explains what method was chosen in the draft methodology.

Part of the project method is the CDM tool "positive list of technologies" that includes carbon projects that are automatically considered additional (UNFCCC, 2021b). One criterion for projects on that list is a low market penetration, which is a sign that a project cannot be implemented without additional revenue generated from selling carbon credits. Market penetration is the percentage of people using CBS in the project area (Verra, 2019b). The draft methodology defines additionality of CBS projects via a market penetration below 5%. Since percentage CBS usage worldwide is still limited and increasing slowly (Russel et al., 2019), this was considered the most feasible approach to demonstrate additionality for novel projects such as CBS, as it reduces assessment efforts for the project proponent (del Valle Rosales, 2021; Etter et al., 2021).

If this upper bound for market penetration is exceeded in a project region the CDM combined tool to assess the baseline and show additionality can be used (UNFCCC, 2017a). This tool follows the project method and is used in approved methodologies in the sanitation sector (UNFCCC, 2009, 2019). The CBS project would need to be analysed in detail regarding barriers to implementation like financial, technological and institutional barriers (World Bank, 2016). Market penetration is considered the manifestation of these boundaries and is sufficient to demonstrate additionality of CBS.

The standardized performance method is disregarded because it requires projects to achieve a prescribed performance benchmark of GHG emission reductions (Verra, 2019a). Due to the aggregate baseline in the CBS sector, such a standardized value could not be easily defined (see variability in section 3.3.2).

The project proponent needs to demonstrate additionality of the CBS project when registering on the carbon market. With official documents, statistics and population surveys of alternative sanitation pathways the project proponent shall assess the market penetration.

3.1.5 Baseline Assessment

Background for Sanitation Systems

The baseline for a CBS project implemented in LMICs might consist of various co-existing sanitation pathways that are not fully managed. This demands an aggregate baseline scenario which is a combination of the usage weighted shares of likely sanitation pathways (Verra, 2019b).

The draft methodology distinguishes three main sanitation pathways, as concluded from a literature study on sanitation systems: Wastewater/sewerage, on-site sanitation and open defecation. On-site sanitation includes discharge of excreta into containment tanks or pits at site the of excreta production (SFD Promotion Initiative, 2018a). The term 'wastewater' refers to wastewater that is transported through a sewer, whereas 'faecal sludge' is what accumulates in on-site sanitation technologies (Tilley et al., 2014). Open defecation means a lack of sanitation facilities (Ritchie & Roser, 2021).

A list of formal on-site sanitation facilities was derived from a literature review (Table 4 in Appendix A.2). The construction methods of on-site containment systems in LMICs may not adhere to the requirements set in the technological framework (Graham & Polizzotto, 2013; Tayler, 2021; Tilley et al., 2014). Deduced from SFD reports, an overview of possible unsafe on-site containment variations and open defecation options that have been observed in LMICs is provided in Table 3 in Appendix A.1. Faecal sludge that is emptied from containments in LMICs is often disposed of directly in the environment, in water bodies or on open ground (Kabir & Salahuddin, 2014). For wastewater and faecal sludge handling, several sub-categories of disposal sites or treatment plants were identified (Appendix A.2).

Choice of Baseline Sanitation Categories

The sanitation systems and disposal sites in Appendices A.1 and A.2 were filtered in accordance with the baseline boundaries defined in section 3.1.3: Treatment options or systems that render a product safe for reuse, or that capture and recover biogas emissions were excluded. Treatment options not pertaining to biological degradation, such as addition of lime were not considered (see Table 4 in Appendix A.2).

In a second step, only the sanitation categories remained where available information from literature allowed an estimation of GHG emissions (see Table 6, Appendix A.3 and Table 8, Appendix A.4). The on-site containment categories are six pit latrines (Figure 6) and a septic tank (Figure 15, Appendix A.3), which includes water-tight lining and an overflow (Tilley et al., 2014). Categories of treatment facilities and disposal sites are defined collectively for wastewater and faecal sludge (Table 5 in Appendix A.4).

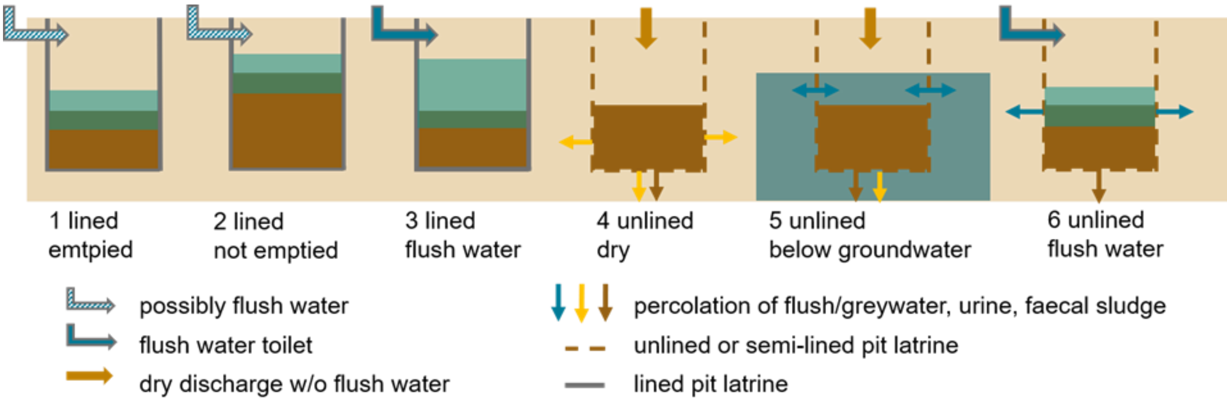

Figure 6: Pit latrine categories as per the draft methodology, distinguished by the criteria 'lining', 'flush water' and 'groundwater interaction'. See also Table 7 in Appendix A.3

All other sanitation systems needed to be allocated to one of these pre-defined categories. Merging of the overall identified discharge pathways and the defined categories for treatment or disposal is explained in Appendix A.4. The criteria for the categorization of on-site containment categories are shown in Table 7, Appendix A.3. Partially lined pit latrines where leakage to the ground is still possible were categorized as unlined latrines. If a septic tank does not include an outlet, the containment facility should be categorized as a lined pit latrine with connection to a flush toilet.

Implementation by Project Proponent

The project proponent needs to perform the baseline assessment for the respective project region. The relevant information about the sanitation pathways and their percentage usage needs to be collected. Sanitation pathways include the type of on-site sanitation and possible discharge sites of faecal sludge, wastewater discharge sites and sites of open defecation. Official records and local or regional data like surveys, census or SFDs can be used. Baseline assessment should not be conducted solely based on literature research, because terms and understandings for sanitation systems among the population and even professional sanitation constructors may differ from official terms and definitions, as Strande et al. have emphasized (Strande et al., 2021). To clarify the construction and usage of each system, key informant interviews and on-site visits should be conducted. If no SFD, official data or sanitation literature describing the project region are available, the draft methodology stipulates that a survey must be conducted in the project region to assess the baseline scenario. A representative sample size within the project region should be chosen such that a confidence level of about 90% can be reached, in accordance with requirements of carbon project auditing (del Valle Rosales, 2021; Kibuacha, 2021).

The sanitation systems that are found in a region need to be ascribed to the pre-defined categories of the draft methodology. A decision tree helps allocate sanitation systems (supplement in draft methodology in Appendix E). In turn, the formulation of survey questions or key informant interviews to assess the baseline are guided by the decision tree and the technical definitions of the sanitation categories provided in the draft methodology.

The methodology stipulates that the project proponent shall assess certain parameters pertaining to the baseline quantification in the baseline assessment (see section 3.1.6).

3.1.6 Baseline Quantification

Approach

The main baseline quantification equations for methane (CH_4) and nitrous oxide (N_2O) were taken from the IPCC Guidelines (D. Bartram et al., 2019; Doorn et al., 2006). CH_4 emission quantification is done by multiplication of an emission factor (EF) specific to a sanitation system with the organics content inside the sanitation system (both parameters are considered in the next paragraphs). N_2O emissions from excreta degradation are quantified with an analogous approach, but the emission factors are based on nitrogen content.

Considerations for Organics and Nitrogen Contents

Default values for the organics and the nitrogen contents in excreta were taken from a study conducted by Rose et al. (Rose et al., 2015). IPCC Guidelines provide organics default values for wastewater BOD_5 production per person. However, the draft methodology uses input loads exclusively for excreta from Rose et al., as CBS project activities do not replace disposal of greywater or other organic wastes.

To assess the amounts of faecal sludge removed from on-site containments via emptying, a simplified method was developed that does not require extensive data or measurements. Average values for the containment volume of a sanitation category and the respective emptying frequency shall be derived by the project proponent within the baseline assessment in order to quantify annually removed amounts of faecal sludge. Default values for concentrations of organics and nitrogen in faecal sludge are provided and can be used if no regional values or locally documented measurements are available (Bassan et al., 2013; Gudda et al., 2017; Misi et al., 2018; Ward et al., 2021).

In the quantification model of the draft methodology, the amounts of organics and nitrogen remaining in the effluent of aerobic WWTPs (Figure 16, Appendix A.4) and septic tanks (Figure 15, Appendix A.3) may be determined with default values from IPCC Guidelines (D. Bartram et al., 2019). Quantification of secondary sludge production for aerobic WWTPs requires assessment of inflow and outflow organics and the solids retention time. It is always the preferred option to use local measurements and data. The concept of using default values is in line with IPCC Guidelines and other methodologies that often allow for plug-in of default values if no national values or local data are available.

Considerations for Emission Factors

Emission factors reflect the conditions within the systems and the pertaining degradation pathways. In IPCC Guidelines, CH_4 emission factors are made up from a maximum CH_4 producing capacity (B_0) per organics weight (in biological or chemical oxygen demand (BOD or COD)). A second factor ascribes a correction for actual CH_4 production to individual processes. This methane correction factor (MCF) is between 0 for completely aerobic conditions and 1 for systems with a complete lack of oxygen. Studies identifying CH_4 from the sanitation sector have also used these emission factors (Noyola et al., 2016; Reid et al., 2014).

The draft methodology uses IPCC Guidelines emission factors and emission factors sourced from personal communication with the University of Leeds based on a public presentation of a workshop on GHG emissions from citywide sanitation from 2018 (Evans, 2021).

Considerations for Quantification Equations

The following paragraphs describe how the drafted quantification approaches for the three main sanitation pathways identified in paragraph 3.1.5 differ from the main equations for CH_4 and N_2O emissions in the IPCC Wastewater Guidelines (D. Bartram et al., 2019).

The draft methodology simplifies the emission calculation for direct discharge of wastewater to treatment or disposal sites to a multiplication of the organics or nitrogen input via excreta production (see paragraph on 'input parameters') with the respective emission factor. The same approach was used for open defecation, with fewer possibilities of final disposal sites. The draft methodology considers separate treatment or disposal of removed secondary sludge from aerobic WWTPs as well as residual effluent emissions, as is done in IPCC Guidelines (see Figure 16, Appendix A.4).

For on-site sanitation, the draft methodology considers two sites of possible emissions: The containment categories and the disposal or treatment sites in case faecal sludge is emptied from containments. To assess the organics and nitrogen contents in the containments, organics and nitrogen removed via faecal sludge emptying are subtracted from the respective inputs. For unlined pit latrines (categories 4 – 6 in Figure 6), there may be a certain degree of percolation to the ground (Graham & Polizzotto, 2013). To account for loss of faecal sludge to the ground, the draft methodology considers a correction factor of 0.7 for input organics to pit latrines that are below the groundwater table or where flush water is discharged into the pit latrine (categories 5 and 6 in Figure 6) (Evans, 2021; Nwaneri et al., 2008). CH_4 Emissions from the ground or groundwater were not quantified as they are expected to be minimal (Truhlar et al., 2016). Percolation of nitrogen to the ground was not included in the draft methodology.

For septic tanks, removal of organics and nutrients via the outflow is integrated in the methodology (Figure 15, Appendix A.3). For outflow discharge to sewers or disposal sites, further emissions must be considered, analogous to an aerobic WWTP as shown in Figure 16, Appendix A.4 (D. Bartram et al., 2019). For outflow discharge to constructed leach fields CH_4 emissions are assumed negligible, and N_2O emissions are considered as per Truhlar et al. (Diaz-Valbuena et al., 2011; Truhlar et al., 2016). Faecal sludge removal from septic tanks is estimated with the same approach as for other on-site containments. This approach differs from IPCC Guidelines that estimated 50% organics removal from septic tanks. 50% organics removal via sludge emptying might overestimate real conditions, because the possibility of septic tanks not being emptied regularly is high in LMICs (Huynh et al., 2021).

Implementation

The project proponent performs the step of baseline quantification by use of the equations and default values established in the draft methodology. Therein, the Excel calculator serves as a tool to quantify the direct emissions based on the inputs of percentage usage of sanitation systems and disposal sites in the project region, as established by the project proponent in the baseline assessment.

Use of fossil energy in treatment plants or motorized transport and/or emptying must be quantified and monitored separately with the respective CDM tool (UNFCCC, 2017b). Project proponents must acquire data or estimations for transport ranges and fuel usage and convert these values to a per person basis.

3.1.7 CBS Project Quantification with Emission Modules

Re-valorisation processes applied in CBS projects are listed in Table 2. Furthermore, the draft methodology includes vermi-composting, as this is a possible secondary treatment for digestate produced in the anaerobic digestion process. There is no emission module for transformation of source separated urine. This will be discussed in section 4.1.3. For more detailed considerations of the process modules, refer to Appendix B, and for the quantification methods, refer to the draft methodology (Appendix E).

In the project activities, energy use in the form of electricity or heat or for transport may be necessary. Fuel and electricity use need to be monitored by the CBS project. The emissions are considered as per the latest version of the respective methodological tool (UNFCCC, 2017b).

Table 2: Consolidated overview of project emission modules: transformation processes and quantification methods of the most relevant GHG emission. EF = emission factor.

Process Module	Products	Expected GHG Sources	Quantification Method
Anaerobic Digestion	Biogas	Energy input for stirring; direct GHG emission slips	CDM methodology (UNFCCC, 2010)
	Digestate	Depending on further treatment	As per further treatment (modules)

Composting	Compost	Direct GHG emissions; fossil fuel for waste turning (McNicol et al., 2020)	CDM methodology (UNFCCC, 2016)
Black Soldier Fly Larvae Treatment	Animal fodder (Dortmans, 2019)	Direct GHG emissions Fossil fuel use	EF based on wet waste input (Mertenat et al., 2019) CDM tool (UNFCCC, 2017b)
Briquetting	Solid biofuel (Ward et al., 2014)	Fossil fuel use for drying, size reduction and pressing	CDM tool (UNFCCC, 2017b)
Pyrolysis	Biochar	Fossil fuel use for starting up pyrolysis Leakage of pyrolysis gas	CDM tool (UNFCCC, 2017b) EF based on wet waste input (Towprayoon et al., 2019)
Vermicomposting	Compost	Direct GHG emissions Fossil fuel use	EF based on wet waste input (Nigussie et al., 2016) CDM tool (UNFCCC, 2017b)

The draft methodology does not consider direct emissions from drying of excreta or faeces as a pre-treatment for the CBS transformation process. It was assumed that source-separated faeces and excreta from containers have a relatively low moisture content due to addition of cover materials (Semiyaga et al., 2018). Faeces and excreta from containers thus dehydrate without degradation or transformation that would generate GHG emissions (Getahun et al., 2020; Tilley et al., 2014).

3.2 Case Study: Application of the Methodology to Mosan

3.2.1 Background

The goal of this case study was to demonstrate how the draft methodology is applied, with the example of the Mosan system. Mosan is a social enterprise founded in Switzerland that provides a CBS system in rural regions in Guatemala. In 2018, the Mosan social enterprise started a pilot project in Santa Catarina Palopó at Lake Atitlán, serving roughly 40 households. Mosan's current activities also include research and development, inter alia in fertilizer development and participatory design for user inclusion. Mosan is looking to expand the CBS service to other communities around Lake Atitlán.

Figure 7: Mosan dry toilet. [Source: Mosan. Reproduced with Mosan's permission.]

The World Bank Group identifies sanitation as one of the major challenges in Guatemala's development (World Bank, 2018). Up to 80% of wastewater is discharged into Lake Atitlán without any treatment, polluting this valuable source of drinking water, and aquatic ecosystems (Ferráns et al., 2017; Neher et al., 2021). Sanitation services in Guatemala are insufficient, especially in poorer rural areas such as the watershed region of Lake Atitlán (Dix et al., 2003; World Bank, 2018). 90% of residents at Lake Atitlán are indigenous. From a socio-ecologic analysis of the Lake Atitlán watershed region, it is evident that the vast majority of people live in poverty or even extreme poverty in these rural areas (Dix et al., 2003). Municipalities that attract tourists show higher income and life quality than the rural Mayan communities.

Container-based sanitation could alleviate risks for human health and help preserve Lake Atitlán. Mosan's CBS system is depicted in Figure 8. Both urine and faeces are conditioned to produce valuable end-products safe for reuse (Agegnehu et al., 2016; González-Ponce et al., 2009). Collected urine is stored in a closed container for about a month and then transformed into the organic fertilizer struvite by precipitation with magnesium oxide. Faeces are pyrolyzed into biochar, using liquefied petroleum gas

(LPG) to provide the initial heat. During pyrolysis, pathogens are destroyed, and biochar can be safely applied as a soil conditioner (Strande et al., 2019).

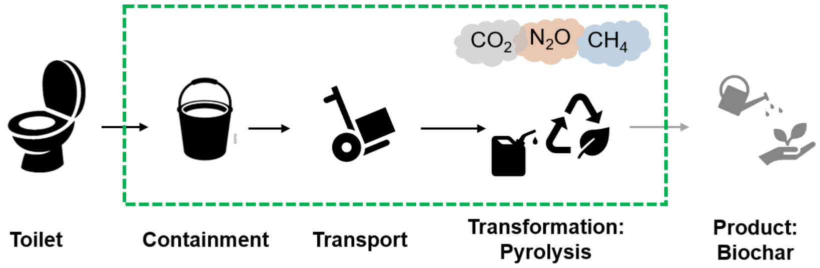

Figure 8: Mosan's CBS system: Source-separating toilet, bi-weekly collection of urine and faeces containers, non-motorized transport to transformation centre,and pyrolysis of faeces into biochar, with use of liquefied petroleum gas to start pyrolysis.

3.2.2 Applicability

The baseline and project conditions specific to the Mosan social enterprise were assessed. The Mosan system was compared vis-à-vis the conditions and boundaries that the draft methodology defines (see paragraph 3.1.3). The project activities as assessed during the field visit of the transformation centre in Santa Catarina Palopó fulfil the conditions of the draft methodology (see Figure 8).

Existing baseline solutions were evaluated regarding the criterion of "limited access to sanitation". In both the wastewater and the on-site sanitation sector, the service level is low for the majority of residents around Lake Atitlán (Ferráns et al., 2017). Regulations for on-site sanitation and faecal sludge management and enforcement thereof are only observed for on-site sanitation at hotels and restaurants around the lake (Romero, 2021). These public facilities are not part of the aggregate baseline scenario since the draft methodology only considers household facilities. Wastewater treatment plants (WWTP) at Lake Atitlán do not comply with effluent requirements (Barreno Ortiz & Reyes Morales, 2019; Ferráns et al., 2017). There are political barriers regarding improvement of the sanitation situation (Ovando Fernández, 2021): With each four-year municipal government period, the municipal staff changes, including the WWTP facility manager and maintenance team, who are not professionally trained. Legislation does not effectively oblige the municipalities or local government to provide sanitation solutions for the low-income population in the highlands of Guatemala (Basterrechea Dáz et al., 2020). In conclusion, there is limited access to safe sanitation in the Lake Atitlán region.

3.2.3 Additionality

As per the draft methodology, additionality is shown in the first instance via the percentage market penetration of the respective technology entailing all project activities defined in the methodology. There is no mention of container-based sanitation in any of the documents provided by the Authority for the Sustainable Management of the Catchment Area of the Lake Atitlán and its Surroundings (AMSCLAE) or other official publications (Basterrechea Dáz et al., 2020; INE, 2019; World Bank, 2018). Mosan social enterprise operates the only CBS system in Guatemala. Market penetration is therefore substantially below 5% in the region of Lake Atitlán.

3.2.4 Aggregate Baseline Scenario

The watershed region of Lake Atitlán constitutes the project region for which the baseline scenario shall be assessed. The municipalities around the lake show socio-economic and ecological similarities (Dix et al., 2003). Usage of sanitation systems at Lake Atitlán were taken from official reports and statistics by AMSCLAE as well as the National Institute of Statistics (Basterrechea Dáz et al., 2020; INE, 2019). To categorize the sanitation systems into the categories defined in the methodology (Table 6 in Appendix A.3 and Table 8 in Appendix A.4) more details of construction and usage were assessed from local key informants. The assessed baseline scenario is shown in Figure 9.

In Santa Catarina Palopó, two thirds of sewerage is discharged directly to the lake. One third is biologically treated, with removal and drying of secondary sludge for application in agriculture. Nutrient concentrations in Lake Atitlán reach high values and thus, the category of a “hypoxic, lentic water body” was assumed (see Table 8 in Appendix A.4) (Rejmánková et al., 2011). A detailed description of the WWTP in the municipality is provided in Appendix C.1.

Figure 9: Aggregate baseline scenario for Lake Atitlán: Percentage usage of excreta discharge pathway based on (Basterrechea Dáz et al., 2020; Don Miguel, 2021; INE, 2019; Romero, 2021). WWTP = wastewater treatment plant

Faecal sludge from on-site sanitation systems gets rarely emptied, because containment systems fill up slowly and emptying services are not feasible for the local population (Romero, 2021). The groundwater table is generally assumed to be low and the risk of groundwater influence on containment facilities is reported to be minor (MAGA, 2013; Romero, 2021).

For the WWTPs around lake Atitlán, an average of 85% organics removal in biological degradation was assumed based on a regional measurement campaign (Barreno Ortiz & Reyes Morales, 2019). Based on this organics removal rate, secondary sludge production was estimated (see Appendix C.1). Primary sludge removal was found to be missing from the WWTP in Santa Catarina Palopó and is thus not considered. All secondary sludge is assumed to be stored in open drying beds.

3.2.5 Quantification of Baseline Emissions

The percentages of usage of discharge categories in the Lake Atitlán watershed region were inserted in the Excel baseline calculator (Figure 10, left), along with the identified wastewater discharge or treatment sites in further input fields. The output of the Excel calculator provides an overview of GHG emissions pertaining to the aggregate baseline of one unit of CBS (Figure 10, right). One unit of CBS (= one toilet) was estimated to be shared on average by a family of five people in the Lake Atitlán region.

Primary input to Excel calculator

User discharge to:	fi [%]
Lined pit (emptied when full)	0%
Lined pit (not emptied)	0%
Lined pit (with flush toilet)	20%
Unlined pit (dry)	6%
Unlined pit (FS below groundwater)	0%
Unlined pit (with flush toilet)	47%
Septic tank with dispersial field	0%
Sewered sanitation	24%
Open defecation	3%
SUM	**100%**

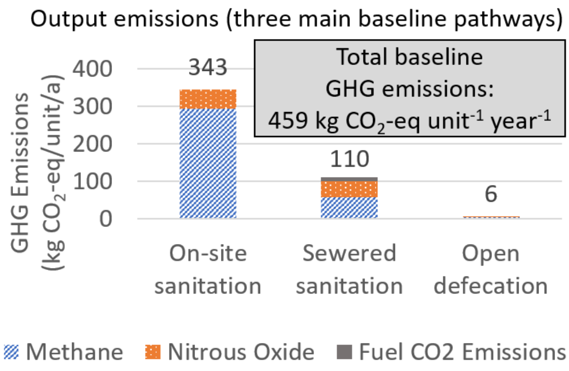

Figure 10: Initial input to the Excel baseline calculator are the percentages of usage of initial excreta disposal pathways encountered in the Lake Atitlán region (left). Further input fields for categories of discharge sites are not depicted. On the right, the annual baseline GHG emissions for one toilet unit are shown (= direct emissions and fuel use emissions). Fuel emissions for aeration at WWTPs was calculated separately as described in Appendix C.2

Quantification of fuel emissions for aerobic wastewater treatment resulted in about 10 kg CO_2-eq for the percentage of the five people that discharge wastewater to a WWTP as per the baseline assessment (see Appendix C.2).

3.2.6 Quantification of Project Emissions

For the project emission quantification of the Mosan system, no transport emissions were considered because transport is currently not motorized due to the limited road access to customer households. As established in the draft methodology, no emissions are considered from the toilets nor from urine storage and transformation to struvite.

The calculation of the pyrolysis emissions based on the developed project module is described in detail in the draft methodology in Appendix E. Combined direct CH_4 and N_2O emissions are minimal with 1.3 kg CO_2-eq per unit per year. For wet waste, a default value for faeces production of 130 g per person per day was provided in the draft methodology (Rose et al., 2015). Fuel consumption is estimated at 2.5 kg liquefied petroleum gas (LPG) per unit per month based on internal documentation of Mosan's transformation process. The assumed fossil fuel consumption was multiplied by an emission factor of 2.98 kg CO_2 per kg LPG (Garg et al., 2006). Annual CO_2 emissions from LPG combustion amount to 89.4 kg CO_2 per unit CBS shared by five people.

3.2.7 Potential of Emission Savings

Emission savings of the Mosan system resulted in roughly 370 kg CO_2-eq per CBS unit shared by five people per year.

Carbon credit revenue potential for a ton of GHG emission savings depends largely on the per ton price that the credits can be sold for. Common carbon prices in the Verified Carbon Standard (VCS) (see paragraph 2.1.1) fluctuate and could be as low as USD 3 – 5. However, there are currently carbon credits being traded for up to USD 20 – 50 (Holder, 2021). A carbon consultant estimated the value of a potential CBS carbon credit currently at USD 7 – 8 (del Valle Rosales, 2021). With this range of prices and the estimated emission savings, potential annual revenue streams per CBS unit for the Mosan system were assessed. Figure 11 shows the minimum service sizes that would be needed for different carbon prices to cover annual auditing costs, which amount to at least USD 9000 (del Valle Rosales, 2021).

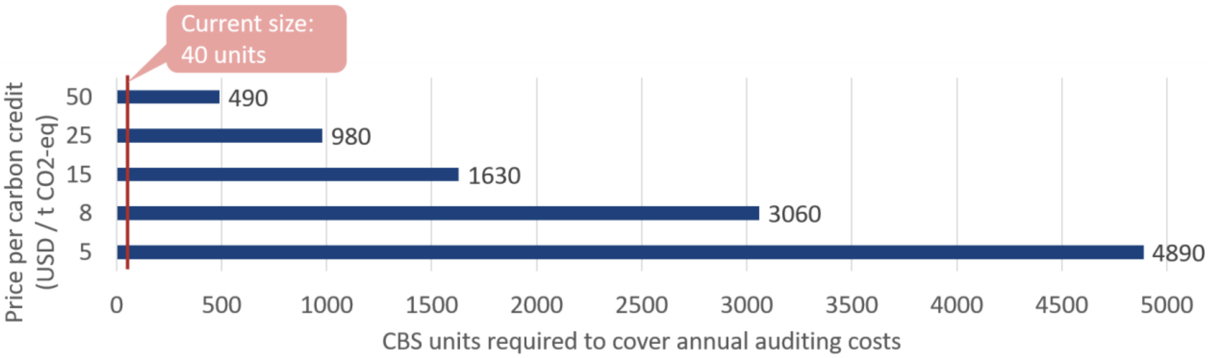

Figure 11: Minimum service sizes needed for the Mosan CBS system (in units of household toilets shared on average by five people) to cover annual auditing costs of USD 9000. Different carbon prices are considered, resulting in carbon revenue per toilet unit of about USD 2 – 20 per year. Current service size of the Mosan CBS system is roughly 40 toilets.

The service size of the Mosan system has to increase at least tenfold with the assumption of a high carbon price of USD 50 before carbon crediting could become viable. Disregarding fixed costs for registration on a carbon market or auditing, approximately 10% of direct running costs could be covered with resulting carbon revenue, depending on the service size and assuming a carbon price of USD 50 (CBSA, 2018). For the currently realistic carbon price of around USD 8, a service size of more than 3000 units has to be reached to cover annual auditing costs. With a service size of 3000 units approximately 1.1 t CO_2-eq greenhouse gases could be mitigated per year.

For the Mosan social enterprise, selling biochar might be an opportunity for revenue once production amounts allow streamlined distribution. Moreover, a VCS methodology for biochar application (including carbon sequestration) is currently under stakeholder review (Agegnehu et al., 2016; Etter et al., 2021).

3.3 Uncertainty Analysis

3.3.1 Assumptions

This uncertainty analysis is conducted to show 1) the variability in emissions between sanitation systems with the default assumptions of the draft methodology and 2) the uncertainty ranges of the parameters and their effect on overall system emissions. The Excel What-If Analyses were conducted with one sanitation pathway at a time, assessing annual emissions of one household consisting of five people (= 1 unit) each.

3.3.2 Variability of Sanitation System Emissions

On-Site Containments and Open Defecation

N_2O and CH_4 contributions and their variability between on-site sanitation categories were assessed. As can be seen from Figure 12, combined GHG baseline emissions for on-site sanitation categories with the default model assumptions show a large range between 260 – 730 kg CO_2-eq per year per five people, with N_2O contribution of around 8 – 20%. Large differences in absolute CH_4 emissions are observed.

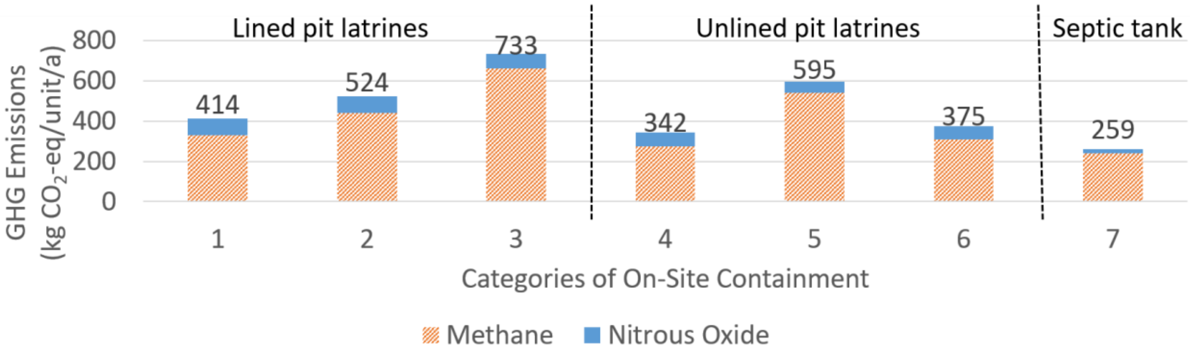

Figure 12: GHG emissions from on-site containment categories as defined in Figure 6 and a septic tank (category 7), on the basis of one CBS unit shared by five people. The numbers above the bars are the combined GHG emissions.

For open defecation, overall GHG emissions of about 200 kg CO_2-eq were calculated, with relatively high N_2O contribution of around 45%.

Treatment and Disposal Sites

Figure 13 shows the emissions from wastewater discharge to disposal sites or treatment plants. Direct CH_4 emissions range between 40 kg CO_2-eq to 880 kg CO_2-eq per household per year connected to the specific discharge site. N_2O shows the largest contribution to overall GHG emissions for rivers (58%) and ranges between 0 (deep lagoon) and up to 210 kg CO_2-eq per year in hypoxic and stagnant water bodies.

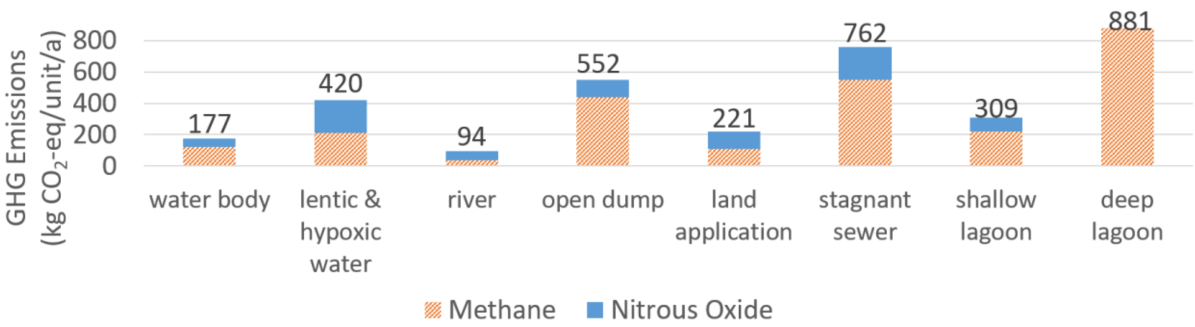

Figure 13: Baseline GHG emissions in CO_2-equivalents per year per household (5 people) for discharge of wastewater or treatment in facilities other than centralized aerobic treatment plants. The numbers above the bars are the total GHG emissions.

Similar considerations were conducted for faecal sludge disposal after on-site containment in a lined pit latrine (category 1 in Figure 6) with an assumed filling rate of 100 L per person per year (Gudda et al., 2019; Prasad et al., 2021). From Figure 17 in Appendix D.1 a 'buffering effect' of the containment on overall emissions is identified: Overall emissions range between about 350 – 550 kg CO_2-eq per unit per year, which is a more narrow range than for direct disposal in the same sites in Figure 13 (90 – 880 kg CO_2-eq). In the example in Appendix D.1, the contribution of the containment emissions is constant and input to the faecal sludge discharge sites is smaller than for direct discharge of wastewater.

Scenario Analysis of an Aerobic WWTP

In a scenario analysis for aerated biological treatment plants with effluent and secondary sludge removal, several border conditions were tested out, as described and shown in Appendix D.2. These results show the high variability in CH_4 emissions quantification of an aerobic WWTP. Emissions from secondary sludge handling are relevant to overall methane emissions, while the contribution from the effluent is about 10% at most in the tested scenarios. This scenario analysis demonstrates the importance of accounting for several stages in the aerobic treatment plant. Furthermore, accurate estimation of the secondary sludge production by the project proponent is critical due to the high sensitivity of the overall output CH_4 emissions to sludge emissions. Moreover, N_2O emissions contributed significantly to overall emissions. However, considering N_2O emissions in the current scenario analysis might have led to inconsistent conclusions because the model does not account for N_2O from secondary sludge handling.

3.3.3 Sensitivity Analysis

Parameter Uncertainty

For all sanitation pathways, nitrogen and organics production per person per day was considered the same. The variations of these factors were taken from Rose et al. They are +/- 35% for the organics load (COD) and +207%/-78% for the nitrogen load (Rose et al., 2015). Each of these parameters was tested individually and the linearly dependent model outputs (CH_4 and N_2O emissions) varied in the respective ranges. For on-site sanitation with faecal sludge removal, only the emissions from the containment are directly dependent on excreta input.

Another parameter that is constant throughout all CH_4 emission calculations is the maximum CH_4 producing capacity (B_0). A default uncertainty range of +/- 30% was used for B_0 (D. Bartram et al., 2019). The output CH_4 emissions for the specific sanitation systems naturally varied with the same percentages. Furthermore, ranges of emission factors for N_2O and CH_4 were tested to analyse the sensitivity of the model outputs. The most interesting results were found for sanitation pathways with several stages (e.g. on-site sanitation with faecal sludge emptying and disposal), because overall output emissions did not change with the same magnitude as the input parameter. Examples are shown in the next paragraph.

On-Site Sanitation and Faecal Sludge Management

To illustrate the intricacies of GHG emissions from on-site sanitation with faecal sludge disposal, one example is presented in more detail in Appendix D.3: A pit latrine of category 1 (lined household latrine with emptying, see Figure 6) and a ‘water body’ as the disposal site for faecal sludge. Appendix D.3 explains the effects of the tested parameters on overall emissions of this specific example. A main conclusion is that the quantification model reacts critically for high volumes, emptying frequencies and organics concentration in faecal sludge. These parameters are used to determine the organics that are removed from the containment and are independent of the input organics and thus independent of the accumulated content of the containment. To be able to test high values for the parameters that determine the faecal sludge removal, the model outputs had to be limited so that logical results can be achieved. However, such border results are not able to reflect real emission conditions properly.

Further analyses of on-site sanitation with faecal sludge disposal revealed that every combination of a containment and a disposal type led to differing sensitivity of CH_4 emissions to the same tested parameters (see Table 11 in Appendix D.3). Therefore, each combination must be analysed separately. For septic tanks, discharge of effluent has to be considered additionally to faecal sludge emptying. Conclusions from the scenario analysis of the aerobic WWTP (see Appendix D.2) can partially be applied to the septic tank.

These analyses were conducted for nitrogen and N_2O emissions analogously. Similar conclusions can be made, but the contributions of N_2O are generally less significant than CH_4 in on-site sanitation systems and faecal sludge management (see also Figure 17 in Appendix D.1).

4 Discussion

4.1 Draft Methodology

4.1.1 Baseline Scenario

The draft methodology is formulated to fit it to the needs of CBS projects in need of financial revenues to enable upscaling (Couder & Kibuthu, 2020). Providing safe sanitation to all people must be the primary concern in the sanitation sector (SDG 6.2) (J. Bartram et al., 2018). Within SDG 6.2, improving the greenhouse gas (GHG) emission balance is a desirable effect of a sanitation project (Dickin et al., 2020).

To reflect the conditions that CBS projects are operating in, the draft methodology accounts for unsafe sanitation practices for the baseline scenario. The next paragraphs elaborate on this assumption in the context of carbon methodologies. In the methodological framework for carbon crediting, only managed and unsafe baseline processes are assumed (UNFCCC, 2021b). This principle entails assumptions about what technology or process the baseline would be upgraded to if it were to adhere to regulations and standards. Such assumptions would facilitate emission calculations due to more scientific foundation for specific managed wastewater treatment facilities (UNFCCC, 2017a).

There is no straightforward assumption regarding a potential safe sanitation system that the population would or should be upgraded to in a place currently without access to safe sanitation. Assuming centralized wastewater treatment plants might be far-fetched in many low- and middle-income regions (Tayler, 2021). Assuming on-site containment with faecal sludge management might be an option, but as established in paragraph 3.1.2 decentralized sanitation solutions are currently not covered in carbon methodologies. Moreover, such assumptions would have contradicted the objective of the current work to estimate GHG savings of CBS projects as realistically as possible. As stated in the previous paragraph, the primary goal of CBS is to replace unsafe sanitation. This goal was formulated as one of the applicability conditions in the draft methodology. Consequently, the baseline considerations had to reflect the replacement of unsafe sanitation. These conditions are to incentivize CBS to focus the implementation where it is needed most. In the further development of the draft methodology, the baseline scenario could be further reflected upon to get the methodology in line with carbon crediting principles (UNFCCC, 2017a).

To show the difficulties in taking the common carbon methodology approach, the draft methodology is set in contrast to other carbon methodologies in the sanitation sector. CDM carbon projects in the sector 13 (waste handling and disposal) are looking to improve the GHG balance specific to existing (centralized) WWTPs (see paragraph 3.1.2). CBS is a modular approach, currently only partially replacing regional baseline scenarios (World Bank, 2019). The aggregate baseline scenarios that are often needed in regions with largely unmanaged sanitation show the variety of (co-existing) systems that might be replaced by CBS in LMICs (see paragraph 3.1.5). An example of a carbon project in the sanitation sector in LMICs is the provision of safe drinking water. The baseline scenario for safe drinking water entails emissions from boiling of water with combustion of wood or fossil fuels (UNFCCC, 2020). Sanitizing water by boiling is a 'best practice' that is widely applied in LMICs, even though parts of the population might be forced to use unsafe drinking water in the baseline scenario (Pickering et al., 2017). Such a uniformly applied baseline system cannot necessarily be assumed for CBS projects.

4.1.2 Revision of Boundaries

The CBS project as a safe sanitation service needs to ensure transformation of excreta for safe disposal or reuse following the collection of excreta containers (Ritchie & Roser, 2021) (see 'applicability conditions' paragraph 3.1.3). Application of the end-products is a separate GHG savings project and separate baseline scenario, i.e. the replacement of alternative products, and is thus not covered in the draft CBS methodology. A methodology for end-product application complementing the draft CBS methodology would need to take into account the product characteristics, application pathways and resulting emissions. For soil conditioner production such as compost or biochar, carbon sequestration might lead to negative emissions and partially replace synthetic fertilizers (Baldi et al., 2010), but the magnitude of these processes are the topic of a separate ongoing debate (Jeong et al., 2019). However, a carbon methodology for the application of biochar has recently been developed and is under review (Etter et al., 2021).

The draft methodology excludes public or shared facilities. Literature often distinguishes between shared facilities (public) and household facilities (Prasad et al., 2021; Ward et al., 2021). Emission factors for shared facilities are available and their inclusion in the draft methodology was considered. The decision to exclude shared facilities is in line with the applicability condition that CBS provides a safely managed sanitation service. Shared facilities are considered a limited service and thus not safely managed (Ritchie & Roser, 2021). However, shared facilities were preliminarily included in the sensitivity analyses within this work, and the draft methodology is formulated such that they can easily be amended. There could be a need for this amendment if the public toilets are the only feasible (short-term) option (Tidwell et al., 2020), or if a CBS toilet implemented in a household replaces the need of that household to use existing public toilets. Implementation of public toilets is the case in some CBS projects (CBSA, 2018).

It is assumed that in unsafe sanitation services and systems CH_4 in biogas and other gases escape to the environment without flaring or recovery (see paragraph 3.1.5). Firstly, excluding safe baseline options ensures that there is no overlap with existing carbon projects, such as the recovery of CH_4 from wastewater treatment plants (UNFCCC, 2019). Secondly, the replacement of existing safe sanitation solutions with a CBS solution is not regarded as a realistic scenario at this moment (Coates & Gray, 2021). Thirdly, the replacement of safe sanitation solutions should not be incentivized, regardless of potential additional GHG emission savings with CBS. If the need for considering safe sanitation pathways in the baseline should arise, the draft methodology could be extended to subtract the amounts of recovered GHG and amend more sanitation categories and emission factors.

In CBS projects where excreta is handled in external treatment facilities transformation emissions would not be ascribed to the CBS project in order to avoid double counting of emissions in the carbon crediting scheme (Gold Standard, 2021). Ownership of GHG emissions and savings goes to the project that is in control of the respective activity (DIN, 2019). This ownership needs to be clarified to ensure that the necessary emissions for excreta transformation are accounted for (Gold Standard, 2021). The project auditing might require checking activities outside of the quantification boundaries, depending on where ownership of respective carbon credits lies (del Valle Rosales, 2021; DIN, 2019). Defining potential quality checks was outside of the scope of the draft methodology.

4.1.3 Source-Separated Urine

Urine was included as an input to both the baseline and the CBS project. In the baseline, urine and faeces are not separated. To account for the nitrous oxide emissions from excreta, the nitrogen content was the key parameter to determine. Rose et al. determined that 85% of the nitrogen content of combined excreta originates from urine, mainly from urea (Rose et al., 2015). To make it more widely applicable, the draft methodology enables application for CBS projects with and without source separating toilets. Total nitrogen content in excreta from non-separating toilets serves as the basis for direct N_2O emission calculation. Source separating toilets only consider the (lower) nitrogen content in faeces for the transformation.

Storage of urine entails sealed containers and no aeration (CBSA, 2018). The conditions are thus not considered favourable for biological nitrification or subsequent denitrification that cause the main share of N_2O emissions in typical biological WWTPs (Kampschreur et al., 2009). According to an LCA of urine diversion compared to conventional wastewater treatment, direct emissions from separate urine treatment are expected to be small in comparison (Hilton et al., 2021). However, further investigations are needed to assess the N_2O generation and emission from urine storage containers. In line with the general boundaries, emissions from soil infiltration of the effluent after struvite precipitation is not considered in the draft methodology. Depending on the nitrate concentrations in the effluent, there might be relevant N_2O emissions from the percolation to the ground (Rao et al., 2015). Emissions from separate urine transformation are not accounted for in the draft methodology. More work is needed to account for all N_2O emissions in the further development of the methodology.

Urine handling in a CBS project requires significant organizational effort. Collection and transport of rapidly accumulating volumes of urine is not economic, and special care has to be taken to disinfect containers in order to lower health risks (Ahmad & Gupta, 2019; Bischel et al., 2019). Urine usage as a fertilizer at the household level is possible, and CBS projects are already implementing this option, reducing collection and transport efforts (Remington, 2021). At the household level urine could be applied to soil directly or after a brief storage period, but respective guidelines regarding storage period and type of plants shall be adhered to (Schönning & Stenström, 2004; WHO, 2006). If urine fertilizer application is not in accordance with WHO regulations, the CBS project does not guarantee safe sanitation and is not eligible for registration on the carbon market as per the draft methodology (paragraph 3.1.3).

Although organic nitrogen fertilizer can potentially decrease N_2O emissions from soil compared to synthetic fertilizer, the N_2O emissions following from urine or urea application could be significant (Aguilera et al., 2013; Marsden et al., 2018; Siqueira Neto et al., 2016). The draft methodology does not account for these emissions, because infiltration to soil at the household level is regarded as application of the product 'urine fertilizer' and thus not within the draft methodology boundaries.

4.1.4 Emission Quantification: On-Site Sanitation

Moisture Content and Anaerobicity

For the draft methodology, substantial simplifications had to be made for on-site sanitation systems. Aggregation of the large variability of sanitation systems was necessary to allow for practical application of the draft methodology. The pit latrine categories in the draft methodology are distinguished, inter alia based on water content (see Figure 6). Water content is reflected in the emission calculation via generic emission factors for the respective categories. It has been reported that increased water content in pit latrines and less contact to air increase anaerobicity (Couderc et al., 2008; Foxon, 2008). Factors that influence the oxygen content during biological waste degradation essentially affect the percentage generation and amount of GHG (Kulak et al., 2017). There is still some debate about the degree of anaerobicity in pit latrines in general (Bourgault et al., 2019; van Eekert et al., 2019a, 2019b). The ranges of possible CH_4 and N_2O emission factors as assessed from literature are large and the resulting overall GHG emissions from on-site containments are especially sensitive to the uncertainty in CH_4 emission factors (section 3.3). Comprehensive sensitivity analyses show that the CH_4 emission factor in containment sites has a key influence on the overall emissions, contributing up to 93% (see Figure 12).

Lining is identified by the SFD Promotion Initiative as a criterion to distinguish pit latrines in excreta flow diagrams (SFD Promotion Initiative, 2018a). Lining not only adds stability to the pit, but also prevents leakage of faecal sludge to the ground and possibly the groundwater, if watertight. In unlined pit latrines urine and flush water might percolate into the ground (Figure 6 in paragraph 3.1.5) Unlined pit latrines below the groundwater table might on the one hand have a higher water content regardless of flush water use and thus a higher ascribed CH_4 emission factor, which increases CH_4 emissions. On the other hand, more organics could be washed out due to groundwater flow, which counteracts the extent of CH_4 emissions (Chuah & Ziegler, 2018; Graham & Polizzotto, 2013). The draft methodology associates this washout with overall lower GHG emissions than comparable categories (lined) without washout (see Figure 12 in paragraph 3.3.2). For unlined pit latrines above the groundwater table, the discharge of additional water might be the determining factor for washout and anaerobicity conditions and thus, two subcategories are distinguished based on flush water use (see Figure 6). Lined pit latrines are assumed watertight and no percolation or interaction with groundwater are considered here.

The quantification model does not account for percolation of nitrogen to the ground (see paragraph 3.1.6). Further research is needed on the percolation of faecal sludge and the associated N_2O emission pathways.

These emissions from the ground might be significant due to possible soil conditions that allow alternating nitrification and denitrification (Kampschreur et al., 2009; Rao et al., 2015). N_2O emissions from prevalently anaerobic on-site sanitation containments have been estimated to be low (Doorn & Liles, 1999). However, the calculations in Figure 12 show that N_2O contributions are low (7 – 20%) but not negligible with the default assumptions of the draft methodology.

Filling Rates

Steady state excreta production and degradation processes are assumed for simplicity in this work. Filling rates are currently not directly included in the draft methodology, but faecal sludge amounts have to be estimated by the project proponent via estimated containment volumes and emptying frequencies (see paragraph 3.1.6). There are ongoing efforts trying to quantify filling rates (Prasad et al., 2021; Strande et al., 2021). Filling rates are variable and complex, as they depend on the construction method, local conditions such as precipitation or groundwater table, which affect washout and percolation to the ground, as well as manner of usage, e.g. if the containment serves as a public facility (Still & Foxon, 2012). These conditions affect the degradation rate of excreta, which in turn affects contents of containments.

Changara et al. measured organics concentrations in faecal sludge from the uppermost layers of almost full pit latrines that had been in use for 1.5 to 5 years. Results indicated, that the organics concentrations might be higher for older pit latrines, which could indicate that degradation is smaller in older containments (Misi et al., 2018), and possibly more anaerobic. On-site containments are simplified as black boxes with steady state conditions due to long residence times. The assumption is that residence times in containments in the target regions of CBS are at least one year (Chowdhry & Koné, 2012). Degradation rates – and thus possibly GHG generation – vary in on-site containments with depth and sludge age (Foxon, 2008). Faecal sludge layering is neglected with the black box assumption. The contribution of emissions from remaining biodegradable material at the bottom of the containment might not be as significant as the readily biodegradable input from fresh excreta daily (van Eekert et al., 2019a). Major parts of organics degradation might happen in the top layer within the first month after excreta production, where oxygen supply is larger (Bourgault et al., 2019).

In future development of the draft methodology, considering filling rates might contribute to a more accurate reproduction of the complex conditions in on-site containments. Assuming a filling rate based on literature values (e.g. (Strande et al., 2021)) does not account for degradation and emission processes. Detailed analyses of accumulation and degradation of faecal sludge in on-site sanitation could increase the assessment efforts for the project proponents, as parameters like the sludge accumulation are not linear with time and difficult to estimate (Still & Foxon, 2012; Velkushanova et al., 2021).

The quantification model does not connect excreta input to faecal sludge accumulation. Emptied faecal sludge is already partially degraded in on-site containments and organics and nitrogen concentrations are lower than in fresh excreta, which has a buffering effect on sensitivity of the overall emissions to parameters in the containment or the disposal sites (see paragraph 3.3.2). The influence of reduced biodegradability of older faecal sludge is not quantified. Even though degradation of old faecal sludge might be lower, and thus less GHG emissions might occur. The baseline quantification model could be improved by connecting input loads to filling rate and thus faecal sludge removal.

Septic Tanks

Emission calculations for the on-site sanitation category septic tank integrate outflow of nitrogen (85%) and organics (37.5%) according to IPCC Guidelines. The septic tank CH_4 emission factor is lower than the recommendation in IPCC Guidelines (Evans, 2021). The draft methodology assumes that CH_4 emissions from effluent soil infiltration are negligible (Truhlar et al., 2016). Further investigations of the outflow CH_4 emissions from the septic tank could be needed. N_2O emissions from soil infiltration are quantified but were found to be insignificant to overall emissions (see Figure 12). Emissions from septic tanks with outflow to a dispersal field were around 260 kg CO_2-eq per toilet unit shared by five people per year (Figure 12). Truhlar et al. measured higher overall emissions from septic tank systems, amounting to 690 kg CO_2-eq for five people per year. Compared to this and other studies, the draft methodology underestimates overall emissions from septic tanks (Diaz-Valbuena et al., 2011; Huynh et al., 2021; Truhlar et al., 2016). If removal of organics and nitrogen via the effluent are not considered, the estimate for overall GHG emissions is higher (440 kg CO_2-eq per year). Similarly to scenario analyses conducted for aerobic WWTPs, emissions from faecal sludge disposal are relevant for overall septic tank emissions (see paragraph 3.3.2). Assessment of the real situation by the project proponent is paramount.

Additional Factors for Characterization

The influence of other parameters such as temperature and pH value, pit additives and cover materials could not be considered. The effect of pit additives on the degradation is debated in literature (Appiah-Effah et al., 2020; Bakare et al., 2015): while Bakare et al. do not observe any effect of pit additives on the faecal sludge, Appiah-Effah et al. report significant reduction of faecal sludge, organics and pathogens. Such a reduction might lead to decreased GHG emissions because faecal sludge is already chemically degraded, and microbial activity could be limited due to possible changes in pH value. faecal sludge can also be stabilized with addition of lime minerals (Greya et al., 2016; Valderrama et al., 2013). However, these effects are currently not quantified reliably to support calculation of GHG emissions and are thus excluded from the draft methodology.

Cover materials such as sawdust or charcoal are primarily used to limit odour emissions but they also have a drying effect on pit contents (Semiyaga et al., 2018). Drier materials lower anaerobicity and might also decrease CH_4 emissions (Tilley et al., 2014). These effects were not translated into concrete numbers within this work and are excluded from the draft methodology (see also discussion above on 'moisture content'). As additives are common practice in many regions, their effect on degradation of excreta and emissions needs to be investigated further and integrated in the CBS methodology.

Extreme pH values and low temperatures limit the activity of microorganisms. Influence and limitation of microbial activities due to these factors were not considered. The degradation rate typically increases with higher temperatures (Tchobanoglous et al., 2014). Strong limitations due to low temperatures are not expected in the operating regions of the known CBS projects.

4.1.5 Emission Quantification: Treatment Plants

Treatment or Disposal

Existing methodologies for WWTPs often have anaerobic lagoons or shallow lagoons in the baseline scenario. CDM methodologies AMS-III.I and AM0080 adjust the CH_4 emission factor for temperature variations and depth of the lagoon with aggregation of monthly factors (UNFCCC, 2009, 2019). Part of the assessment efforts are shifted to the project proponent as not all parameters can be quantified with default values. Such detailed assessment was not in line with the objective of the current work to minimize measurement and assessment efforts for the CBS project and was outside of the scope.

Treatment plants for wastewater or faecal sludge control anaerobicity to a certain degree. If generated biogas passes through aerobic layers, the oxygen present may reduce CH_4 to CO_2 (McNicol et al., 2020). For intentional anaerobic treatment, closed reactors with high residence times can be employed (Madikizela et al., 2017). Aerobic degradation is generally more effective and faster but needs more energy input for aeration than anaerobic digestion (McCarty, 2018). Wastewater ponds or similar constructions can vary in depth, increasing anaerobicity with increasing depth to surface ratio (Hernandez-Paniagua et al., 2014). Furthermore, plants can be added to drying beds or waste wetlands to improve the circulation of oxygen, decreasing CH_4 emissions (Tilley et al., 2014).

Assumptions for anaerobicity of wastewater discharge sites were addressed in section 3.3 assessing the variability and sensitivity of the CH_4 and N_2O emission factors, reflecting the range of possible anaerobicity in the respective system. Where faecal sludge or sewage accumulates in the environment, oxygen content usually decreases and thus the CH_4 emission factor is higher. In contrast, open defecation in open spaces leads to scattered excreta or faeces, which poses a risk for human health, but is not associated with high levels of CH_4 emissions (paragraph 3.3.2), as degradation is assumed to be mostly aerobic (WINROCK, 2008). The overall emissions for pit latrines with faecal sludge disposal in the environment do not vary linearly with changes of disposal site emission factors, because the containments serve as a buffer in the quantification model.

The CH_4 emission factors for water bodies are comparatively low. This might be associated with larger dilution of organics and nutrients as well as reduction of generated CH_4 to CO_2 in upper layers of water bodies, where oxygen levels are higher. Distinctly, eutrophic and lentic water bodies are associated with a higher CH_4 emission factor. Ascribed N_2O emissions are higher in systems where higher conversion rates of nitrogen via nitrification and denitrification are expected, i.e. sanitation systems that are more aerobic are usually associated with higher N_2O emissions (McNicol et al., 2020). However, sufficient aeration can transform generated N_2O into N_2 gas (Kampschreur et al., 2009). In turn, anaerobic systems inhibit nitrification. Denitrification might thus be limited by the small amount of nitrate present. For rivers, only small nitrous oxide emissions were considered in adherence IPCC Guidelines (D. Bartram et al., 2019). Several studies have concluded that rivers that are subject to organic waste discharge might cause considerable emissions of N_2O (McMahon & Dennehy, 1999; Yu et al., 2013).

Aerobic WWTPs

Aerobic treatment plants typically need more maintenance and operational efforts than anaerobic treatment, which leads to a more complicated quantification model (paragraph 3.1.6). The draft methodology considers a more detailed analysis for aerobic WWTPs to approximate real conditions better and adhere to IPCC Guidelines. A drawback is the increasing assessment effort for WWTPs. The project proponent must estimate the real amounts of sludge organics removed per influent load. Furthermore, the percentage removal of organics and nitrogen and resulting residual effluent loads should be estimated to allow for a more accurate result (paragraph 3.3.2). CH_4 emissions from overloaded biological treatment were modelled to be ten times higher than for a well-managed facility.

Since the current work did not focus on the assessment of WWTP emissions, the draft methodology as well as the baseline calculation for the Mosan social enterprise rely heavily on IPCC Guidelines on organics and nitrogen removal and simplified secondary sludge calculations (see paragraph 3.2.5). Another limitation of the draft methodology is that only CH_4 emissions are considered from the secondary sludge handling. Secondary sludge handling in LMIC settings might entail relatively aerobic conditions, e.g. in scattered drying beds or in direct application to soil (Liu et al., 2017; National Research Council, 1996), and thus also more N_2O emissions. The draft methodology would in this case underestimate real N_2O emissions. Other considerations for N_2O emissions (from the biological treatment and the effluent) are analogous to the above discussion in 'treatment or disposal'.

The scenario analysis (paragraph 3.3.2) revealed that there are high uncertainties in the GHG emission calculation of aerobic WWTPs. If the real conditions (effluent quality and sludge removal) are not estimated accurately in the baseline assessment, resulting emissions could involve high uncertainties.

4.1.6 General Assumptions

In this work, the established quantification approach with input-based emission factors is chosen instead of more accurate but more complex emission estimates, such as the assessment of the biomethane potential or direct emission measurements (Palaniswamy et al., 2013). Firstly, assessment and measurement efforts can be simplified for the project proponent by providing default values. Secondly, adherence to established methods in the development of a new methodology increases the chances of acceptance. Lastly, it is also a way of standardizing GHG emission quantifications within and across sectors and thus allows for better comparability of the results. Using local values or measurements is always stated as the preferred option in the draft methodology and could significantly increase the accuracy of estimated emission savings.

Obtaining organics loads from wastewater treatment influent or faecal sludge, as required in other methodologies (e.g. (UNFCCC, 2019)) might include the contribution of other sources, such as organic household waste or greywater. The approach taken in the draft methodology – using literature values for excreta – ensures that the real benefits of CBS implementation are not distorted by different bases for human waste per person, i.e. that the units for which open degradation is avoided correspond with units treated in CBS. Using default values for per person production allows to scale calculations with each new project participant and avoids measurement campaigns of wastewater and faecal sludge during the baseline assessment. IPCC Guidelines use a more detailed calculation of nitrogen in wastewater, based on factors of protein consumption per person (D. Bartram et al., 2019). This approach requires more data. The draft methodology uses nitrogen production per person (analogous to organics production), an approach applied in other current research (Evans, 2021). Uncertainties coming from the default assumption of input loads could be mitigated with the characterization of collected material before the CBS transformation process. The draft methodology states this as a recommendation. Excreta production and the composition of urine and faeces is largely influenced by diet and is a significant source of uncertainty (Rose et al., 2015) (see paragraph 3.3.3).

For simplicity, the same input loads of organics and nitrogen are used in open defecation, even though urination and defecation might not happen at the same sites. Furthermore, interactions of urine and faeces might be less pronounced and thus, separate faeces and urine could degrade differently than excreta mixed together in on-site containments or sewers. However, investigation of these intricacies was outside the scope of this work. They could be addressed by using separate emission quantifications for urine to soil (Marsden et al., 2018) and for mostly aerobic degradation of faecal matter (WINROCK, 2008).

Another underlying assumption of the draft methodology are the global warming potentials for a 100-year time horizon (GWP_{100}) used to compare greenhouse gases (paragraph 2.1.5). They are based on GWP_{100} values with consideration of climate-carbon feedbacks. These values are a bit higher than conventional GWP_{100} that assume linear climate response to GHG emissions (Myhre et al., 2013). Testing different assumptions of GWP_{100} values for the conversion of GHG emissions was outside the scope of this work. Assuming lower GWP or other time horizons would decrease the effective CO_2-equivalent emissions of CH_4 and N_2O. However, the approach to consider climate-carbon feedback loops in GHG emission projections is regarded as increasingly critical considering the global climate crisis (Gasser et al., 2017).

4.1.7 Uncertainties and Limitations

A known error in the model is that emptied amounts of faecal sludge from on-site containments can be higher than input to the containment, because due to simplicity in assessment, calculation of emptied faecal sludge is not linked to the input parameters. The Excel calculator includes a barrier that emissions from the pit latrine are set to zero if assumed emptying exceeds the theoretical contents, and the emptied faecal sludge components are not higher than input in the subsequent faecal sludge pathway. Such conditions do not reflect reality, in that there would be emissions from pit latrines even if they are emptied as regularly as once a year.

In the sensitivity analysis in Excel possible ranges of baseline emission outputs were assessed. Section 3.3 shows the uncertainty of model outputs due to the uncertainty in the default parameters chosen for the draft methodology. Default values might not always reflect reality, particularly if they are based on "author judgement" in IPCC Guidelines and no measurement. Pre-emptive verification of these values was attempted in the course of a literature study, as well as in gathering information from one of the authors of the 2019 Refinement to the 2006 IPCC Guidelines for wastewater (D. Bartram, 2021). However, there is little scientific evidence, in particular for GHG emission factors from on-site sanitation. Values for the characterization of faecal sludge (concentrations and amounts of organics and nitrogen) are more explored but are variable between systems and dependent on many external conditions.

Uncertainty and variability in construction and functionality of sanitation systems are especially pronounced in LMICs (Tayler, 2021). Approximations and simplification were necessary in defining the categories of sanitation systems and ascribing default values. To increase accuracy of baseline emissions, measurements or local data are always the preferred option. However, this increases baseline assessment efforts for the project proponent. In the baseline assessment, difficulties and decisions of the project proponent to categorize sanitation systems according to the draft methodology lead to further uncertainties.

External factors like climate and the weather influence degradation. These external uncertainties remain even when the correct approximations in the baseline assessment have been found. Nonetheless, testing of the model robustness might also account for parts of the inaccuracy pertaining to simplifications and external influences.

Emission factors and excreta characterisation can vary in large ranges due to a lack of data and the variability of characterization. This has significant effects on the overall baseline emissions, entailing unreliability of the calculated emission savings. All these uncertainties could justify multiplication of all baseline emissions by a factor of 0.84 to 0.94, as is done in existing methodologies (AM0080, AM0039, AMS-III.I). Such a factor should be introduced in the further development of the CBS methodology as a conservativeness factor. Conservativeness is one of the principles of carbon crediting, that ensure high-quality carbon offsets (Broekhoff et al., 2019).

Mostly direct baseline emissions are discussed within this report, as a methodological gap was identified regarding a baseline methodology for unsafe sanitation. Quantification and monitoring for processes that are referenced in the draft methodology, especially fuel use in emptying and transport during faecal sludge management as well as in baseline treatment plants might be costly for the project proponent. These efforts have not been a focus of the current work and need to be assessed in detail for comprehensive quality control of the calculated emission savings. Furthermore, there was no in-depth analysis of the project transformation modules within this work. However, most of these processes are better explored than GHG emissions from on-site sanitation and were based on the existing methodological framework. Uncertainties are assumed to be smaller than for the baseline quantification due to more established knowledge of transformation processes. Furthermore, monitoring of certain parameters during the project registration is more viable compared to measurements of baseline options, and accuracy of resulting project emissions could be increased feasibly with measurement of project parameters (del Valle Rosales, 2021).

4.2 Case Study: Mosan Social Enterprise

4.2.1 Emission Mitigation Potential

The calculated emission savings in the case of the Mosan system were 370 kg CO_2-eq per unit (5 people) per year. Previous work on other CBS projects indicates emission savings of 34 – 243 kg CO_2-eq per person per year (Harroff et al., 2019; Montgomery et al., 2020). The estimation for Mosan's emission savings is at the lower end of that range on a per person basis. In contrast to Harroff et al., the current case study did not involve transport emissions. However, transport emissions are not estimated to be significant for overall CBS project emissions (Montgomery et al., 2020). Harroff et al. included emissions and potential emission savings from end-product application to soil. Furthermore, they considered food waste disposal in addition to excreta, as certain CBS projects involve co-processing of these waste streams. The emission savings calculated for the Mosan system are highly uncertain, pertaining to uncertainties in assumptions that were taken in the development of the draft methodology, as well as in its application. The categorization of sanitation systems is limited by availability of information. The emission outputs from the baseline calculator could not be verified with measurements in Mosan's project region. The emissions of the aerobic treatment plant are sensitive to the chosen input parameters, as the scenario analysis of the aerobic treatment plant (paragraph 3.3.3) has shown. Field measurements at the WWTP as well as of collected faeces could increase the accuracy of emission savings calculations.

The transformation process and its efficiency are relevant for the potential emission savings (see paragraph 3.2.6). In the Mosan system, the current annual fuel use to start up pyrolysis causes about 90 kg CO_2 emissions per five people. As emphasized in Strande et al. (2019), faeces should be dry enough (70 – 90% dry solids content) to lower energy consumption of pyrolysis (Strande et al., 2019). Studies indicate that source separated faecal matter consists of 25 – 30% dry solids, which is 15 – 25% more than the solids content of excreta (Getahun et al., 2020; Rose et al., 2015). In the Mosan system, faeces are pre-dried with recirculated heat from the pyrolysis, increasing the dry solids content. The Mosan social enterprise is currently upgrading the pyrolysis reactor to use less fuel. Prospectively, emissions from auxiliary energy use could further be decreased by using alternative fuels or renewable energy sources. Interesting work has been done by the University of Colorado Boulder that uses concentrated solar power to pyrolyze faeces (Ward et al., 2014).

Optimizing the transformation process entails ensuring the quality of the produced biochar for soil amendment. The importance of the peak temperature in pyrolysis on the stability of the produced biochar has been mentioned in previous work (Manyà et al., 2018; Ward et al., 2014). The stability of biochar is important to decrease the risk of further emissions and ensure its persistence in soils. Persistence of emission savings is one of the principles of high-quality carbon offsets (Broekhoff et al., 2019). Persistent and inert end-products adhere to the applicability conditions in the draft methodology (paragraph 3.1.3) and ensure safe re-use of end-products, which is a criterion for safe sanitation. Biochar application is a further potential source of revenue for the Mosan social enterprise. Ensuring permanence of biochar has a significant role in prospective auditing for a carbon project on biochar, according to the VCS methodology on biochar application that is currently under global stakeholder review (Etter et al., 2021).

4.2.2 Outlook for Carbon Crediting

Registration of the Mosan project on the carbon market would require different methodologies from three main areas: 1) Avoidance of GHG emissions from replacement of unsafe sanitation solutions (draft methodology); 2) application of biochar to soil (VCS methodology under review until September 9, 2021 (Etter et al., 2021)); and 3) application of struvite or another urine-derived product to soil to replace synthetic fertilizer and soil conditioner. For part 3, no methodology has been developed, but emission savings could primarily come from replacement of alternative fertilizer production, as has been shown in an LCA on the topic (Hilton et al., 2021).

Registering a project under a carbon standard entails a one-off expense for registration as well as annual auditing costs. Figure 11 in paragraph 3.2.7 shows that increasing Mosan's CBS service size is needed in order to cover such costs. The benchmark service size that would make carbon crediting profitable depends on the carbon credit price. Currently, this price is estimated at around USD 7 – 8 (del Valle Rosales, 2021; Holder, 2021). There are several arguments that would justify higher prospective prices for CBS carbon credits. Apart from climate benefits, CBS entails social, health and environmental benefits by providing a dry sanitation service to replace unsafe and poorly-managed sanitation options (J. Bartram et al., 2018; Smith, 2020). Furthermore, emission avoidance due to discontinued usage of pit latrines or other sanitation solutions is permanent. Permanence and diverse benefits related to sustainable development can increase the value of carbon credits and mobilise climate financing by impact investors (Greiner et al., 2019). Other revenue streams are needed to achieve increasing the service size to the required benchmark.

Eventually, there are two appropriate carbon programmes for registration of a CBS project with an aggregate baseline (del Valle Rosales, 2021). With a project design document (PDD) a new baseline assessment and demonstration of additionality would be necessary if Mosan expands its system to new geographical regions. This is associated with additional efforts and costs. The second option would be to register a Programme of Activities or a master PDD, where a wider baseline is assessed initially and expansion to a new geographical region would not require a new baseline assessment (UNFCCC, 2021a).

4.3 Potential of Container-Based Sanitation

The potential for climate benefits of CBS is in the avoidance of GHG emissions from on-site sanitation systems and uncontrolled degradation in the environment. As was established in paragraph 3.3.2, large parts of GHG emissions from baseline sanitation are pertaining to CH_4. This is in line with previous studies (Doorn & Liles, 1999; Pan et al., 2016; Reid et al., 2014; Truhlar et al., 2016). According to the Sixth Assessment Report of the IPCC, CH_4 emissions are related to one quarter of the 1.1 °C global warming above pre-industrial levels so far (IPCC, 2021). CH_4 emissions are relevant for global warming, with wastewater identified as one of the key contributors to anthropogenic CH_4 emissions (Saunois et al., 2020). CH_4 has a high global warming potential and is relatively short-lived compared to CO_2 (Myhre et al., 2013). Cutting CH_4 emissions could therefore have more immediate benefits than other GHG savings. This establishes that CBS has the potential for positive near-term climate effects. N_2O emissions have rarely been mentioned in studies on on-site sanitation. In prevalently anaerobic degradation systems, N_2O emissions are often assumed to be minor, in literature as well as in carbon methodologies (Doorn & Liles, 1999; Truhlar et al., 2016; UNFCCC, 2009). Due to the high global warming potential of N_2O, its contribution to overall GHG emissions might not be negligible (Daelman et al., 2013). Considering N_2O emissions expands the feasibility of carbon crediting for CBS projects to replacing open defecation or other partially aerobic but unsafe baseline sanitation pathways (see also paragraph 3.3.2).

Since the transformation processes and aggregate baseline scenarios differ significantly between CBS projects worldwide, overall real emission savings cannot be easily estimated (Harroff et al., 2019). Currently, at least 1 billion people use pit latrines worldwide (Graham & Polizzotto, 2013; Strande, 2014). For an extrapolation of the potential of emission savings in the CBS sector, a pit latrine of category 2 (lined, has never been never emptied) is assumed (Figure 6) and no faecal sludge emptying is considered. Figure 12 in paragraph 3.3.2 shows estimated annual baseline emissions of 524 kg CO_2-eq per unit shared by five people. With assumed project emissions as established for the Mosan system in paragraph 3.2.6, approximately 434 kg CO_2-eq per year could be mitigated by replacing the pit latrine used by a household of five with a CBS toilet. If a CBS service could be provided to just 10% of the 1 billion people using such pit latrines, the draft methodology approximates potential annual emission savings of around 8.7 Mt CO_2-eq. This equates to emission savings that would originate from reducing the passenger car fleet by 1.9 million cars, assuming typical annual CO_2 emissions of 4.6 t per car per year (EPA, 2018).

The estimation of the emission mitigation potential of CBS is substantial. Climate financing could be one of the tools to gain revenue in CBS (Dickin et al., 2020; Montgomery et al., 2020; Russel et al., 2019). However, financing should be based on a broad range of revenue streams (J. Bartram et al., 2018; Dickin et al., 2020). The demonstration of additionality and auditing thereof can be costly but is necessary (del Valle Rosales, 2021). Previous failures of the carbon market under the Kyoto protocol to achieve additionality and permanence of carbon offsets led the collapse of the carbon credit prices and with it the failure in emission reductions and reaching the climate goals (Dufrasne, 2020; Galatowitsch, 2009). With Article 6 of the Paris Agreement, an attempt is being made to modify the carbon markets and standards, so that the climate goals set for this century can be reached (Greiner et al., 2019; Michaelowa et al., 2019; UNFCCC, 2015). Currently, carbon credit prices on the (voluntary) carbon market are expected to increase, especially for projects entailing significant social and environmental benefits (Holder, 2021). Carbon credit revenue could still be an unreliable revenue stream due to fluctuating carbon prices and the ongoing changes in the carbon markets (Dufrasne, 2020; Greiner et al., 2019).

The draft methodology is currently only applicable to CBS projects. There exist many other decentralized sanitation solutions in LMICs that minimise contamination of living spaces with excreta and wastewater: Valuable efforts are made to provide emptying and treatment services for faecal sludge from pit latrines (Greene et al., 2021; Peletz et al., 2020; Yesaya & Tilley, 2021). Other innovative projects provide safe sanitation with composting toilets and biogas toilets (Crossweller, 2021; Madikizela et al., 2017; Mutai et al., 2016). Going forward with the development of a carbon methodology for sustainable decentralized sanitation solutions, the draft methodology should be expanded and generalized to include different projects delivering safe sanitation services (del Valle Rosales, 2021). In this expansion, the baseline methodology for unsafe sanitation is a key common denominator.

5 Conclusion and Outlook

A draft methodology was developed that serves as guidance to quantify and monitor GHG emission savings of CBS projects worldwide. To answer the research questions, the following conclusions can be drawn:

1. Anaerobic degradation in baseline sanitation systems causes significant CH_4 emissions. Contribution of N_2O is generally smaller but can be relevant in more aerobic systems.
2. To assess the GHG mitigation potential of CBS, avoided emissions from degradation in the entire (unmanaged) baseline sanitation scenario are considered. The transport of containers and excreta transformation are inherent to CBS projects and associated emissions are accounted for.
3. The quantification of GHG emissions is based on the broadly accepted approach of IPCC Guidelines for National Greenhouse Gas Inventories, complemented with default parameters derived from a sound scientific literature assessment.
4. Providing default parameters reduces measurement and monitoring efforts for the project proponent.
5. The Mosan CBS system can mitigate GHG emissions and provides a safe sanitation service in a region with numerous barriers to the implementation of managed sanitation solutions. In the first instance, additional funds and revenue streams are required to increase the service size of the Mosan system. Due to relatively high fixed costs, potential carbon crediting is only profitable when a larger service size is reached, and different revenue streams are needed.

Safe sanitation is one of the key targets in global sustainable development. Emission quantifications in the sanitation sector in low- and middle-income countries with few managed and safe sanitation services entail large uncertainties. Further research is needed on GHG emission factors for on-site sanitation in particular. This could improve the accuracy of standardized emission quantifications in the context of a carbon methodology. There is ongoing research in this area, assessing the significance of GHG emissions from sanitation systems. Moreover, coverage of climate financing for sustainable sanitation at the World Water Week conference 2021 showed that global awareness of and interest in these issues are rising.

More work is needed to eventually unlock carbon crediting for the CBS sector and sustainable sanitation services in LMICs in general. The draft methodology is the first step in this process. It will serve as a foundation for a carbon consulting company to conduct a feasibility study on carbon crediting for sustainable sanitation projects. Subsequently, an official methodology needs to be developed. Therein, the draft CBS methodology needs to be extended to include other safe and sustainable sanitation solutions, and elements that currently differ from the consistent framework of a carbon standard will need adjusting. With the prospective authorization of an official sanitation methodology under a carbon standard, CBS projects that have reached a certain service size could become eligible for carbon crediting. The whole process could take up to two years. In eventually creating revenue from their inherent GHG emission savings, sustainable sanitation services in LMICs could accelerate expansion of the service distribution. Mitigation of financial constraints in the sector of safe sanitation is necessary to fulfil the UN Sustainable Development Goal 6.2: Providing safe sanitation services to everyone until the year 2030.

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Appendix

A. Baseline Sanitation

A.1 Usage of Unsafe Sanitation

An aggregation of SFD reports in South East Asia, Africa and Latin America shows the widespread use of on-site sanitation (OSS), and the overwhelming percentages of unsafe sanitation. From 23 SFD reports (one city per country in Africa and Latin America where several were available, one each for Vietnam and Cambodia), approximately 2/3 of sanitation practices are unsafe.

Usage of on-site sanitation containment systems is called unsafely managed if excreta is not safely contained or safely treated off-site in accordance with guidelines for on-site sanitation (Ritchie & Roser, 2021). This involves access to a sanitation facility, that prevents user contact with human excreta. By the year 2020, still 6% of the global population lacked access to any sanitation facility. Local or larger-scale absence of any sanitation infrastructure is primarily observed in LMICs, where people may resort to open defecation. Direct disposal of excreta in the open environment or directly polluting water source poses a risk to human health and the environment. Hanging toilets involve a toilet or latrine structure but are built above water bodies into which excreta are discharged directly, which has the same effect on the environment as open defecation.

Sewered sanitation is not intrinsically well-managed. In locations where governmental regulations and funding are lacking, sewers might lead directly into water bodies or open spaces on land. If transport water is not sufficient to convey excreta or if other wastes are deposited in (open) sewers and block the conveyance, stagnant puddles could occur in the sewer itself (Doorn & Liles, 1999).

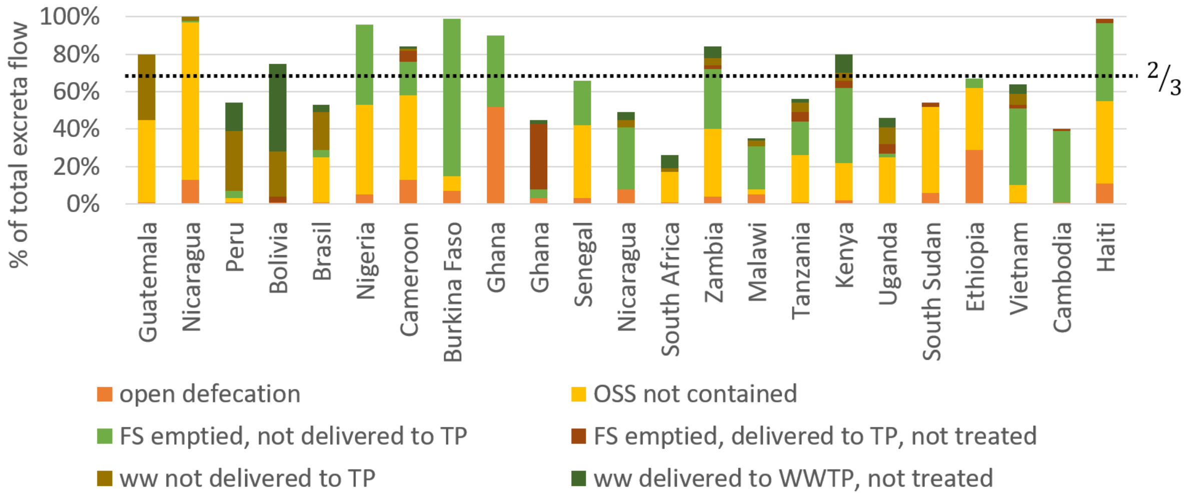

Figure 14: Overview of unsafe sanitation usage in 23 cities exemplarily selected from countries with available SFD reports Africa and Latin America, Vietnam, Cambodia and Haiti, in percentage to overall sanitation systems. An average of 2/3 unsafe sanitation usage is observed here. (OSS: on-site sanitation; FS: faecal sludge; ww: wastewater; TP: treatment plant; WWTP: wastewater treatment plant). Information based on Excreta flow diagrams (SFD) from Lake Atitlán, Guatemala, Bilwi, Nicaragua, Lima, Peru, Tarija, Bolivia, Manaus, Brasil, Eket, Nigeria, Duala, Cameroon, Ouahigouya, Burkina Faso, Wa, Ghana, Bignona, Senegal, Managua, Nicaragua, Durban, South Africa, Lusaka, Zambia, Kasungu, Malawi, Dar es Salaam, Tanzania, Mavoko, Kenya, Kampala, Uganda, Yei, South Sudan, Bure, Ethiopia, Hanoi, Vietnam, Battambang, Cambodia, Cap Haitien, Haiti. (Basterrechea Dáz et al., 2020; SFD Promotion Initiative, 2015, 2016a, 2016b, 2016c, 2016d, 2017, 2018b, 2018c, 2018d, 2018e, 2018f, 2018g, 2018h, 2019)

Table 3: A selection of on-site sanitation systems identified from SFD reports (Latin America and Africa), and possible disposal or treatment sites of emptied faecal sludge (FS)

On-site sanitation	Discharge/treatment of FS	Source
Shallow unlined pit connected to dry latrine	-	(SFD Promotion Initiative, 2018b)
Hanging latrine with direct discharge to a water body (stream or ocean)	-	(SFD Promotion Initiative, 2018b)
Lined pit latrine with impermeable walls but open bottom connected to flush/pour flush toilet	-	(SFD Promotion Initiative, 2018b)
Sealed plastic septic tanks with discharge to soak pit and where FS is removed and buried on-site, connected to pour flush toilet	Partially buried on site	(SFD Promotion Initiative, 2018b)
Fully lined septic tank with effluent discharge to soak pit	Partially emptied and brought to lagoon treatment plant	(SFD Promotion Initiative, 2018g)
Soak pit with direct infiltration into the soil	-	(Ferráns et al., 2017)
Unlined pit latrine with no outlet or overflow	-	(Ferráns et al., 2017)
Cement lined pit latrine connected to flush toilet,	Partially emptied and treated at WWTP	(SFD Promotion Initiative, 2017)
Septic tank connected to flush toilet and discharge to soakaway	Partially emptied and treated at WWTP	(SFD Promotion Initiative, 2017)
Sealed tank (not functioning septic tanks)	Landfill	(SFD Promotion Initiative, 2016d)
Open defecation in river/channel	-	(SFD Promotion Initiative, 2016d)
Open defecation in trench (open drain or storm sewer)	-	(SFD Promotion Initiative, 2018e)
Toilet with direct discharge to open ground	-	(SFD Promotion Initiative, 2018e)
Ventilated double pit latrines with semi-permeable walls and open bottom	-	(SFD Promotion Initiative, 2018f)
Flush toilet discharging to collective sewer network	-	(SFD Promotion Initiative, 2018f)
Aqua privy (sealed septic tank)	Emptied and disposal at dumping site	(SFD Promotion Initiative, 2015)
Pit latrine where depth coincides with groundwater table; salt is added to pit when full	-	(SFD Promotion Initiative, 2019)
Chamber in mobile toilet	Disposal in stream	(SFD Promotion Initiative, 2019)
Elevated tank	Partially emptied and disposed in water body, to soil or in authorized sludge disposal site	(SFD Promotion Initiative, 2016c)

	where FS discharges directly to river	
Sealed pit latrine with hole towards water body or open drain	Flows to water body or open ground	(SFD Promotion Initiative, 2018h)
Brick lined leach pit with open bottom	FS packed into bags and disposed of in rivers, at seaside or deposit site	(SFD Promotion Initiative, 2018c)
Pit latrine with two compartments connected to flush toilet, lined compartment (watertight) and unlined infiltration compartment	FS packed into bags and disposed of in rivers, at seaside or deposit site (open dump)	(SFD Promotion Initiative, 2018c)
Pit latrine	FS unsafely applied in agricultural fields (as organic soil conditioner)	(SFD Promotion Initiative, 2016b)
Pit latrine (ventilated or simple)	Disposal in open field, lecachat to ground and rain water washoff to river	(SFD Promotion Initiative, 2016b)
Unlined tanks, semi-lined pits and not properly sealed tanks	Never emptied, discharge to soil and fluidising of pit contents in rainy season (washout to porous sub-soil)	(SFD Promotion Initiative, 2016c, 2018c)

A.2 Formal Sanitation Categories

On-Site Sanitation

A framework of technologies and definitions of on-site sanitation systems in the context of LMICs has been developed over time (Franceys et al., 1992; Gokçekuş et al., 2020; Tayler, 2021; Tilley et al., 2014). Construction and usage requirements aim at providing safe sanitation to avoid pollution of water resources and living spaces.

Table 4: On-site sanitation containment (OSS) systems identified from a framework of formal on-site sanitation solutions; Exclusion criteria for the draft methodology: Rendering a product or not pertaining to biological degradation. Sanitation systems initially excluded from the draft methodology are marked with a red field.

Sanitation System	Source	Exclusion
Single pit	(Tilley et al., 2014)	
Ventilated pit	(Tilley et al., 2014)	
Double pit (ventilated), twin pit dry system	(Tilley et al., 2014)	
Twin pits for flush toilet	(Tilley et al., 2014)	
Deep trench latrine	(Gensch et al., 2018)	
Shallow trench latrine	(Gensch et al., 2018)	
Borehole latrine	(Gensch et al., 2018)	
Shallow pit	(Gensch et al., 2018)	
Raised latrine	(Gensch et al., 2018)	
Urine diverting dry toilet: single vault or double vault	(Tilley et al., 2014)	
Urine diverting flush toilet: single or double vault	(Tilley et al., 2014)	
Dehydration vaults	(Tilley et al., 2014)	
Composting chambers	(Tilley et al., 2014)	

Cesspit	(Franceys et al., 1992)	
Septic tank	(Tilley et al., 2014)	
Anaerobic baffled reactor (ABR)	(Tilley et al., 2014)	
Anaerobic filter	(Tilley et al., 2014)	
Biogas reactor/biogas toilet	(Mutai 2016)	
Urea treatment	(Tilley et al., 2014)	
Treatment with hydrated lime	(Tilley et al., 2014)	
Lactic acid fermentation (LAF)	(Tilley et al., 2014)	
Caustic soda treatment	(Tilley et al., 2014)	
Worm-based toilet	(Tilley et al., 2014)	
Urinal	(Gensch et al., 2018)	
Controlled open defecation	(Gensch et al., 2018)	
Hanging latrine	(Reid et al., 2014)	
Bucket latrine	(Reid et al., 2014)	
Container-based sanitation	(WHO/UNICEF, 2018)	

Full On-Site Containments

Sanitation containments fill up over time. When pit latrines are full, there are two common possibilities for the sanitation system: The pit latrine can either be covered and abandoned and a new pit must be built in the vicinity, or the pit contents are emptied. A third option is ensuring that pit contents are reduced while the pit is not in use temporarily, by method of providing sufficient residence or storage time or even enhancing reduction with pit additives such as lime (as is done in certain systems in Guatemala) (Romero, 2021; Valderrama et al., 2013). A double vault is an example of a system applying this third option: One pit is filled while contents of the other are degraded until it can be reused again (Foxon, 2008). Pit emptying (option two) is a separate sanitation issue. Pit emptying is often stigmatized or illegal, or treatment of sludge is not feasible, e.g., if there is no treatment plant available within transport range (Jenkins et al., 2014; Rath et al., 2020). Emptying and transport of faecal sludge can occur either manually or with motorized pumps and trucks. The latter is usually part of a professional service (Mikhael et al., 2014).

Treatment Systems

Treatment plants for faecal sludge aim to dewater and stabilize the faecal sludge and reduce the pathogen content (Niwagaba et al., 2014). Advanced treatment plants might address nutrient management and application of treated faecal sludge to the soil (Tilley et al., 2014). Wastewater treatment plants should allow safe discharge of the effluent into water bodies (Tchobanoglous et al., 2014). The structure of the treatment plant depends on the locally defined treatment objectives. Expert maintenance, high investments and possibly auxiliary energy input are necessary to ensure operability of faecal sludge treatment plants and avoid release of pathogens to the environment (Dodane et al., 2012; McCarty, 2018; McConville et al., 2019; Tayler, 2021).

If toilets are operated with flush water and are connected to a drainage or sewer, they fall under the category of sewerage (Tilley et al., 2014).

Table 5: Treatment facilities and variations thereof

Treatment Plant	**Source**
Waste stabilization pond (aerobic, facultative, anaerobic)	(Tilley et al., 2014)
Constructed wetland (horizontal flow or vertical flow)	(Tilley et al., 2014)
Sedimentation and thickening pond	(Tilley et al., 2014)
Drying bed (planted and unplanted)	(Tilley et al., 2014)
Aerated biological wastewater treatment plant (mechanical, biological or advanced)	(D. Bartram et al., 2019)

A common treatment facility in high-income countries is aerobic treatment with separation of sludge and separate anaerobic sludge treatment (Tchobanoglous et al., 2014). Many subcategories exist. Less energy intensive and low-cost treatment options for wastewater include constructed wetlands (Koottatep et al., 2001) and anaerobic or facultative lagoons.

A.3 Choice of Containment Categories and Allocation

Definitions of Containment Categories

Table 6: Definitions of containment categories that were chosen for the draft methodology based work conducted by other researchers (Evans, 2021).

OSS No.	Definition
1.	Lined pit latrine which are effectively sealed, connected to individual household toilet facilities and emptied once full.
2.	Lined pit latrine which are effectively sealed, connected to individual household toilet facilities and to have never been emptied. Lower rates of greywater discharge than in shared facilities, greywater largely retained
3.	Lined pit latrine connected to flush toilet. More water content, which is largely retained. With the higher moisture content, more anoxic conditions are assumed
4.	Unlined pit latrine below the groundwater table. Infiltration of groundwater make conditions anaerobic.
5.	Unlined pit latrine above the groundwater table, little greywater is discharged
6.	Unlined pit latrine connected to a flush toilet. More water content, which can infiltrate to the ground
7.	Septic tank connected to flush toilets with two or three lined compartments, with an outlet for effluent water that infiltrates to the ground. Often also discharge of greywater.

Septic Tank

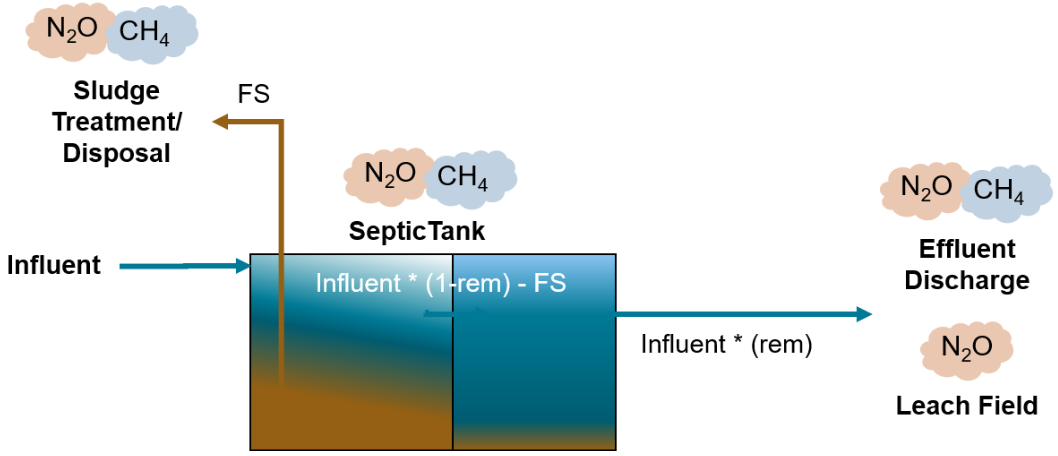

Figure 15: Schematic of a septic tank (lined) with effluent to a leach field or a different disposal site or treatment plant and faecal sludge (FS) removal to treatment or discharge site, showing consideration of GHG emission from each stage. Emissions from the septic tank are in principal calculated based on the organics or nitrogen within the tank that are neither going to the effluent nor removed as faecal sludge

Criteria for Pit Latrine Categories

Table 7: Criteria to allocate containment systems to the pre-defined categories. Correlates with the table of containment categories definitions (Table 6). Based on work conducted by other researchers (Evans, 2021). FS = faecal sludge

Category	Lining	Flush water or greywater	Emptying	Groundwater table
1.	lined	Little	yes	-
2.	lined	Little	never	-
3.	lined	Yes		-
4.	unlined	Little		below FS
5.	unlined	-		higher than FS
6.	unlined	Yes		below FS

Category 7) of on-site containments is a septic tank as described in the paragraph above.

A.4 Choice of Treatment Categories and Allocation

Definitions of Treatment or Disposal Sites

Table 8: Definitions of treatment and disposal sites that were chosen for the draft methodology.

No.	Name	Explanation	Source
1.	Aquatic environments	In general, if no information available on type of water body, otherwise categorization into water body 2 or 3	(D. Bartram et al., 2019)
2.	Lentic water bodies	Reservoirs, lakes and estuaries; eutrophic	(D. Bartram et al., 2019)
3.	Rivers	Flowing water body, or other aquatic environments less strained than water body 2.	(D. Bartram et al., 2019)
4.	Discharge to soil	Based on emission factors of open dump/unmanaged landfill	(Wagner Silva Alves et al., 2006)
5.	Land application	Application of wastewater or sewage sludge in agriculture, but could also be applied for dumping of faecal sludge more spread out than in category 3.	(De Klein et al., 2006; UNFCCC, 2019)
6.	Stagnant sewer	Disposal of faecal matter in a sewer where transport water is not sufficient. For nitrous oxide emissions, this category is assumed to resemble conditions in a	(D. Bartram et al., 2019)

		eutrophic lake, based on considerations made in (Doorn & Liles, 1999)	
7.	Shallow lagoons	Anaerobic shallow lagoon (< 2 m depth), facultative lagoon or shallow waste ponds	(D. Bartram et al., 2019)
8.	Deep lagoon	Anaerobic deep lagoon (> 2 m depth) or waste ponds	(D. Bartram et al., 2019)
9.	Anaerobic reactor	Controlled anaerobic digestion of secondary sludge or faecal sludge w/o CH_4 recovery	(D. Bartram et al., 2019)
10.	Constructed wetlands (three types, see draft methodology)	Based on three categories described on the 2013 IPCC Supplement for Wetlands	(Hiraishi et al., 2014)
11.	Aerobic treatment plant	Entails biological aerated treatment. Three types with different considerations of the degree of treatment (see separate elaboration and Appendix).	(D. Bartram et al., 2019)
12.	Drying bed	No distinction is made here between planted and unplanted drying bed	(Evans, 2021)
13.	Thickening tank	Settling and thickening tank for sludge	(Evans, 2021)
14.	Faecal sludge storage	Similar assumption to drying bed, relatively dry conditions or not piled but spread out (allowing for more oxygen supply)	(Evans, 2021)

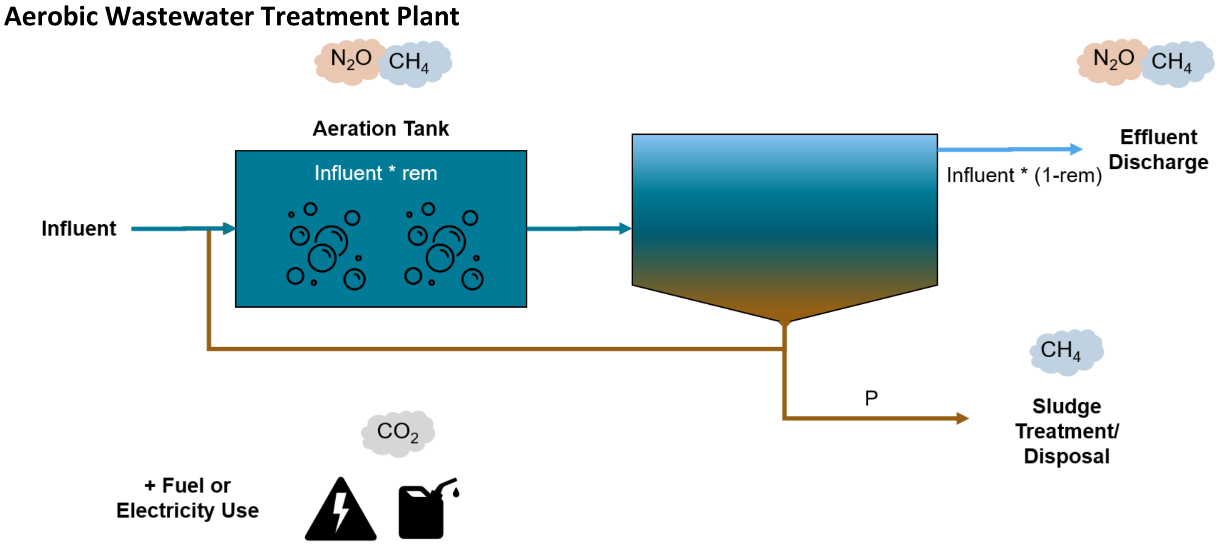

Figure 16: Overview of the emission model considerations for an aerobic WWTP. Organics and nitrogen content in the input and outflows of the facility are set in relation to influent components. Only secondary sludge production (P) is considered and only CH_4 emissions from further handling are calculated. Fuel use or electricity use in aeration has to be determined and the associated emissions are calculated according to (UNFCCC, 2017b)

Allocation of Treatment Systems to Categories

With this information, the described sanitation system can be allocated to the categories of sanitation defined for the subsequent calculation of emissions as well.

Waste stabilization ponds are built in series, with anaerobic and facultative or aerobic ponds (Ho et al., 2021). The anaerobicity is primarily controlled via the depth and can be decreased with plants. Planted and unplanted drying beds are similar constructions, but mainly with the purpose of sludge treatment (faecal sludge or secondary sludge) . It is good practice to build drainage systems to these facilities and safely dispose of the generated sludge. However, these requirements might not be followed, or maintenance might lack. In this work, only shallow and deep lagoons are distinguished. Systems with a depth of more than 2 m are considered deep lagoons, the rest are classified as shallow (facultative or aerobic) lagoons as per IPCC Guidelines. No further distinctions as to the functionality are made. In that, depth is a good indicator for the level of anaerobic degradation. However, if a pond deeper than 2 m is effectively aerated, it falls to the category of aerobic or facultative lagoon, as do vegetated sludge treatment facilities. This is derived from reports of significantly reduced CH_4 emissions from planted or ventilated treatment wetlands (Liang et al., 2021). Conditions in these treatment systems do not compare to aerobic WWT, as the bottom of the lagoons are still anaerobic, and aeration is not strong enough to keep influent materials in suspension (Ho et al., 2021). As sludge drying beds have been identified to cause significant CH_4 emissions, this distinction is not made for drying beds where sludge with a typically high organics and nutrients load is deposited.

Constructed wetlands work similarly but are typically planted (Casas Ledón et al., 2017). They are distinguished by the flow direction (vertical, horizontal) and CH_4 emissions may vary significantly, while influence of vegetation on GHG emissions is somewhat inconclusive between the different types (Maucieri et al., 2017). Constructed wetlands are reported to have similar CH_4 emissions per area than natural wetlands. Planted wetlands are relatively oxidised, or are able to oxidise generated CH_4 (Tanner et al., 1997). They are considered as per the 2013 supplement to the 2006 IPCC guidelines (Hiraishi et al., 2014).

Furthermore, the categories of sludge drying on a drying bed or open storage in a controlled environment (e.g., at a WWT facility for secondary sludge, or in large open space for faecal sludge disposal) are identified. Dumping of faecal sludge or secondary sludge in an unmanaged fashion might lead to more anaerobic conditions, as is observed in open dumps, which is categorized as “discharge to soil" in the draft methodology. . Sludge dewatering in a tank as pre-treatment before storage or drying can be approximated with the category “thickening tank”, which entails rather high levels of anaerobicity.

Open Defecation

For sites of open defecation, at least three categories were identified with an associated emission factor: 1) open environment; 2) open drain (dry season); and 3) open drain (wet season). The latter two could also be disposal sites for faecal sludge. If faecal sludge is deposited in open drains, the pathway should be categorized as a stagnant sewer.

B. Project Transformation Modules

Anaerobic Digestion for Biogas

Faeces or excreta (combined faeces and urine) can be transformed in an anaerobic digestor with generation of biogas and digestate (solid residuals). Biogas consisting of CH_4, CO_2 and trace gases is used as a source of energy. An existing CDM methodological tool can be applied.

The by-product of controlled anaerobic digestion for biogas is digestate. The transformation of digestate into a product safe for reuse or disposal is implied in the main process and its direct emissions are to be included in the corresponding process emissions. Possible further processing includes, but is not limited to composting, vermi-composting and pasteurization. Further processing is considered as per other emission modules.

Composting

Composting or co-composting of faeces, excreta or digestate (from the above anaerobic digestion) entails direct emissions from during the composting as well as during potential pre-processing of the organic waste such as drying of materials too wet for direct composting. Since the input materials inherently originate from dry toilets in the CBS project modules, pre-drying is not a foreseen part of the identified transformation processes. The approved CDM methodological tool for composting can be referred to.

Indirect GHG emissions in composting result from usage of fossil energy sources in the system operation. Turning of the organic waste might be necessary to homogenize the waste material and ensure aerobic conditions in the composting pile.

Black Soldier Fly Larvae Treatment

Black soldier fly larvae (BSFL) treatment is usually applied to compost organic household waste in low- and middle-income countries. Aside from being a solution to waste management issues, the black soldier fly larvae can be further processed, rendering a high-protein animal fodder as a product.

Analogous to composting, BSFL composting entails direct CH_4 and N_2O emissions during the process and indirect CO_2 project emissions of fossil energy use, although direct emissions are estimated to be significantly lower compared to conventional composting (Mertenat et al., 2019). Owing to the similarity of the biological degradation processes the project module of BSFL treatment was elaborated based on the methodological tool for composting. Input mass-based emission factors measured in a study from 2019 by Mertenat et al. (Mertenat et al., 2019) are used. Other recent studies report direct GHG emissions from BSFL treatment of organic substrates (Ermolaev et al., 2019; Parodi et al., 2020). Mertenat et al. additionally report energy usage and corresponding CO_2 emissions. These emission values have been used in previous work on CBS GHG emissions by L. Harroff (Harroff, 2021).

Briquetting

Briquetting is a method to consolidate low-bulk-density material to fuel with a high energy concentration (Mwampamba et al., 2013). With the perspective of climate protection as well as waste management, recent research increasingly focuses on the production of briquettes originating from organic materials (Ji et al., 2018; Ward et al., 2014; Zhang et al., 2019). The CBS project Sanivation co-processes CBS excreta with faecal sludge and organic residues from flower farms in a briquetting plant (Hakspiel et al., 2018).

The main sub-processes identified from literature are 1. Sieving or cleaning; 2. Drying; 3. Size reduction; 4. Pressing/briquetting (Szeląg-Sikora et al., 2018; Ward et al., 2014). All of these processes potentially require energy. In the draft methodology, no direct CH_4 and N_2O emissions from biological degradation during drying or other processes are considered, since no significant direct emissions have been reported in the studies on briquetting of biomass. The majority of GHG emissions are reported to stem from the application of fossil heat to the drying process (Kpalo et al., 2020). Renewable energy sources, such as the on-site burning of bio-briquettes or application of (concentrated) solar energy in the drying process or natural drying can thus influence GHG emissions.

Pyrolysis for Biochar

Biochar is a valuable soil amendment that can be produced from pyrolysis, i.e. heating of biomass without oxygen supply (Agegnehu et al., 2016; Manyà et al., 2018). Other direct emissions might result from leakage of pyrolysis gas. The draft methodology uses the approved CDM methodology AM0057 as a basis, where direct emissions from pyrolysis are considered as combustion emissions. Default emission factors on a per wet waste basis are taken from IPCC Guidelines on waste burning (Towprayoon et al., 2019).

Vermicomposting

If vermicomposting is used as a secondary treatment of digestate after anaerobic digestion, direct emissions are considered with emission factors adapted from Nigussie et al. on the basis of wet waste input (Nigussie et al., 2016).

C. Case Study: Mosan

C.1 Baseline Assessment

Biological Wastewater Treatment Plant in Santa Catarina Palopó

The following information is mostly based on the information provided on a tour of the treatment plant by Amigos del Lago, the organisation that started the initiative to build the WWTP with the municipality, as well as the current operating staff. The treatment plant is constructed for greywater only, but many residents in SCP illegally connect their flush toilets to the drainage. The WWTP capacity of 3 L s^{-1} is not sufficient for the incoming wastewater. The influent to the rake as the first pre-treatment step is approximately 9 L s^{-1}, a third of which consequently goes to the overflow which leads to the lake without further treatment. The stormwater overflow of the rainy season is also washed out here and enters the lake without further treatment. The quantity that gets treated does not fulfil all local requirement for effluent water, at least in part due to the fact that the treatment plant is not equipped to treat blackwater.

The primary settling stage and grease trap is small, leading to insufficient performance and a high loading of biodegradables and nutrients in the nitrification and denitrification stages. During nitrification, air is diffused at 25 cm from the bottom of the 5 m deep tanks. After denitrification, there is a shallow planted plug flow tank as a post-treatment. Only part of the water infiltrates to infiltration wells after the planted plug flow reactor, the rest of the effluent from the plug flow reactors goes to the lake. Sludge is removed from the aeration tanks every 25 days and pumped to a digestor with no gas recovery (i.e., open to the top) for intermediate storage. Then it is transported by gravity driven pipes to one of two drying beds. One of these has no roofs, making drying more challenging during rainy season. Once the sludge is dried, it is applied to plants and vegetables growing outside of the soil.

The treatment facility is not well-managed, as the operating staff do not have sufficient capacity and know-how. According to (Barreno Ortiz & Reyes Morales, 2019) Santa Catarina Palopó has one of the best performing wastewater treatment systems around the lake. A new treatment plant – also intended for greywater – has been installed recently. It is not yet in operation due to technical issues.

C.2 Baseline Quantification

Direct Baseline Emissions

Table 9: Direct GHG emissions from Mosan's sanitation baseline scenario

Sanitation Pathway	Usage [%]	Methane [kg CO_2-eq/unit/a]	Nitrous Oxide [kg CO_2-eq/unit/a]	Total GHG [kg CO_2-eq/unit/a]
Lined pit with flush toilet	20%	132.2	14.4	146.6
Unlined pit above groundwater table	6%	15.4	3.9	19.3
Unlined pit with flush water	47%	139.8	31.0	170.9
Sewered sanitation to lake	16%	33.5	33.8	67.3
Aerobic WWTP	8%	23.2	15.8	39.0
Open Defecation	3%	3.3	2.7	6.0
Sum	100%	347.3	101.7	**449.0**

Secondary Sludge Production in aerobic WWTPs in Lake Atitlán Region

For the case of Mosan, where secondary sludge production is not measured in the WWTP, the formula from Metcalf & Eddy was applied (Tchobanoglous et al., 2014)

:

$$ss_{COD} = \frac{Q \cdot \frac{Y}{1 + b \cdot \theta}\left(c_0 \cdot \left(\frac{1}{r_{BOD}} - 1\right)\right)}{Q \cdot c_0} = 5\% \qquad (1)$$

Q	= 3 L/s	(Amigos del Lago, 2021)
Y	= 0.6 mg VSS/mg BOD	(Tchobanoglous et al., 2014)
b	= 0.1 mg VSS/mg VSS/d	(Tchobanoglous et al., 2014)
θ	= 25 d	(Amigos del Lago, 2021)
c_0	=11.3 mg BOD/L	(Barreno Ortiz & Reyes Morales, 2019)
r_{BOD}	=0.85	(Barreno Ortiz & Reyes Morales, 2019)

Quantification of Fuel Emissions in Aerobic WWTPs in Lake Atiltán Region

$$5\,\frac{PE}{unit} \cdot 0.08 \cdot \frac{0.16\mathrm{kWh}}{\mathrm{PE\ d}} \cdot 365\,\frac{\mathrm{d}}{\mathrm{a}} \cdot 0.3\,\frac{\mathrm{L\ LPG}}{\mathrm{kWh}} \cdot 0.5\,\frac{\mathrm{kg}}{\mathrm{L\ LPG}} \cdot 0.0000473\,\frac{\mathrm{TJ}}{\mathrm{kg}} \cdot 63100\,\frac{kg\ CO2}{TJ} = 10.46\,\frac{kg\ CO2}{unit \cdot year} \qquad (2)$$

Aeration energy use	= 0.16 kWh/PE/d	(Siatou et al., 2020)
Fuel need	= 0.3 L LPG/kWh	(EIA, 2021)
Energy content petroleum	= 0.0000473 TJ/kg	(Garg et al., 2006)
Density petroleum	= 0.5 kg/L	(EIA, 2021)
CO_2 emissions of petroleum	= 63100 kg CO_2/TJ	(Garg et al., 2006)
Percentage discharge to WWTP	= 8%	Baseline assessment (see Figure 9)

D.Uncertainty Analysis

D.1 Variability of On-Site Containments with Faecal Sludge Removal

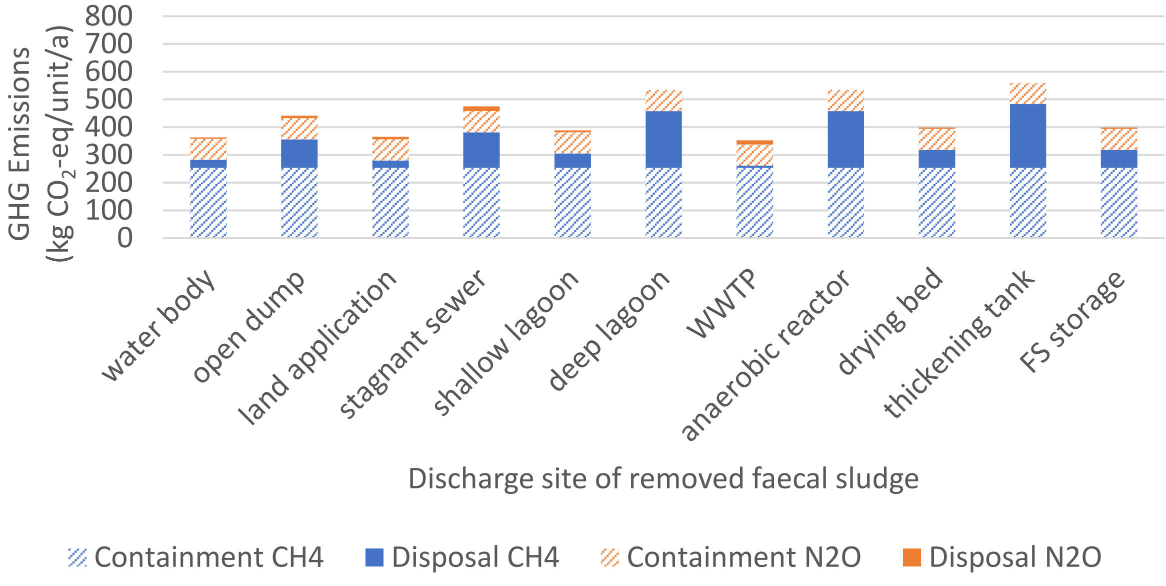

Figure 17: GHG Emissions for a pit latrine (category 1) with emptying of faecal sludge. Variability in emissions is pertaining to the type of faecal sludge disposal or treatment site; CH_4 = methane, N_2O = nitrous oxide.

D.2 Scenario Analysis of an Aerobic WWTP

Table 10: Exemplatory scenarios for which emission quantifications were conducted. Generally, the MCF (= methane correction factor) given in IPCC Guidelines of 0.03 was assumed (D. Bartram et al., 2019). Scenario 2 shows the assumption of an "unmanaged facilitys" with an MCF of 0.3.(Evans, 2021).

Scenario	Description
1	No secondary sludge, no effluent organics
2	No secondary sludge, no effluent organics, MCF = 0.3
3	50% of organics inflow to stagnant sewer (sludge), 15% of organics inflow to water body
4	40% of organics inflow to sludge drying bed, 10% of organics inflow to water body
5	50% of organics inflow to stagnant sewer (sludge), 10% of organics inflow to water body
6	No sludge removal, 15% of organics inflow to eutrophic, lentic water body

For default assumptions in the model, N_2O emissions contribute 85% to overall emissions from the wastewater treatment facility (scenario 1). When the MCF of poorly managed facilities is considered, N_2O emissions would make up for 30% to 50% (scenario 2), depending on the N_2O emission factor uncertainty range for aerobic biological treatment (+180%/-100%) (D. Bartram et al., 2019).

In the quantification model of the draft methodology, the amounts of organics and nitrogen remaining in the effluent may be determined with IPCC default values for primary, secondary (biological degradation) and tertiary treatment (advanced biological degradation).

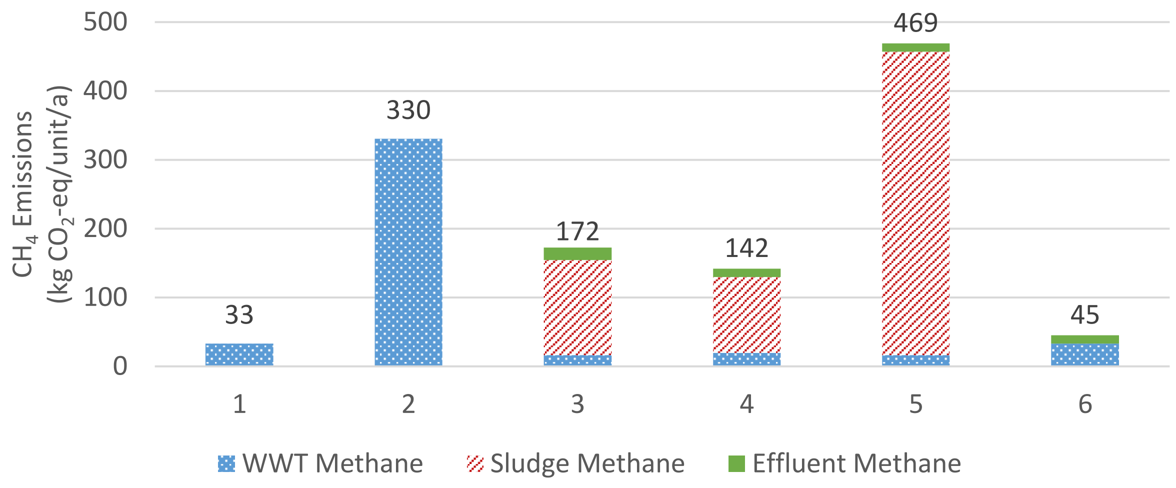

Figure 18: Methane emissions for 6 scenario considerations for aerobic treatment plants modelling in the Excel baseline calculator, as described in Table 10.

D.3 Sensitivity Analysis for On-Site Containment with Faecal Sludge Disposal

The following tables show the variation of total CH_4 emissions from a category 1 lined pit latrine with emptying of faecal sludge to a tier 1 water body. The pit has a volume of 3 m^3 and emptying interval of 6 years. The accumulation rate of faecal sludge is thus 100 L/p/a. Colour coding correlates between the tables from low (green) to high emissions (red).

Table 11: Summarized result from the sensitivity analysis of on-site sanitation with faecal sludge emptying. Ranges for emptying interval and containment volumes were taken from (Chowdhry & Koné, 2012), faecal sludge (FS) concentration ranges from (Changara et al., 2019; Gold et al., 2018; Gudda et al., 2017; Kalulu et al., 2021; Prasad et al., 2021; Ward et al., 2021) (Lansing et al., 2016). Numbers marked in red show that the limits of the model were reached

	Containment (kg CO_2-eq $unit^{-1}a^{-1}$)		Disposal Site (kg CO_2-eq $unit^{-1}a^{-1}$)		Overall Emissions (kg CO_2-eq $unit^{-1}a^{-1}$)	
	Low	High	Low	High	Low	High
Base Case	318		5		322	
1. Emptying interval (0.25 – 20 a) + Volume (1 to 12 m^3)	0	320	7	330	120	330
2. COD input (0.046 – 0.096 kg COD p^{-1} d^{-1}) + COD conc. FS (10 – 400 kg COD m^{-3} FS)	0	550	2	60	30	560
3. MCF (0.004 – 0.8) + B_0 (0.175 – 0.325)	220	460	0	44	220	460
4. Analysis 1 with disposal site 'stagnant sewer'	0	330	6	550	330	550
5. Analysis 3 with 2x initial COD concentration in FS.	210	400	0	530	130	760

Due to limitations in the model, the effects of volume and emptying frequency cannot be explored well at emptying frequencies higher than approximately two years. At the limiting boundary of the model, overall emissions are around 120 kg CO_2-eq. In scenario 1, emissions from containment are more significant and smaller amounts of faecal sludge organics emptied from containment yield higher overall annual emissions (up to 330 kg CO_2-eq). In scenario 4 with a more anaerobic disposal site for faecal sludge, the effect is smaller because with more faecal sludge emptied and disposed, the relative increase of emissions from the disposal site is larger than the decrease in emissions from the containment.

For scenario 2, the model again limits CH_4 emissions at the lower end at 30 kg CO_2-eq, for extreme COD concentrations in faecal sludge of up to 400 kg COD/m^3 FS and low input COD loads. With lower COD concentrations in faecal sludge, the overall CH_4 emissions increase slightly due to the disproportional effect of the increasing pit latrine emissions. For increasing COD input, overall CH_4 emissions increase substantially up to 560 kg CO_2-eq. This is solely due to increasing emissions from the pit latrine. In the quantification model, the input COD does not affect the faecal sludge amounts emptied from the containment.

Scenario 4 shows high sensitivity of overall CH_4 emissions to the CH_4 emission factor of the disposal site. Despite the buffering effect of the faecal sludge degraded in the pit latrine, this variation is coming from a MCF of 0.004 as the lower boundary for very aerobic or diluted systems to 0.8 as the upper boundary for intentional anaerobic digestion, with additional variation of B_0 as described in the previous paragraph (D. Bartram et al., 2019). In scenario 5, the CH_4 emission factor of the disposal site has an even larger effect on overall emissions: More COD is modelled to be emptied from the pit latrine, which leads to lower overall emissions. In this scenario 5, the emissions from the pit latrine decrease more than the emissions from the disposal sites increase. Only with very high CH_4 emission factors of the disposal site, the high emissions from the disposal site outweigh the lower (but steady) pit latrine emissions.

Table 12: Total CH_4 emissions from a lined pit latrine with emptying of faecal sludge (FS) with disposal in a water body with variation of the parameters Emptying frequency (horizontal) and containment volume (vertical).

TOTAL CH_4

Emptying frequency [1/year]

Containment volume [m^3] / **322**	4	3	2	1	1/2	1/3	1/4	1/5	1/6	1/8	0.1	0.08	0.07	0.05
1	137	185	234	282	306	314	318	321	322	324	326	326	327	328
1.5	121	121	185	258	294	306	312	316	318	321	323	324	326	327
2	121	121	137	234	282	298	306	311	314	318	321	322	324	326
2.5	121	121	121	209	270	290	300	306	310	315	318	320	322	324
3	121	121	121	185	258	282	294	301	306	312	316	318	321	323
3.5	121	121	121	161	246	274	288	297	302	309	313	316	319	322
4	121	121	121	137	234	266	282	292	298	306	311	314	317	321
5	121	121	121	121	209	250	270	282	290	300	306	310	314	318
6	121	121	121	121	185	234	258	272	282	294	301	306	311	316
7	121	121	121	121	161	217	246	263	274	288	297	302	308	313
8	121	121	121	121	137	201	234	253	266	282	292	298	305	311
9	121	121	121	121	121	185	221	243	258	276	287	294	301	309
10	121	121	121	121	121	169	209	234	250	270	282	290	298	306
12	121	121	121	121	121	137	185	214	234	258	272	282	292	301

Table 13: Total CH_4 emissions from on-site and emptying with variation of the parameters COD concentration in faecal sludge (FS) (horizontal) and COD input to containment load (vertical).

TOTAL CH_4		COD concentration in FS [kg/m^3] -83%	-67%	-50%	-33%	-17%	0%	17%	33%	50%	67%	83%	100%	117%	233%	400%	567%
COD input [kg/p/d]	**322**	10	20	30	40	50	60	70	80	90	100	110	120	130	200	300	400
-77%	0.016	72	69	66	64	61	58	56	53	50	48	45	42	39	27	27	27
-59%	0.029	132	130	127	124	122	119	116	113	111	108	105	103	100	81	54	49
-35%	0.046	211	209	206	203	201	198	195	193	190	187	184	182	179	160	133	106
-28%	0.051	235	232	229	227	224	221	218	216	213	210	208	205	202	184	157	130
-21%	0.056	258	255	253	250	247	244	242	239	236	234	231	228	226	207	180	153
-14%	0.061	281	278	276	273	270	268	265	262	260	257	254	252	249	230	203	176
-7%	0.066	304	302	299	296	294	291	288	286	283	280	278	275	272	253	226	199
0%	0.071	328	325	322	320	317	314	312	309	306	303	301	298	295	277	250	223
7%	0.076	351	348	346	343	340	338	335	332	329	327	324	321	319	300	273	246
14%	0.081	374	372	369	366	363	361	358	355	353	350	347	345	342	323	296	269
21%	0.086	398	395	392	389	387	384	381	379	376	373	371	368	365	346	319	293
28%	0.091	421	418	415	413	410	407	405	402	399	397	394	391	388	370	343	316
35%	0.096	444	441	439	436	433	431	428	425	423	420	417	414	412	393	366	339
46%	0.104	481	479	476	473	471	468	465	462	460	457	454	452	449	430	403	376
69%	0.12	556	553	550	548	545	542	540	537	534	532	529	526	523	505	478	451

Table 14: Total CH_4 emissions from on-site and emptying and disposal of faecal sludge (FS), with variation of the two compounds of the emission factor for CH_4 at the disposal sites. This analysis simulates the effect of varying degrees of anaerobicity in the disposal site on overall emissions.

TOTAL CH_4		Maximum CH_4 production capacity B_0 [kg CH4 /kg COD] -30%	-20%	-10%	0%	10%	20%	30%
MCF disposal site [-]	**322**	0.175	0.2	0.225	0.25	0.275	0.3	0.325
-96%	0.004	222	254	286	318	350	381	413
-91%	0.01	223	254	286	318	350	382	414
-68%	0.035	223	255	287	319	351	383	415
-45%	0.06	224	256	288	320	352	384	416
-27%	0.08	225	257	289	321	353	385	417
0%	0.11	226	258	290	322	355	387	419
36%	0.15	227	259	292	324	356	389	421
73%	0.19	228	261	293	326	358	391	423
145%	0.27	230	263	296	329	362	395	428
264%	0.4	234	268	301	335	368	402	435
355%	0.5	237	271	305	339	373	407	441
627%	0.8	246	281	316	352	387	422	457

E. Draft Methodology

Prototype Methodology: GHG Emission avoidance through container-based sanitation

Title	GHG emission avoidance through container-based sanitation and collection service with treatment at a central plant
Concept Type	New baseline and monitoring methodology Small methodology: GHG emission reduction of up to 60 kt CO_2-eq/year
Date of Issue	03-September-2021
Sectoral Scope	13 – Waste handling and disposal
Prepared By	Daniela Seitz

Contents

1 SUMMARY DESCRIPTION OF THE PROPOSED METHODOLOGY

Additionality and Crediting Method	
Additionality	Activity Method
Crediting Baseline	Project Method

This methodology is for the systematic quantification, monitoring and reporting of the GHG impact and savings potential of container-based sanitation projects. The project activities executed by the project proponent include 1) provision of sealed containers for the safe capture of excreta; 2) collection and transport service to a treatment facility; 3) transformation of the excreta or source-separated faeces to products safe for reuse.

For the purpose of this methodology the following definitions apply:

Blackwater	Mixture of faeces, urine, flush water and possibly cleansing materials or anal cleansing water
Container-based sanitation (CBS)	(CBSA) Sanitation service that provides safely managed sanitation (end-to-end). The user interface consists of a waterless toilet where the excreta or source-separated faeces and urine are contained in sealable and removable containers. A hygienic collection service ensures transport and safe disposal (e.g., of urine as a privately used fertilizer) or delivery to a treatment facility, where the excreta are transformed into valuable end products.
Dry toilet / sanitation	Toilet facility/sanitation without flush water to transport the human waste
Excreta	Faeces and urine that are not mixed with flush water
Faecal sludge	The mixture of excreta and water that accumulates in on-site sanitation technologies. Can also contain other wastes; has not been transported through a sewer.
Faeces / faecal matter	Human excrement that is source-separated from urine and not mixed with flush water
Greywater	Part of wastewater stemming from household facilities excluding toilets: washing water (food, clothes, dishes) or bathing water.
Human waste / excrement	Excreta or faeces and urine if source-separated
Project (operational) region	The geographic operating space of the project activities in a city or region. The project region excludes the high-income demographic and people with access to a safely managed sanitation service chain.

Safely managed sanitation	(WHO) includes a private improved toilet facility where faecal wastes are safely disposed on site or transported and treated off-site.
Sanitation service chain	Services and activities that enable the provision of safely managed sanitation
(Sewage) Sludge	(semi-)solid residuals that are removed from the wastewater in an (off-site) aerobic treatment plant (not the same as “faecal sludge”)
Urine	Source-separated liquid human excrement. It is separated from faeces by urine-diversion and not mixed with flush water.
Wastewater / sewage	Mixture of excreta, water, greywater and possibly other wastes that has been transported through a sewer. Here predominantly used to describe excreta that is

2 RELATIONSHIP TO APPROVED OR PENDING METHODOLOGIES

Project participants shall apply the “General guidelines for SSC CDM methodologies and information on additionality (attachment A to Appendix B) provided at: <http://cdm.unfccc.int/methodologies/SSCmethodologies/approved.html> mutatis mutandis.

This baseline and monitoring methodology is based on elements from the following approved baseline and monitoring methodologies:

Table 1: Similar Methodologies

Methodology	Title	GHG Program	Comments
AMS-III.H	Methane recovery in wastewater treatment	CDM	Methane recovery in wastewater treatment, not transferrable to CBS project activity
ACM0014	Mitigation of greenhouse gas emissions from treatment of industrial wastewater	CDM	Secondary sludge treatment to replace open anaerobic digestion
AMS-III.I	Avoidance of methane production in wastewater treatment through replacement of anaerobic systems by aerobic systems	CDM	Wastewater treatment in open lagoon replaced by aerobic with effluent discharge, secondary sludge treatment and final disposal

AM0039	Methane emissions reduction from organic wastewater and bioorganic solid waste using co-composting	CDM	Co-composting instead of multi-baseline of decay in deep lagoons (ww), storage tanks (sludge) and landfills (organic solid waste)
AM0073	GHG emission reductions through multi-site manure collection and treatment in a central plant	CDM	For farms, not sanitation; this project activity doesn't include multi-baseline for initial containment
AMS-III.E	Avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/thermal treatment	CDM	Treatment / transformation of organic solid waste to avoid anaerobic decay in SWDS
AMS-III.L	Avoidance of methane production from biomass decay through controlled pyrolysis	CDM	Treatment / transformation of organic solid waste to avoid anaerobic decay in SWDS; replacement of GHG intensive fuel
AMS-III.F	Avoidance of methane emissions controlled biological treatment of biomass	CDM	Composting of organic solid waste to avoid anaerobic decay in SWDS
AM0112	Less carbon intensive power generation through continuous reductive distillation of waste	CDM	Waste treatment to replace disposal in landfill and grid electricity
AM0057	Avoided emissions from biomass wastes through use as feed stock in pulp and paper, cardboard, fibreboard or bio-oil production	CDM	Basis for the emission module of waste pyrolysis

This methodology also refers to the latest versions of the following approved methodologies, methodological tools and guidelines:

- CDM "Combined tool to identify the baseline scenario and demonstrate additionality" Version 7.0
- CDM "Project and leakage emissions from transportation of freight" Version 1.1
- CDM "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion" Version 3.0

- CDM “Tool to calculate baseline, project and/or leakage emissions from electricity consumption” Version 3.0
- CDM “Project and leakage emissions from composting” Version 2.0
- CDM “Project and leakage emissions from anaerobic digesters” Version 2.0
- CDM “Emissions from solid waste disposal sites” Version 8.0
- VCS Standard v4.1
- VCS Methodology Requirements v4.0
- “CDM Positive list of technologies” Version 3.0
- CDM “Leakage in biomass small-scale project activities” Version 4.0
- DIN EN ISO 14064-2
- “WHO guidelines for the safe use of wastewater, excreta and greywater”

3 PROJECT ACTIVITIES AND APPLICABILITY CONDITIONS

3.1 Project Activities

3.1.1 Summary Description

This methodology applies to the project activities of safe collection and re-valorization of human excreta. This safe collection includes the containment of excreta from the source until the excreta is delivered to a treatment facility and the subsequent transformation into products that are no longer harmful to human health. Container-based sanitation systems are adjusted to the needs of the global low- and middle-income population. It is a relatively new technology, and market penetration is minimal. On-site sanitation systems are a sector that is currently not represented in the carbon market. This methodology aims to capture the GHG emission savings potential of CBS projects in regions with limited access to safe sanitation systems with predominant biomass decay in the open environment.

3.1.2 Inclusion of CBS Project Activities

A CBS project is a holistic service ensuring safe sanitation along the entire service chain. A project involves the following activities

(1) Provision of dry toilets to customers (project participant households). Dry toilets function without the use of flush water (see also: Definitions). They either separate faeces and urine into two separate containers or collect and contain combined excreta in one container. Cover material (inter alia: sawdust or charcoal) is recommended and often provided as part of this project activity.

(2) Collection of containers weekly or bi-weekly from the customer households or semi-centralized collection points and transport to the project transformation facilities. Transport can be manual, e.g., with human-powered carts or motorized. Source-separated urine may be applied directly at the customer household and might not need to be transported as a project activity

(3) Transformation of excreta or faeces and possibly urine into end-products such as soil conditioner, fertilizer or biofuel. The process needs to be managed according to the requirements described or referenced in the transformation emission modules within this methodology. Any pre-treatment (e.g., drying) or post-treatment steps (seepage of clean water in infiltration well) required for the correct implementation of the transformation processes are included in the transformation activity. Energy input is necessary in most processes. If the project biofuel or biogas or other renewable energy sources cannot cover the energy needs of the transformation process, fossil fuel and regional electricity mix inputs are required. Transformation processes include, inter alia:

- Pyrolysis of faecal matter or combined excreta
- Composting of faecal matter or combined excreta
- Black soldier fly larvae (BSFL) treatment of faecal matter or combined excreta
- Biogas reactor with recovery of the biogas as an energy source, and further processing of the digestate, e.g., with one of the above processes
- Struvite precipitation for urine or similar process to produce fertilizer
- Storage of urine for hygienization and application as fertilizer
- Urine treatment separated from project activities: possibly storage and then application (at household level)

3.1.3 Exclusion of Activities associated with the CBS Project

If the project proponent does not execute the transformation within the scope of their project, they must ensure that the external transformation follows the guidelines for the transformation processes described in this methodology (see also below and chapter 3.2). The project proponent must make sure that there is no double counting of GHG emission savings and that carbon credits are ascribed to the appropriate owner in case the transformation takes place in an external facility not controlled by the project proponent (DIN, 2019). This might be important if the respective treatment facility issues carbon credits for separate project activities, as e.g., methane gas recovery. The same applies to urine that is a.) stored and applied directly at the customer households; or b) hygienised or treated at an external treatment site.

External treatment and transformation are excluded from the project activity (3) as described above. However, the corresponding emissions must be considered as project leakage emissions in the scope of this methodology.

The products of the transformation activity are not within the boundaries, i.e., the following activities are not considered in this methodology:

- Application of the products

- Replacement of alternative products

A project that issues carbon credits for a product resulting from transformation of excreta, faecal matter or urine needs to be analyzed separately. In combining the current waste collection methodology with a product application methodology, the activity of the transformation facility that turns excreta into useful products would overlap between the two projects (collection and transformation of faecal matter and usage of the final product). Double counting must be avoided by clearly defining the credit owner and attributing emissions accordingly.

3.2 Applicability Conditions

According to the definition of the operating space (geographical and demographic), CBS project activities are not intended to replace the sanitation service of high-income residents connected to a safe sanitation service chain (e.g., well-functioning sewer systems and properly managed wastewater treatment plant with methane recovery). Treatment plants and the paths leading up to it are included in the baseline scenario if parts of the service chain are not safe or not fully managed, inter alia overloaded treatment plants and sewers or a treatment plant with final unsafe disposal of sludge, e.g., if it hasn't been fully sanitized.

Project eligibility is established with the following criteria:

- The methodology is applicable in regions with limited access to a safe sanitation service chain, i.e., where not 100% of the population have affordable access to sewered sanitation infrastructure that goes into a managed disposal system, or where local legislation does not properly regulate sanitation.
- Project service provides a collection service of concealed containers so that they do not leak materials or gaseous emissions.
- Project service ensures subsequent treatment of the contained and collected excreta at a (semi-)centralized transformation facility. Urine may also be stored and applied at the customer household if it is shown to be safe and follows national legislation. If no national legislation is applicable, WHO guidelines regarding storage time of urine, time from application until harvest and consumption of different crops, fruit and vegetables shall be followed.
- The transformation of excreta renders products that are safe for reuse and are applied or used as soil conditioner, fertilizer or an energy source (biofuel). External transformation can render other products (e.g., clean water in case of urine discharge to a WWTP). Faecal matter and urine are conditioned so that the output is completely stabilized and sanitized and no longer harmful to human health or the environment (monitoring of product quality and key parameters might be necessary). Those products are going to ensure that GHG emissions that would have been generated from excreta are prevented (avoided). National or international legislation and guidelines for application of the products must be followed in all cases (e.g. WHO guidelines on application of urine and excreta (WHO, 2006)).
- Furthermore, the end products and handling thereof are going to ensure that that no further direct GHG emissions can be generated from their storage or disposal, not pertaining to

biogenic CO_2 emissions from using products as an energy source or from plants when applied to soil.

- The application or use of the final products are not considered a project activity but should be part of the value chain, and the disposal of the stabilized and sanitized material in a landfill or flaring (combustion without usage of energy) of biogas are not an option as a downstream pathway for CBS projects.

3.3 Baseline Scenario

The baseline scenario for the project activity of containment and collection of container-based sanitation is an aggregate baseline scenario due to a large variety of possible sanitation pathways in regions where access to a sanitation service chain and centralized treatment facility is lacking. The aggregate baseline scenario shall be determined by combining the likely sanitation pathways in the target region weighted by the percentage of usage as identified in during the assessment of the baseline scenario. Sanitation pathways with transformation of human waste to a product safe for reuse are excluded from the aggregate baseline scenario altogether. After exclusion of a sanitation pathway, the percentages of the remaining pathways are readjusted to the new total of usage, i.e., the size of the target population.

Three main pathways are differentiated for the assessment of the baseline scenario as well as the quantification of greenhouse gas emissions:

A) On-site sanitation: Toilets that discharge to an on-site containment facility

B) Sewer-based: Toilets that discharge to a sewer or drain, must include flush water

C) Open defecation: Absence of a toilet structure and defecation in the open

Pathway A) consists of several stages where greenhouse gas emissions are possibly generated:

- Stage 1: Containment of excreta in on-site facilities, possibly in compound with, inter alia, flush water, cleansing material or water, cover material, chemical additives, as well as additional household waste materials.
- Stage 2: Plan of action when end-of-life of on-site containment facility is reached: Emptying of faecal sludge with possible transport to a final disposal site or basic treatment facility, burial on-site or direct covering of the containment facility when its capacity is reached
- Stage 3: Disposal of faecal sludge in the environment, in a covered pit on-site or where a treatment facility is installed.

Pathway B) is simplified for the purpose of CBS project target regions:

- Type 1: To only consider emissions from the site where the sewer or drainage discharges to. Processes to be considered are degradation of biomass at a disposal site or more controlled degradation in treatment facilities.
- Type 2: Transport to a centralized aerobic treatment plant w/o methane recovery. Processes to be considered are degradation of biomass during biological treatment, secondary sludge treatment or disposal and effluent discharge.

Treatment facilities for faecal sludge (stage 3 in pathway A) and for wastewater/sewage treatment are assumed to be basic in the target region of CBS projects. Well-managed treatment facilities with methane recovery or production of a product safe for reuse are excluded from the aggregate baseline scenario. Treatment facilities might require input of fossil fuel or electricity. As a first approximation, only the initial treatment step of wastewater or faecal sludge is considered. Residual biological degradation in the effluent from anaerobic treatment facilities is not characterized nor quantified in this methodology.

Pathway C) only involves the process of biomass decay at the site of open defecation.

Table 2: Summary of gases and source to be considered in the boundary of the project and the baseline scenario

	Path	Stage and Source	Gas	Inclusion	Justification / Explanation
Baseline	A) On-site sanitation	Stage 1: biomass decay	CH_4	Yes	CH_4 emissions from anaerobic degradation
			N_2O	Yes	N_2O emissions from inefficient nitrification/denitrification pockets
			CO_2	No	CO_2 emissions from biomass decay is considered GHG neutral
		Stage 2: emptying and transport	CH_4	No	Direct CH_4 minimal due to short stage 2 residence time; CH_4 from combustion not considered as per IPCC V5 Ch.4
			N_2O	No	Direct N_2O minimal due to short stage 2 residence time; N_2O from combustion not considered as per IPCC V5 Ch.4
			CO_2	Yes	Emissions from combustion of fossil fuel in transport vehicles and for pumping
		Stage 3: further biochemical degradation at disposal site or in treatment facilities	CH_4	Yes	CH_4 emissions from anaerobic degradation
			N_2O	Yes	N_2O emissions from inefficient nitrification/ denitrification pockets
			CO_2	No	CO_2 emissions from biomass decay is considered GHG neutral
	B) Sewer-based sanitation	Sewer-based transport	CH_4	No	Not significant due to short residence time
			N_2O	No	Not significant due to short residence time
			CO_2	No	CO_2 emissions from biomass decay is considered GHG neutral
			CH_4	Yes	CH_4 emissions from anaerobic degradation

		Biochemical degradation at disposal site or in treatment facilities	N_2O	Yes	N_2O emissions from inefficient nitrification/ denitrification pockets
			CO_2	Yes	CO_2 emissions from combustion of fossil fuels or usage of electricity in treatment
		Secondary sludge treatment and disposal from Type 2 treatment facility	CH_4	Yes	CH_4 emissions from anaerobic degradation
			N_2O	No	N_2O not quantified in referenced methodology for secondary sludge production, thus not considered here
			CO_2	Yes	CO_2 emissions from combustion of fossil fuels or usage of electricity in treatment
		Effluent from Type 2 treatment facility	CH_4	Yes	CH_4 emissions from anaerobic degradation
			N_2O	Yes	N_2O emissions from inefficient nitrification/ denitrification pockets
			CO_2	No	CO_2 emissions from biomass decay is considered GHG neutral
	C) Open defecation	Biomass decay	CH_4	Yes	CH_4 emissions from anaerobic degradation
			N_2O	Yes	N_2O emissions from inefficient nitrification/ denitrification pockets
			CO_2	No	CO_2 emissions from biomass decay is considered GHG neutral
Project	1) Provision of toilet	Provision of dry toilet and usage	CH_4	No	Direct CH_4 negligible due to short residence time in concealed containers
			N_2O	No	Direct N_2O negligible due to short residence time in concealed containers
			CO_2	No	CO_2 emissions from biomass decay is considered GHG neutral. No indirect emissions for provision and application of cover materials considered
	2) Collection	Collection of containers	CH_4	No	Direct CH_4 negligible due to short transport in concealed containers CH_4 from combustion not considered as per IPCC V5 Ch.4
			N_2O	No	Direct N_2O negligible due to short transport in concealed containers

					N_2O from combustion not considered as per IPCC V5 Ch.4
			CO_2	Yes	Emissions from combustion of fossil fuel in transport vehicles
	3) Transformation	Transformation of excreta or faeces	CH_4	Yes	CH_4 emissions from anaerobic degradation
			N_2O	Yes	N_2O emissions from inefficient nitrification/ denitrification pockets
			CO_2	Yes	CO_2 emissions from combustion of fossil fuels or usage of electricity in treatment, biogenic CO_2 emissions not considered
		Urine transformation or storage (incl. at private level)	CH_4	No	No CH_4 emissions expected from sealed containers during storage or treatment
			N_2O	No	Direct N_2O negligible from concealed containers
			CO_2	No	Urine storage and transformation does not require combustion of fossil fuels or usage of electricity
CBS Products		Application of transformation products or regulation compliant use of urine as fertilizer	CH_4	No	Not within project boundary setting
			N_2O	No	Not within project boundary setting
			CO_2	No	Not within project boundary setting, will be biogenic

4 DEMONSTRATION OF ADDITIONALITY

Additionality is demonstrated by method of activity penetration: A CBS project fulfils the additionality criterion if market penetration of the project activity in the project region is less than 5%. The market penetration is evaluated according to the results of the survey with which the aggregate baseline scenario is assessed.

If activity penetration of CBS surpasses 5% before or during the crediting period, the UNFCCC tool "Combined tool to identify the baseline scenario and demonstrate additionality" shall be used to show additionality.

The baseline scenario is assessed in a representative survey in the target region, specifically with the target demographic. The common output of the project and the baseline shall be the disposing of excreta. Possible baseline alternatives for this shall contain any sanitation pathway that is used by humans for defecation and urination in the project region, and the subsequent fate of the excreta. Alternative baseline pathways shall be in line with the applicability conditions presented in chapter 3 of this methodology. The survey information is aggregated with the help of a decision tree (Appendix C).

Definitions of sanitation systems can also be found in the Appendix B. Possible realistic and credible alternative pathways used for defecation and urination in the aggregate baseline scenario include, inter alia:

- Open defecation in the open environment or open drains
- Defecation into unlined pits dug into the ground that have never been emptied (usually w/o the use of flush water)
- Defecation into unlined pits dug into the ground that are emptied every few years, with subsequent transport of faecal sludge to a disposal site like a water body or an open dump
- Flush toilets connected to lined or semi-lined pits or septic tanks, with subsequent transport of faecal sludge to a disposal site like a water body or an open dump or storage
- Flush toilets connected to lined or semi-lined pits or septic tanks, with subsequent transport of faecal sludge to a treatment facility like a lagoon or waste stabilization pond
- Flush toilets connected to a drainage system and discharge in a water body
- Flush toilets connected to a drainage system and transport to an anerobic treatment plant (e.g., deep lagoon, waste stabilization ponds or constructed wetlands)
- Flush toilets connected to a drainage system and transport to an aerobic treatment plant with secondary sludge removal and storage on drying beds, and effluent discharge into a water body

Appendix A contains an exemplary demonstration of additionality for a CBS project.

5 QUANTIFICATION OF EMISSION REDUCTIONS

Emission reductions are calculated as follows:

$$\mathrm{ER} = \mathrm{BE} - \mathrm{PE} \tag{1}$$

ER	Emission reductions for one year (t CO_2-eq)
BE	Emissions of the aggregate baseline scenario for one year (t CO_2-eq)
PE	Emissions of the project activities for one year (t CO_2-eq)

Direct and indirect emissions of different GHG are compared in CO_2-equivalents, which means multiplying the GHG in question by its GWP as defined in IPCC Guidelines (2013) (Myhre et al., 2013):

- Methane 34 kg CO_2-eq / kg CH_4
- Nitrous oxide 298 kg CO_2-eq / kg N_2O

5.1 Baseline methodology

5.1.1 Definition and Boundary

The aggregate baseline scenario consists of all sanitation alternatives that are not safely managed along the entire sanitation chain. This may include leakage of excreta from on-site sanitation systems, disposal of faecal sludge that is not sufficiently sanitized in the environment as well as (overloaded) treatment plants with leakage of wastewater. These pathways can lead to pollution of groundwater, surface water bodies, or other contamination of the environment or of living spaces with excreta or faecal sludge.

The baseline boundary are the physical geographical sites of containment, storage, and degradation, including leakage on-site; in case of transport to an off-site dumping site, transport and dumping of unsatisfactorily sanitized faecal sludge are also included. Furthermore, treatment facilities of faecal sludge as well as wastewater are included in the baseline boundary.

Wastewater and sludge treatment systems equipped with a biogas recovery facility in the baseline shall be excluded from the baseline emission calculations (AMS-III.H). Improved treatment facilities rendering a product safe for reuse from the transformation of faecal sludge or secondary sludge from wastewater treatment facilities are not considered in this methodology.

If national or local safety requirements or legal regulations with regards to recovery of methane emissions from wastewater treatment plants are enforced in the project region, the associated baseline pathway shall be excluded (from AMS-III.G)

Baseline scenario emissions for on-site sanitation are the weighted sum of the different pathway options. Emissions of the aggregate baseline scenario are composed of:

$$\mathrm{BE} = \mathrm{CE} + \mathrm{SM} + \mathrm{WD} + \mathrm{WT} + \mathrm{OD} \quad (2)$$

CE	Containment emission from on-site sanitation facilities (t CO_2-eq)
SM	Emissions from management of faecal sludge, involving transport and disposal or treatment (t CO_2-eq)
WD	Emissions from wastewater/sewage discharge in the environment (t CO_2-eq)
WT	Emissions from aerobic wastewater treatment (t CO_2-eq)
OD	Emissions from open defecation in the environment (t CO_2-eq)

5.1.2 On-Site Sanitation

Containment

Emissions from containment on-site are calculated as follows:

$$\mathrm{CE} = \left(CH_4\ Containment_j \cdot CO_2eq_{CH_4} + N_2O\ \mathrm{Containment} \cdot CO_2eq_{N_2O}\right) \div 1000\frac{kg}{t} \quad (3)$$

Direct methane emission from a containment facility j result from degradation of biomass in anaerobic conditions and are calculated as follows (based on IPCC Guidelines for Wastewater (Doorn et al., 2006)):

$$\mathrm{CH_4\ Containment} = \sum_{j} \mathrm{CH_4\ Containment_j} = \sum_{j} \left(\mathrm{TO_j} - \mathrm{S_{COD,j}}\right) \cdot \mathrm{EF_{CH4,j}} \tag{4}$$

$TO_{j\ mi}$	Total organics in excreta discharged to containment facility j ($kg_{COD}\ a^{-1}$)
$EF_{CH4,j}$	Emission factor (methane) of facility j, based on the organics content ($kg_{CH4}\ kg_{COD}^{-1}$)
$S_{COD,j}$	Faecal sludge organics emptied from containment annually ($kg_{COD}\ a^{-1}$)

$$\mathrm{N_2O\ Containment} = \sum_{j} \mathrm{N_2O\ Containment_j} = \sum_{j} \left(\mathrm{N_j} - \mathrm{S_{N,j}}\right) \cdot \mathrm{EF_{N2O,j}} \cdot \frac{44}{28} \tag{5}$$

N_j	Total nitrogen in excreta discharged to containment facility j ($kg_{COD}\ a^{-1}$)
$EF_{N2O,j}$	Emission factor (nitrous oxide) of facility j, based on nitrogen content ($kg_{N2O}\ kg_{N}^{-1}$)
$S_{N,j}$	Faecal sludge organics emptied from containment annually ($kg_{COD}\ a^{-1}$)

Where the total organics in the discharge pathways j consist of:

$$TO_j = P_j \cdot COD_e \cdot 365\ {}^{d}/_{a} \tag{6}$$

And the nitrogen in the discharge pathway j:

$$\mathrm{N_j} = \mathrm{P_j} \cdot \mathrm{N_e} \cdot 365\ {}^{\mathrm{d}}/_{\mathrm{a}} \tag{7}$$

With:

$$\mathrm{P_j} = \mathrm{P_{tot}} \cdot \mathrm{f_j} \tag{8}$$

P_j	Number of project participants formerly utilizing containment sanitation facility j (p)
P_{tot}	Total number of project participants in a crediting year in the project region (p); $P_{tot} = P_j + P_w + P_{OD}$ (see below)
COD_e	Production of COD in excreta per person per day ($kg_{COD}\ p^{-1}\ d^{-1}$). If no regional or national measurements are available, a default value of 0.071 $kg_{COD}\ p^{-1}\ d^{-1}$ (Rose, Parker, Jefferson, & Cartmell, 2015) can be used

N_e	Production of N in excreta per person per day ($kg_N\ p^{-1}\ d^{-1}$); if no regional or national measurements are available, a default value of 0.013 $kg_N\ p^{-1}\ d^{-1}$ (Rose et al., 2015) can be used
f_j	fraction of people in the target region of the project utilizing sanitation containment facility type j in their household in in the baseline scenario (-)

TO of the containment categories unlined pit below groundwater table and unlined pit with flush water is multiplied by a conservativeness factor of 0.7 to account for percolation of organics input to the ground. No subsequent CH_4 emissions from the ground are considered. Nitrogen percolation or a change in N_2O emissions due to percolation to the ground are not considered to be conservative (N_2O emissions from ground would be estimated higher than from containments with these emission models).

Septic tanks have an effluent. In equation (4) for these systems, TO has to be multiplied by (1-r). The effluent r is considered to be discharged to a leach field, where nitrous oxide emissions are quantified based on a per person emission factor of 0.00002 $kg_{N2O}\ p^{-1}\ d^{-1}$ (Truhlar et al., 2016). Methane emissions from the leach field are considered negligible. If the effluent discharges to a sewer or disposal site, the subsequent emissions for nitrous oxide and methane are quantified with the respective inputs (r multiplied by original input) and the respective category emission factors from Table 12 are considered.

Table 3: Removal rates via effluent or outflow septic tanks (organics and nitrogen)

On-site containment with effluent	Organics removal fraction (-)	Nitrogen removal fraction (-)
Septic tank	0.375	0.85

Emission Factors (General)

$$EF_{CH4,i} = B_0 \cdot MCF_i \tag{9}$$

$$EF_{N2O,i} = EF_{N2O-N,i} \cdot \frac{44}{28} \tag{10}$$

$EF_{CH4,i}$	Emission factor for methane based on organics content in input to process i ($kg_{CH4}\ kg_{COD}^{-1}$)
B_0	Maximum methane producing capacity ($kg_{CH4}\ kg_{COD}^{-1}$) of a given quantity of organics in wastewater; 0.25 $kg_{CH4}\ kg_{COD}^{-1}$ (Doorn et al., 2006)
MCF_i	Methane correction factor for a stage i in the wastewater/excreta discharge pathway, according to IPCC guidelines indicating the degree of anaerobicity of biological degradation, from (0 – 1)

$EF_{N2O,i}$	Emission factor for nitrous oxide based on nitrogen content in process i (kg_{N2O} kg_N^{-1})
$EF_{N2O-N,i}$	Emission factor for nitrogen emitted as nitrous oxide gas from a process/stage i in the wastewater/excreta discharge pathway, based on nitrogen in process i (kg_{N2O-N} kg_N^{-1})
44/28	Factor converting N_2O-N to N_2O (kg_{N2O} kg_{N2O-N}^{-1})

If no regional or national data or measurements are available, the EF for the containment sanitation categories j are used in accordance with IPCC, V5 Ch.6 (2019).

Table 4: Methane correction factors (MCF) for on-site containment systems (see definitions in Appendix B)

On-site containment sanitation facility j	**MCF value (Evans, 2021)**
Septic tank (+ land dispersial field)	0.35
Lined pit latrine (household, emptied when full)	0.30
Lined pit (household, never been emptied)	0.40
Lined pit (with flush toilet)	0.60
Unlined pit (household, sludge lies above groundwater table)	0.25
Unlined pit (groundwater table higher than sludge)	0.70
Unlined pit (with flush toilet)	0.40

Table 5: Emission factors for nitrous oxide nitrogen

On-site containment sanitation facility j	**EF_N (kg_{N2O-N}/kg_N) (Evans, 2021)**
Septic tank (+ land dispersial field)	0.0045
Lined pit latrine (household, emptied when full)	0.0075
Lined pit (household, never been emptied)	0.0075
Lined pit (with flush toilet)	0.0065

Unlined pit (household, sludge lies above groundwater table)	0.006
Unlined pit (groundwater table higher than sludge)	0.005
Unlined pit (with flush toilet)	0.006

These categories were partly matched to the categories for methane correction factors.

Faecal Sludge Quantification

The organics (COD) or nitrogen (N) components transferred from the containment sanitation facility j as faecal sludge (S) to another stage are assessed according to the following equations. With the number of specific on-site containment facilities j formerly utilized by project participants that reaches capacity per year, the amount of faecal sludge components at that is emptied from containment is determined:

$$\mathrm{FS_{COD,j}} = \mathrm{h_j} \cdot \mathrm{V_{j,\emptyset}} \cdot \mathrm{c_{COD,j}} \cdot \mathrm{frq_j} \quad (11)$$

$$\mathrm{FS_{N,j}} = \mathrm{h_j} \cdot \mathrm{V_{j,\emptyset}} \cdot \mathrm{c_{N,j}} \cdot \mathrm{frq_j} \quad (12)$$

Transfer from an on-site facility to another stage can occur via an emptying service or by covering the on-site pit with soil material. S_j is the faecal sludge components in containment sanitation facility j that is emptied and transferred to the next stage, summed over the destination treatment or disposal sites k.

$$\mathrm{S_{COD,j}} = \sum_{\mathrm{k}} \mathrm{FS_{COD,j}} \cdot \mathrm{t_{j,k}} \quad (13)$$

$$\mathrm{S_{N,j}} = \sum_{\mathrm{k}} \mathrm{FS_{N,j}} \cdot \mathrm{t_{j,k}} \quad (14)$$

$FS_{COD,j}$	Amount of faecal sludge components (organics) within the containment facilities j that would have reached capacity per year in the project baseline (kg_{COD} a^{-1})
$FS_{N,j}$	Amount of faecal sludge components (nitrogen) within the containment facilities j that would have reached capacity per year in the project baseline (kg_{COD} a^{-1})
h_j	Number of project participant households formerly utilizing containment sanitation facility j in their household, estimated from the total number of customer households weighted with the percentage of individuals in the target region using facility j: $h_j = \frac{n_j}{n_{tot}} \cdot h_{tot}$

$t_{j,k}$	Fraction of containment facilities j that are emptied regularly and transferred to treatment or disposal site of type k, or covered with soil when full (-)
$V_{j,av}$	Volume of sludge or average volume of containment facility j (m^3)
$c_{COD,j}$	Concentration of COD in faecal sludge from containment sanitation facility j when full (kg_{COD} m^{-3}). If no national or regional values are available, use default values provided in this methodology
$c_{N,j}$	Concentration of nitrogen in faecal sludge from containment sanitation facility j when full (kg_N m^{-3}). If no national or regional values are available, use default values provided in this methodology
frq_j	Frequency of emptying or filling up of a typical containment sanitation facility j (a^{-1})

Vj,av is the amount of faecal sludge that is emptied either manually or via an exhauster truck from a containment sanitation facility j. If there are no official records of an emptying service and the respective amounts of faecal sludge that are brought to a treatment or disposal site k, Vj, hj, tj,k and frqj will be determined based on baseline survey results. Otherwise, directly reported amounts of faecal sludge (volume or mass based, if density of sludge can be approximated) could be used to determine faecal sludge transfers from facility j to site k. If no direct or regional COD content measurements of faecal sludge are available, an average default value of 0.05 kg_{COD} kg_{FS}^{-1} can be used (Harroff, 2021). Assumption: Faecal sludge contents of a household in the project region only get transferred to one type of disposal or treatment site k.

For the default volume concentrations, the respective default values in the following table are applied. It is highly recommended to conduct characterization studies of faecal sludge in the project region and use those measured local values.

Table 6: Concentration default values for COD and nitrogen per faecal sludge volume

On-site containment sanitation facility j	cFS (gCOD/L)	cFS (gN/L) (Ward et al., 2021)
Septic tank (connected to wet toilet)	20 (Gold et al., 2018)	3
Lined pit latrine	30 (Strande et al., 2018)	3
Unlined pit latrine	120 (Ward et al., 2021)	4

Disposal/Treatment of Faecal Sludge

For a baseline pathway with emptying of faecal sludge from the on-site containment facility the greenhouse gas emissions of the faecal sludge management (FSM) are calculated as follows:

$$\mathrm{SM} = \mathrm{DT} + \mathrm{ET} \tag{15}$$

SM	Emissions from management of faecal sludge, involving transport and disposal or treatment (t CO_2-eq)
DT	Direct emissions from faecal sludge decay in the disposal site or treatment plant (t CO_2-eq)
ET	Emissions for motorized emptying and transport services (t CO_2-eq)

Where emissions from the treatment or disposal sites k are calculated as follows:

$$\mathrm{DT} = \left(CH_4\ Disp./Treat \cdot CO_2eq_{CH_4} + N_2O\ Disp./Treat \cdot CO_2eq_{N_2O}\right) \div 1000\frac{kg}{t} \tag{16}$$

The methane and nitrous oxide emissions from the disposal sites k where faecal sludge emptied from on-site containment facilities is brought to are determined as follows:

$$\mathrm{CH_4\ Disp./Treat} = \sum_{\mathrm{k}} \mathrm{CH_4\ Disp./Treat_k} = \sum_{\mathrm{k}} \mathrm{S_{COD,k}} \cdot \mathrm{EF_{CH4,k}} \tag{17}$$

$$\mathrm{N_2O\ Disp./Treat} = \sum_{\mathrm{k}} \mathrm{N_2O\ Disp./Treat_k} = \sum_{\mathrm{k}} \mathrm{S_{N,k}} \cdot \mathrm{EF_{N2O,k}} \tag{18}$$

Category k “covering of on-site containment with soil when full” is also included here but involves neither emptying nor transport activities, and emissions from covering of the containment are considered negligible. Similarly, emptying and transport activities for faecal sludge that is emptied and buried on-site are considered to be mostly manual and thus negligible (“burying of faecal sludge on-site”), i.e., no estimations for road transport or pumping have to be made.

The amount of faecal sludge organics or nitrogen components ending up at disposal site k is the sum of fractions of the annual End-of-Life sludge components in each containment sanitation facility that are transported to the disposal site k. Quantification of the faecal sludge amounts at each disposal site is based on a multiplication of the matrix of target population fractions with transfer of containment j to disposal site k times the amount of faecal sludge components from each containment j.

$$\begin{pmatrix} S_{COD,1} \\ \vdots \\ S_{COD,k} \end{pmatrix} = \begin{bmatrix} t_{1,1} & \cdots & t_{j,1} \\ \vdots & \ddots & \vdots \\ t_{1,k} & \cdots & t_{j,k} \end{bmatrix} \times \begin{pmatrix} FS_{COD,1} \\ \vdots \\ FS_{COD,j} \end{pmatrix}$$

For each disposal site k receiving faecal sludge from the facilities j:

$$S_{COD,k} = \sum_j FS_{COD,j} \cdot t_{j,k} \tag{19}$$

$$S_{N,k} = \sum_j FS_{N,j} \cdot t_{j,k} \tag{20}$$

The matrix with the transfer fractions t is created from the baseline survey. The amounts of faecal sludge components (organics or nitrogen) in each containment facility j at capacity annually are calculated as shown above.

The methane emissions from the treatment facilities k where faecal sludge emptied from on-site containment facilities is brought to are considered to be anaerobic or facultative and predominantly poorly managed, as per the applicability conditions of this methodology. Removal of secondary sludge (as in aerobic treatment plants, IPCC 2019) or a water overflow that is reintroduced into water bodies are not considered to occur in these faecal sludge treatment plants.

Table 7: Methane correction factors (MCF) for faecal sludge disposal sites (see Appendix B)

Disposal site or treatment facility k		MCF value
Aquatic environments (tier 1)		0.11 (Bartram et al., 2019)
Reservoirs, lakes and estuaries (tier 2)		0.19 (Bartram et al., 2019)
Rivers (tier 2)		0.035 (Bartram et al., 2019)
Discharge to soil (unmanaged landfill or open dump)		0.4 (Wagner Silva Alves et al., 2006)
Land application		0.1 (De Klein et al., 2006; UNFCCC, 2019)
Stagnant sewer		0.5 (Bartram et al., 2019)
Anaerobic shallow lagoon and facultative lagoon		0.2 (Bartram et al., 2019)
Anaerobic deep lagoon (> 2 m depth)		0.8 (Bartram et al., 2019)
Anaerobic reactor (w/o methane recovery)		0.8 (Bartram et al., 2019)
Constructed wetland	Surface flow	0.4 (Hiraishi et al., 2014)
	Horizontal subsurface flow	0.1 (Hiraishi et al., 2014)
	Vertical subsurface flow	0.01 (Hiraishi et al., 2014)
Drying bed		0.25 (Evans, 2021)
Thickening tank		0.9 (Evans, 2021)

Faecal sludge storage	0.25 (Evans, 2021)
Excreta to open drains (dry season)	0.2 (Evans, 2021)
Excreta to open drains (rainy season)	0.3 (Evans, 2021)

Table 8: Emission factors for nitrous oxide nitrogen for faecal sludge disposal sites

Disposal site or treatment facility k		EF_N (kg_{N20-N}/kg_N)
Aquatic environments (tier 1)		0.005 (Bartram et al., 2019)
Reservoirs, lakes and estuaries (tier 2)		0.019 (Bartram et al., 2019)
Other aquatic environments (tier 2)		0.005 (Bartram et al., 2019)
Discharge to soil		0.01 (De Klein et al., 2006; Wagner Silva Alves et al., 2006)
Land Application		0.01 (De Klein et al., 2006; Wagner Silva Alves et al., 2006)
Stagnant sewer		0.019 (Bartram et al., 2019)
Anaerobic shallow lagoon and facultative lagoon		0.008 (Evans, 2021)
Anaerobic deep lagoon		0 (Bartram et al., 2019)
Anaerobic reactor		0 (Bartram et al., 2019)
Constructed wetland	Surface flow	0.0013 (Hiraishi et al., 2014)
	Horizontal subsurface flow	0.0079 (Hiraishi et al., 2014)
	Vertical subsurface flow	0.00023 (Hiraishi et al., 2014)
Drying bed		0.005 (Evans, 2021)
Thickening tank		0 (Evans, 2021)
Faecal sludge storage		0.005 (Evans, 2021)
Excreta to open drains (dry season)		0.008 (Evans, 2021)
Excreta to open drains (rainy season)		0.009 (Evans, 2021)

Transport and Emptying ET

Emissions from transport and emptying activities (ET) are quantified as follows:

- Emissions from combustion of fossil fuels in transport vehicles are determined as per the latest version of the CDM tool "Project and leakage emissions from transportation of freight".
- Emissions from emptying activities (pumps) are determined as per the CDM tool "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion".

These emissions are only quantified if there are records of emptying and transport service providers of the project target area available. For the transportation emissions, documentation of fuel use or number of trips absolved and amounts of trips can be assessed to estimate the fuel use on a travelled distances basis.

If no such data or records or other way of estimating fuel use (formal or informal) for emptying services are available, all emptying and transport services are considered to be manual and no fossil CO_2 emissions will be quantified.

5.1.3 Sewered Discharge/Wastewater

Aggregate baseline scenario pathways that start with flushed discharge of excreta to a sewer or drainage (sewage/wastewater) can either be followed by wastewater discharge to the environment or to a wastewater treatment plant, aerobic or anaerobic. Direct emissions from waste degradation in the sewer as a transport medium are not considered. If there is no connection to a discharge site, or if there is not enough transport water, a stagnant sewer might be the final disposal site of wastewater and the corresponding emissions are considered as a disposal category k.

Wastewater Disposal in Environment or Wastewater Treatment save aerobic WWTP

For a baseline pathway with direct discharge of wastewater to a water body, a stagnant sewer or a treatment plant that is not aerobic, the following emission pathways are possible:

- Methane emissions from anaerobic organic degradation in wastewater treatment processes or disposal sites
- Nitrous oxide emissions, from a combination of nitrification and denitrification in wastewater treatment processes or disposal sites

The emissions WD from the disposal and treatment sites k are calculated as follows:

$$\mathrm{WD} = \left(\mathrm{CH_4\ Wastewater} \cdot \mathrm{CO_2eq_{CH_4}} + \mathrm{N_2O\ Wastewater} \cdot \mathrm{CO_2eq_{N_2O}}\right) \div 1000\frac{\mathrm{kg}}{\mathrm{t}} \tag{21}$$

$$\mathrm{CH_4\ Wastewater} = \sum_{k} \mathrm{CH_4\ Wastewater_k} = \sum_{k} \mathrm{P_w} \cdot \mathrm{COD_e} \cdot \mathrm{MCF_k} \cdot \mathrm{B_0} \cdot \mathrm{t_{w,k}} \cdot 365 \tag{22}$$

$$\mathrm{N_2O\ Wastewater} = \sum_{k} \mathrm{N_2O\ Wastewater_k} = \sum_{k} \mathrm{P_w} \cdot \mathrm{COD_e} \cdot \mathrm{EF_{N2O-N,k}} \cdot \frac{44}{28} \cdot \mathrm{t_{w,k}} \cdot 365 \tag{23}$$

Where:

$$P_w = P_{tot} \cdot f_w \tag{24}$$

With the total organics and total nitrogen in excreta discharged as wastewater: (analogous to equations 6 and 7)

$$TO_w = P_w \cdot COD_e \cdot 365\, {}^{d}/_{a}$$

$$N_w = P_w \cdot N_e \cdot 365\, {}^{d}/_{a}$$

P_w	Number of project customer formerly discharging excreta in wastewater via a pipe to a sewer (#)
$t_{w,k}$	Fraction of wastewater discharged via sewers or drains to disposal site or treatment facility k (-); mathematically, $t_{w,k}$ is a vector with k values
f_w	fraction of people in the operational region of the project discharging excreta via flush toilets to a sewer or drain in the baseline scenario (-)

The daily load of organics and nitrogen in excreta COD_e and N_e are derived as described for on-site sanitation. The method to determine the greenhouse gas emission factors is analogous to the method for faecal sludge disposal in the previous chapter. The disposal site categories for wastewater discharge and treatment and their emission factors considered in this methodology are listed in the following.

Table 9: MCF for wastewater treatment or disposal sites except for aerobic treatment facilities

Disposal site or treatment facility k	MCF value
Aquatic environments (tier 1)	0.11 (Bartram et al., 2019)
Reservoirs, lakes and estuaries (tier 2)	0.19 (Bartram et al., 2019)
Other aquatic environments (tier 2)	0.035 (Bartram et al., 2019)
Discharge to soil (unmanaged landfill or shallow open dump)	0.4 (Wagner Silva Alves et al., 2006)
Land application	0.3 (De Klein et al., 2006; UNFCCC, 2019)
Stagnant sewer	0.5 (Bartram et al., 2019)
Anaerobic shallow lagoon and facultative lagoon	0.4 (Bartram et al., 2019)
Anaerobic deep lagoon (> 2 m depth)	0.8 (Bartram et al., 2019)
Anaerobic reactor (w/o methane recovery)	0.8 (Bartram et al., 2019)

Constructed wetland	Surface flow	0.4 (Hiraishi et al., 2014)
	Horizontal subsurface flow	0.1 (Hiraishi et al., 2014)
	Vertical subsurface flow	0.01 (Hiraishi et al., 2014)
Drying bed		0.25 (Evans, 2021)
Thickening tank		0.9 (Evans, 2021)
Faecal sludge storage		0.25 (Evans, 2021)
Excreta to open drains (dry season)		0.2 (Evans, 2021)
Excreta to open drains (rainy season)		0.3 (Evans, 2021)

Table 10: Emission factors for nitrous oxide nitrogen for wastewater treatment or disposal sites except for aerobic treatment facilities

Disposal site or treatment facility k		EF_N ($kg_{N2O\text{-}N}/kg_N$)
Aquatic environments (tier 1)		0.005 (Bartram et al., 2019)
Reservoirs, lakes and estuaries (tier 2)		0.019 (Bartram et al., 2019)
Other aquatic environments (tier 2)		0.005 (Bartram et al., 2019)
Discharge to soil, shallow open dump		0.01 (De Klein et al., 2006; Wagner Silva Alves et al., 2006)
Land Application		0.01 (De Klein et al., 2006; Wagner Silva Alves et al., 2006)
Stagnant sewer		0.019 (Bartram et al., 2019)
Anaerobic shallow lagoon and facultative lagoon		0.008 (Evans, 2021)
Anaerobic deep lagoon		0 (Bartram et al., 2019)
Anaerobic reactor		0 (Bartram et al., 2019)
Constructed wetland	Surface flow	0.0013 (Hiraishi et al., 2014)
	Horizontal subsurface flow	0.0079 (Hiraishi et al., 2014)
	Vertical subsurface flow	0.00023 (Hiraishi et al., 2014)
Drying bed		0.005 (Evans, 2021)

Thickening tank	0 (Evans, 2021)
Faecal sludge storage	0.005 (Evans, 2021)
Excreta to open drains (dry season)	0.008 (Evans, 2021)
Excreta to open drains (rainy season)	0.009 (Evans, 2021)

Aerobic Wastewater Treatment

Treatment facilities k with aerobic biological treatment contain several sources of GHG emissions from different sites or treatment steps:

- Aerobic wastewater treatment processes (biological treatment):
  - Methane emissions from anaerobic pockets
  - Nitrous oxide slips from intentional nitrification and denitrification processes
- Secondary sludge removal and treatment or disposal: methane from anaerobic degradation
- Methane and nitrous oxide emissions from the water effluent discharge sites
- Electricity or fossil fuel usage to power aeration in aerobic wastewater treatment processes

Biological WWT

Emissions from aerobic treatment plants used for wastewater treatment are calculated as follows:

$$\mathrm{WT} = \begin{pmatrix} (\mathrm{CH_4\ aerobic\ WT} + \mathrm{CH_4\ SS} + \mathrm{CH_4\ Eff}) \cdot \mathrm{CO_2eq_{CH_4}} \\ +(\mathrm{N_2O\ aerobic\ WT} + \mathrm{N_2O\ SS} + \mathrm{N_2O\ Eff}) \cdot \mathrm{CO_2eq_{N_2O}} \end{pmatrix} \div 1000\frac{\mathrm{kg}}{\mathrm{t}} + \mathrm{EU} \tag{25}$$

EU	CO_2 emissions from energy usage in a wastewater treatment plant, e.g. for aeration and pumping activities. (t CO_2-eq)
$t_{OD,k}$	Fraction of open defecation to disposal site k (-)
f_{OD}	fraction of people in the operational region of the project openly defecation in the baseline scenario (-)

The category "aerobic treatment", where sludge is generated and removed in the treatment plant is handled as follows: Emissions from the initial wastewater treatment are considered with the following equations, with k = "aerobic treatment":

$$CH_4\ aerobic\ Treat. = \left(P_w \cdot COD_e \cdot t_{w,k} \cdot 365 \cdot r_{COD}\right) \cdot MCF_k \cdot B_0 \tag{26}$$

$$N_2O\ aerobic\ Treat. = \left(P_w \cdot N_e \cdot t_{w,k} \cdot 365 \cdot r_N\right) \cdot EF_{N2O,k} \cdot \frac{44}{28} \tag{27}$$

If faecal sludge is treated in an aerobic treatment plant, input organics and nitrogen parameters COD_e and N_e in equations (26) and (27) are replaced with $S_{COD,k}$ and $S_{N,k}$, respectively (from equations 19 and 20)..

Table 11: MCF and nitrous oxide emission factor for aerbic biological treatment (Bartram et al., 2019)

Treatment facility	MCF value	EF_N (kg_{N2O-N}/kg_N)
Aerobic treatment plant (poorly managed or overloaded)	0.03; (0.3 (UNFCCC, 2019))	0.016

The removal fractions of COD and nitrogen from wastewater are determined as per 2019 Refinement to the 2006 IPCC Guidelines for Wastewater (Bartram et al., 2019). If the treatment plant provides enough data for removal of organics and nutrients from the inflow and the effluent, this data shall be used, converted to a percentage removal.

r_{COD} Wastewater treatment COD removal fractions for different WWTP (-):

Primary (mechanical): 0.4; Secondary (biological): 0.85; Tertiary (advanced biological): 0.9 (Bartram et al., 2019)

r_N Wastewater treatment N removal fractions for different WWTP (-).

Primary (mechanical): 0.1; Secondary (biological): 0.4; Tertiary (advanced biological): 0.8 (Bartram et al., 2019)

Effluent

The emissions from the effluent discharge are then calculated as follows:

$$\mathrm{CH_4\ Effluent} = \left(P_w \cdot COD_e \cdot t_{w,k} \cdot 365 \cdot (1 - r_{COD})\right) \cdot MCF_{eff} \cdot B_0 \tag{28}$$

$$\mathrm{N_2O\ Effluent} = \left(P_w \cdot N_e \cdot t_{w,k} \cdot 365 \cdot (1 - r_N)\right) \cdot EF_{N2O,eff} \cdot \frac{44}{28} \tag{29}$$

In this case, with k = aerobic treatment facility and eff = site of effluent discharge.

Table 12: MCF and nitrous oxide nitrogen emission factors for the sites of WWT effluent discharge

Effluent discharge site (eff)	MCF value	EF_N (kg_{N2O-N}/kg_N)

Aquatic environments (tier 1) (Bartram et al., 2019)	0.11	0.005
Reservoirs, lakes and estuaries (tier 2) (Bartram et al., 2019)	0.19	0.019
Other aquatic environments (tier 2) (Bartram et al., 2019)	0.035	0.005
Land application (UNFCCC, 2019)	0.1	0.01

Secondary Sludge SS

$$CH_4\ \mathrm{SS} = \left(ss_{COD} \cdot P_w \cdot COD_e \cdot t_{w,k} \cdot 365 \cdot\right) \cdot MCF_{ss} \cdot B_0 \tag{30}$$

In this case, with k = aerobic treatment facility and ss = secondary sludge treatment or disposal site. The parameter ss_{COD} is the percentage of incoming COD that is removed as secondary sludge per time period.

The amount of sludge (dry mass) generated and removed from the wastewater stream annually in per person equivalents has to be estimated based on treatment plant data. If such data is not available, a measuring campaign of 10 days must be conducted during the baseline assessment. The quantification shall then be conducted as per Paragraph 11) of CDM Methodology AMS-III.I. If dry weights of removed sludge is measured at a treatment plant, IPCC Guidelines for Wastewater provide default values for the respective COD concentrations (Table 6.6A, (Bartram et al., 2019)).

If no measurements of the organics component COD are available from the respective treatment plant the following formula shall be used to estimate the amount of secondary sludge production in relation to incoming organics load.

$$ss_{COD} = \frac{Q \cdot \frac{Y}{1 + b \cdot \theta}\left(c_0 \cdot \left(\frac{1}{r_{COD}} - 1\right)\right)}{Q \cdot c_0} \tag{31}$$

Y	Yield, 45 mg VSS / mg COD (Tchobanoglous et al., 2014)
b	0.1 mg VSS / mg VSS / d (Tchobanoglous et al., 2014)
θ	Solids residence time (d), provided by plant operator
Q	Influent flowrate (L/s), provided by plant operator
c_0	Influent COD concentration (mg/L), provided by plant operator or assessed in measurement campaign

Nitrous oxide emissions are not considered for sludge removal and treatment. Primary sludge production is not assessed here.

For the separate handling of the generated sludge, input values for annual amounts of COD are taken as assessed in the previous paragraph. These amounts are multiplied by the emission factors as per the categories ss as follows:

Table 13: MCF and nitrous oxide nitrogen emission factors for the disposal or treatment of secondary sludge

Secondary sludge treatment or disposal (ss)	MCF value	EF_N ($kg_{N2O\text{-}N}/kg_N$)
Discharge to soil, shallow open dump (Wagner Silva Alves et al., 2006)	0.4	0.01
Land application (UNFCCC, 2019)	0.1	0.01
Anaerobic reactor (Bartram et al., 2019)	0.8	0
Drying bed (Evans, 2021)	0.25	0.005
Thickening tank (Evans, 2021)	0.9	0

Energy Usage (EU)

CO_2 emissions are generated from combustion of fossil fuel or use of electricity at the WWT facility (EU), e.g., for aeration or pumping. These emissions will be determined as per:

- CDM "Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion", version 3.0
- CDM "Tool to calculate baseline, project and/or leakage emissions from electricity consumption", version 3.0

The input data have to be provided by the operators of the respective treatment facilities.

5.1.4 Open Defecation

Emissions from open defecation are calculated analogous to the emissions from the sites of direct discharge of wastewater:

$$\mathrm{OD} = \left(CH_4\ OD \cdot CO_2eq_{CH_4} + N_2O\ OD \cdot CO_2eq_{N_2O}\right) \div 1000\frac{kg}{t} \tag{32}$$

Herein:

$$\mathrm{CH_4\ OD} = \sum_k \mathrm{CH_4\ OD_k} = \sum_k \mathrm{P_{OD} \cdot COD_e \cdot MCF_k \cdot B_0 \cdot t_{OD,k} \cdot 365} \tag{33}$$

$$\mathrm{N_2O\ OD} = \sum_k \mathrm{N_2O\ OD_k} = \sum_k \mathrm{P_{OD} \cdot COD_e \cdot EF_{N2O-N,k} \cdot \frac{44}{28} \cdot t_{OD,k} \cdot 365} \tag{34}$$

With:

$$P_{OD} = P_{tot} \cdot f_{OD} \tag{35}$$

$$1 = \sum_j f_j + f_w + f_{OD} = f_{OSS} + f_w + f_{OD} \tag{36}$$

P_{OD}	Number of project customer formerly resorting to open defecation
$t_{OD,k}$	Fraction of open defecation to disposal site k (-)
f_{OD}	fraction of people in the operational region of the project openly defecation in the baseline scenario (-)

Consult the previous subchapters for the description of other parameters. The disposal site categories for wastewater discharge considered in this methodology and the corresponding emission factors are listed in the following:

Table 14: MCF and nitrous oxide nitrogen EF for sites of open defecation (Evans, 2021)

Disposal site or treatment facility k	**MCF value**	**EF_N (kg_{N2O-N}/kg_N)**
Excreta to open drains (dry season)	0.2	0.008
Excreta to open drains (rainy season)	0.3	0.009
Open defecation in open environment	0.1	0.008

5.2 Project Emissions

Project emissions are composed of

$$PE = MT + TE + EU_P \tag{37}$$

PE	Emissions of project and leakage activities for one year (t CO_2-eq)
MT	Emissions for motorized transport services (t CO_2-eq)
TE	Direct emissions during the transformation or faecal matter in the assigned facilities (t CO_2-eq)
EU_P	CO_2 emissions from energy usage in a project transformation plant (t CO_2-eq)

Emissions from the containers before and during collection and transport to the transformation are considered negligible. Collection activities are at least weekly and cover materials are to be used as per the definition of the project activities in chapter 3. Odour as well as gaseous emissions are considered minimal due to a lack of steady state during the frequent short cycles of faeces degradation start-up after each interruption with a new container.

The service provider of the project activities must include a treatment of the excreta to generate products for application in agriculture, as a biofuel, or similar. If the treatment happens outside of the project activities, the emissions associated with the transformation process are accounted for as leakage emissions of the CBS project.

As the transformation processes differ between CBS projects (inconclusive list provided in chapter 3), associated project and leakage emissions are determined with project emission modules. Note that the modules constitute the current state of the art transformation processes available to CBS projects and should be adapted as needed. Input parameters for the modules are the amounts of COD and nitrogen components in faecal material or excreta delivered to the transformation annually. Normally, just the weight of wet waste input to the transformation processes has to be assessed. If COD or nitrous oxide contents of the excreta or faecal matter are available regionally or based on measurements at the treatment facilities, those values can be applied where necessary in the project emission modules.

Table 15: Characterization default values of human waste as excreta or source separated urine and faeces. If no measurements are conducted of incoming excreta at the project treatment facility, the default values can be used (Rose et al., 2015)

Type of human waste	Wet weight (kg/p/d)	COD (kg COD/p/d)	N (kg N/p/d)
Excreta	0.13	71	13
Faecal material (source-separated)	0.13 + 1.4 = 1.53	71	2
Urine (source-separated)	1.4	-	11

Storage of urine for hygienization as well as precipitation to struvite occur in closed containers. Consequently, emissions of nitrous oxide are negligible. The following project emission modules are thus only for excreta or faeces transformation

Emissions or emission savings associated with the application of the transformation product are not considered in this methodology.

The following six modules are for the quantification of direct emissions at faecal matter or excreta transformation facilities:

5.2.1 Anaerobic digestion for biogas and further processing of digestate

The direct methane and nitrous oxide emissions will be determined with the latest version of the UNFCCC tool “Project and leakage emissions from anaerobic digesters”. The further processing of the digestate via composting is assessed as per the latest version of the UNFCCC tool “Project and leakage emissions from composting”. For vermi-composting, BSFL treatment or pasteurization consider the project emission modules in the following.

5.2.2 Composting

Direct methane and nitrous oxide emissions from composting of faecal material or excreta will be determined with the latest version of the UNFCCC tool “Project and leakage emissions from composting” with the given emission factors based on wet mass delivered to the composting facility. The wet mass delivered must be monitored continuously and aggregated yearly.

5.2.3 Black Soldier Fly Larvae Treatment

Direct methane and nitrous oxide emissions during the BSFL treatment are considered based on Mertenat et al. (2019).

$$\mathrm{CO_2-eq\ BSFL} = \left(\mathrm{CH_{4,BSFL}} \cdot \mathrm{CO_2eq_{CH_4}} + \mathrm{N_2O_{BSFL}} \cdot \mathrm{CO_2eq_{N_2O}}\right) \div 1000\frac{kg}{t} \tag{38}$$

$$\mathrm{CH_4\ BSFL} = \mathrm{m_{in,w}} \cdot \mathrm{EF_{CH4,BSFL}} \tag{39}$$

$$\mathrm{N_2O\ BSFL} = \mathrm{m_{in,w}} \cdot \mathrm{EF_{N2O,BSFL}} \tag{40}$$

$m_{in,w}$	Monitored incoming mass of excreta or faeces (wet matter) to the BSFL transformation plant (kg_w/a)
$EF_{CH4,\ BSFL}$	Emission factor for direct emissions of CH_4 during BSFL treatment based on wet waste mass (kg_{CH4}/kg_w). Default value if no national or regional measurements or guidelines are available: $4x10^{-7}$ kg_{CH4}/kg_w (Mertenat, Diener, & Zurbrügg, 2019)
$EF_{N2O,\ BSFL}$	Emission factor for direct emissions of N_2O during BSFL treatment based on wet waste mass (kg_{N2O}/kg_w). Default value if no national or regional measurements or guidelines are available: $8.6x10^{-6}$ kgN2O/kg_w (Mertenat et al., 2019)

For residue post-composting refer to the UNFCCC tool “Project and leakage emissions from composting”.

BSFL treatment entails, inter alia, electricity or fuel use in ventilation, lighting and mixing. The associated non-renewable energy inputs (electricity or heat) are assessed and monitored as per the tools for electricity consumption and fossil fuel combustion to calculate the associated CO_2 emissions (see below).

5.2.4 Vermicomposting

Direct methane and nitrous oxide emissions during vermicomposting are considered based on reference papers (Nigussie, Kuyper, Bruun, & de Neergaard, 2016). If used as a secondary treatment of digestate after anaerobic digester, weight of incoming digestate (wet) must be measured.

$$\mathrm{CO_2 - eq\ vermicomp.} = \left(\mathrm{CH_{4,vermicomp.}} \cdot \mathrm{CO_2eq_{CH_4}} + \mathrm{N_2O_{vermicomp.}} \cdot \mathrm{CO_2eq_{N_2O}}\right) \div 1000\frac{kg}{t} \tag{41}$$

$$\mathrm{CH_4\ vermicomp.} = \mathrm{m_{in,w}} \cdot \mathrm{EF_{CH4,vermicomp.}} \tag{42}$$

$$\mathrm{N_2O\ vermicomp.} = \mathrm{m_{in,w}} \cdot \mathrm{EF_{N2O,vermicomp.}} \tag{43}$$

$m_{in,w}$	Monitored incoming mass of excreta or faeces (wet matter) to the vermicomposting facility (kg_w/a)
$EF_{CH4,\ vermicomp.}$	Emission factor for direct emissions of CH_4 during vermicomposting based on wet waste mass (kg_{CH4}/kg_w). Default value if no national or regional measurements or guidelines are available: $1.5x10^{-5}$ kg_{CH4}/kg_w (Nigussie et al., 2016)
$EF_{N2O,\ vermicomp.}$	Emission factor for direct emissions of N_2O during vermicomposting based on wet waste mass of faecal matter (source-separated urine) (kg_{N2O}/kg_w). Default value if no national or regional measurements or guidelines are available: $5x10^{-5}$ kg_{N2O}/kg_w (adapted from (Nigussie et al., 2016))
$EF_{N2O,\ vermicomp.}$	Emission factor for direct emissions of N_2O during vermicomposting based on wet waste mass of excreta (kg_{N2O}/kg_w). Default value if no national or regional measurements or guidelines are available: $2x10^{-4}$ kg_{N2O}/kg_w (adapted from (Nigussie et al., 2016))

Electricity and fuel use associated with vermicomposting are determined and monitored as per the tools for electricity consumption and fossil fuel combustion (see below).

5.2.5 Briquetting

Project emissions associated with briquetting comprise both the emissions from the mechanical/thermal production process (e.g., electricity and fossil fuel consumption, if relevant) as well as the combustion of briquettes within the project boundary (i.e., at the transformation facility to generate energy that can be used to power the transformation process).

The content of non-biogenic carbon coming from faecal matter or excreta is considered to be zero. Direct (biogenic) CO_2 emissions during combustion of the human organic waste do not have to be taken into account. Emissions of N_2O and CH_4 from combustion of briquettes are neglected because they are considered minor (AM0025).

Direct methane and nitrous oxide emissions from treatment of excreta associated with briquetting result from drying (pre-treatment) of fresh input material (wet). These emissions are not quantified if the dying process is relatively short and input materials have a relatively high dry solids content of >15%.. Other direct emissions in briquetting are considered negligible.

$$CO_2 - \text{eq briq.} = \left(CH_{4,\text{briq.}} \cdot CO_2eq_{CH_4} + N_2O_{\text{briq.}} \cdot CO_2eq_{N_2O}\right) \div 1000\frac{kg}{t} \qquad (44)$$

$$CH_4 \text{ briq.} = m_{in,w} \cdot c_{f,COD} \cdot MCF_{CH4,\text{briq.}} \cdot B_0 \qquad (45)$$

$$N_2O \text{ briq.} = m_{in,w} \cdot c_{f,N} \cdot EF_{N2O-N,\text{briq.}} \cdot \frac{44 kg_{N2O}}{28\ kg_N} \qquad (46)$$

$m_{in,w}$	Monitored incoming mass of excreta or faeces (wet matter) to the briquetting transformation plant (kg_w/a)
$c_{f,COD}$	Concentration of COD in faecal matter (kg_{COD}/kg_w). Default value if no national or regional measurements or guidelines are available: 0.4 kg_{COD}/kg_w, adapted from (Rose et al., 2015)
$c_{f,COD}$	Concentration of total nitrogen N in faecal matter (kg_N/kg_w). Default value if no national or regional measurements or guidelines are available: 0.011 kg_N/kg_w, adapted from (Rose et al., 2015)
$MCF_{CH4,briq.}$	Methane correction factor for direct emissions of CH_4 during the drying process in the transformation to briquettes based on COD load of incoming faeces (-). Approximated with disposal category "drying bed" if no national or regional measurements or guidelines are available: 0.25 (Evans, 2021)
$EF_{N2O\text{-}N,\ briq.}$	Emission factor for direct emissions of N_2O during the drying process in the transformation to briquettes based on the nitrogen load of incoming faeces ($kg_{N2O\text{-}N}/kg_N$). Approximated with disposal category "drying bed" if no national or regional measurements or guidelines are available: 0.005 $kg_{N2O\text{-}N}/kg_N$ (IPCC Ch. 6, 2019)
B_0	0.25 kg_{CH4}/kg_{COD} (Doorn et al., 2006)

Briquetting entails, inter-alia, drying, grinding and pressing (briquetting). The associated non-renewable energy inputs (electricity or heat) are assessed and monitored as per the tools for electricity consumption and fossil fuel combustion (see below).

Renewable energy inputs as concentrated solar power for drying as well as biogenic CO_2 emissions during drying are not considered. As described above, no emissions are considered if briquettes generated from excreta or other organic wastes are combusted for direct energy use

5.2.6 Pyrolysis

The project activities can include transformation of faecal matter and/or excreta into biochar through pyrolysis, with gas as a co-product.

Direct emissions of CO_2 in the pyrolysis gas are considered carbon neutral as faeces and/or excreta only contain biogenic carbon, and thus are not accounted for. If the pyrolysis gas is not flared, CH_4 and N_2O may be directly emitted. They shall be calculated with emission factors for waste combustion based on mass of faeces and/or excreta delivered to the project transformation facility as follows (approach from AM0057):

$$\mathrm{CO_2-eq\ pyro} = \left(\mathrm{CH_{4,pyro.}} \cdot \mathrm{CO_2eq_{CH_4}} + \mathrm{N_2O_{pyro}} \cdot \mathrm{CO_2eq_{N_2O}}\right) \div 1000\frac{kg}{t} \quad (47)$$

$$\mathrm{CH_4\ pyro} = \mathrm{m_{in,w}} \cdot \mathrm{EF_{CH4,pyro}} \quad (48)$$

$$\mathrm{N_2O\ pyro} = \mathrm{m_{in,w}} \cdot \mathrm{EF_{N2O,pyro}} \quad (49)$$

$m_{in,w}$	Monitored incoming mass of excreta or faeces (wet matter) to the transformation facility (kg_w/a)
$EF_{CH4,\ pyro.}$	Emission factor for direct emissions of CH_4 during pyrolysis based on wet waste mass (kg_{CH4}/kg_w). Approximated with aggregate CH_4 emission factor for open burning of MSW if no national or regional measurements or guidelines are available: $6.5x10^{-3}$ kg_{CH4}/kg_w (Guendehou, Koch, Hockstad, Pipatti, & Yamada, 2006) If the off-gas from the pyrolysis process is flared or can be partially oxidised in commercial pyrolysis plants, use default value: $5.8x10^{-6}$ kg_{CH4}/kg_w (Towprayoon, Kim, Jeon, Ishgaki, & Amadou, 2019)
$EF_{N2O,\ pyro.}$	Emission factor for direct emissions of N_2O during pyrolysis based on wet waste mass (kg_{N2O}/kg_w). Approximated with aggregate N_2O emission factor for incineration of dehydrated sewage sludge if no national or regional measurements or guidelines are available: $9x10^{-4}$ kgN2O/kg_w (Guendehou et al., 2006) If the off-gas from the pyrolysis process is flared are can be partially oxidised in commercial pyrolysis plants, use default value: $1.7x10^{-5}$ kg_{N2O}/kg_w (Towprayoon et al., 2019)

The associated emissions from fossil fuel combustion and electricity consumption in the processes associated with pyrolysis are calculated as per the tools for fossil fuel combustion and electricity consumption (see below).

5.2.7 Electricity consumption and fossil fuel combustion

The project emissions for any motorized transportation of faeces, urine or excreta containers from the household to the transformation centres (**MT**) should be assessed and monitored as per the UNFCCC tool for “Project and leakage emissions from road transportation of freight”.

Similarly, the CO_2 emissions related to the consumption of electricity and provision of heat with fossil fuel combustion in the project transformation modules (EU_P, part of modules) will be determined with the latest versions of the UNFCCC tools:

- “Tool to calculate baseline, project and/or leakage emissions from electricity consumption”
- “Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion”

6 MONITORING

Parameters to be assessed before the crediting period:

- Number of project participants and the expected amount of excreta for the project.
- Sanitation scenario of the customer base previous to the implementation of the project sanitation service: survey of possible on-site storage facilities, usage and emptying habits and the ultimate fate of faecal sludge. The information should be as detailed as a Susana SFD for the region. If an SFD is not available in the region or a comparable region in the same geographical area, the information must be assessed by the project proponent with surveys.

During the crediting period: The monitoring includes the weighing of the excreta material that is delivered to the project treatment plant. This data collection is a feasible effort for the project providers that might help in the planning of the transformation processes.

Country-specific or default excreta and faecal sludge characterization values are applied wherever possible and if no other data (regional, national or by the project proponent itself) is available.

This simplified monitoring approach is adjusted to the low-funding and often lack of governmental support for sanitation solutions in intended CBS project regions.

For the parameters used to determine the emissions related to the consumption of electricity and provision of heat with fossil fuel combustion in the project transformation modules please refer to the latest versions of the UNFCCC tools:

- “Tool to calculate baseline, project and/or leakage emissions from electricity consumption”
- “Tool to calculate project or leakage CO_2 emissions from fossil fuel combustion”

The parameters used to determine the project emissions for any motorized transportation of faeces, urine or excreta containers from the household to the transformation centre should be monitored as per the UNFCCC tool for “Project and leakage emissions from road transportation of freight”.

Parameters necessary to determine the project emissions from anaerobic digestion or composting might require additional monitoring and measurements as per the respective UNFCCC tools. For the input that is to be treated in these processes, monitoring and default concentrations of organics and nitrogen defined in the current document should be used instead, replacing alternative measurements and characterization defined in the UNFCCC tools.

Parameters not monitored

Data / Parameter:	f
Data unit:	%
Description:	Percentage of project participants that have formerly been using on-site containment sanitation type j
Source of data:	The percentages of people using a containment sanitation type j, wastewater discharge to a sewer respectively are estimated with data from a survey of a representative number of households. fj with nj denoting the surveyed number of people using category j (j) divided by total number of people surveyed (ntot): $$f_j = \frac{n_j}{n_{tot}}$$ If an official SFD is available for a city/region the respective data can be used. A distinction between specific containment facilities must be made
Measurement procedure (if any):	
Monitoring frequency:	
QA/QC procedures:	Surveys shall apply the 90/10 principle and accepted guidelines for the survey composition shall be used. Key informant interviews, population surveys and SFD can also be used to cross-reference estimates and find appropriate values for each type of containment.
Any comment:	

Data / Parameter:	t
Data unit:	%
Description:	Percentage of sludge emptied from on-site containment sanitation type j that is transported to treatment or disposal site k.
Source of data:	Estimates of the percentages of faecal sludge emptied and brought to treatment or disposal sites k with a formal or informal emptying service are based on survey data from a representative number of households. In case records for faecal sludge input to designated treatment sites within the

	baseline regional boundary are available, these shall be used to determine the corresponding t. If an official SFD is available for a city/region the respective data can be used. If no distinction between emptying practices of different containment facilities is made, an overall (average) percentage is applied for the different containment facilities. IPCC Ch. 6 (2019): discharge pathway fractions by regions or countries
Measurement procedure (if any):	
Monitoring frequency:	
QA/QC procedures:	Surveys shall apply the 90/10 principle and accepted guidelines for the survey composition shall be used. Key informant interviews, population surveys and SFD can also be used to cross-reference estimates and find appropriate values for each type of containment.
Any comment:	

Data / Parameter:	V_{jk}
Data unit:	m^3
Description:	Volume of sludge emptied from a specific type j of on-site sanitation system and brought to a disposal or treatment facility k.
Source of data:	Estimates of average containment (pit latrine or septic tank) volume based on survey data or regional measurements of containment sizes. Where official documentation of emptying practices and emptied volumes of faecal sludge are available, these can be used as the value for the parameter V.
Measurement procedure (if any):	Additional measurements not required if not already available in a region.
Monitoring frequency:	
QA/QC procedures:	In case survey data is used: Apply the 90/10 principle and accepted guidelines for the survey composition.

	Where measurements are available, verify that these have been conducted on a representative number of containment facilities in each containment category and of the entire containment. If official data (e.g. provided by the government or a governmental agency) are available check that these are current and comprehensive. Key informants to verify the quality in any of the three cases are recommended (e.g. with formal and informal constructors of sanitation containment facilities).
Any comment:	Underlying assumption: Emptying only happens when containment is full

Data / Parameter:	frq
Data unit:	1 / year
Description:	Average emptying frequency per faecal sludge containment category
Source of data:	Estimates of average emptying frequency of each containment type (pit latrine or septic tank) are based on survey data or key informant interviews with formal or informal constructors of sanitation containment facilities or emptying service providers. Documentation of emptying service providers should be considered if available.
Measurement procedure (if any):	
Monitoring frequency:	
QA/QC procedures:	Surveys shall apply the 90/10 principle and accepted guidelines for the survey composition shall be used. Key informant interviews and population surveys can also be used to cross-reference estimates and find appropriate average values for each type of containment.
Any comment:	Underlying assumption: Emptying only happens when containment is full

Parameters monitored

Data / Parameter:	P_{tot}
Data unit:	Project participants

Description:	Number of customers using the CBS project service in the geographical region in the current year. If customer numbers have changed throughout the year, an average number weighted by number of months is used.
Source of data:	Documentation of customer acquisition or cancellation by means of customer contracts Project operation data log and customer contracts
Measurement procedure (if any):	
Monitoring frequency:	Monthly, but aggregated to an annual average
QA/QC procedures:	Comparison of service logs of collection services and customer agreements/contracts (if available)
Any comment:	

Data / Parameter:	h_{tot}
Data unit:	households
Description:	Number of households participating in the CBS project service in the geographical region in the current year. If number of households have changed throughout the year, an average number weighted by number of months is used.
Source of data:	Project operation data log and customer contracts
Measurement procedure (if any):	
Monitoring frequency:	Monthly, but aggregated to an annual average
QA/QC procedures:	Comparison of service logs of collection services and customer agreements/contracts (if available)
Any comment:	

Data / Parameter:	m_f / m_u or m_e
Data unit:	t

Description:	Masses of faecal matter and urine or excreta that are delivered to the treatment and transformation facility during one year
Source of data:	Project operation documentation If this data is not assessed, default values can be used: (Rose et al., 2015) **Type of human waste** / **Wet weight (kg/p/d)**: Excreta: 0.13 Faecal material (source-separated): 0.13 + 1.4 = 1.53 Urine (source-separated): 1.4
Measurement procedure (if any):	Weighing of incoming material
Monitoring frequency:	Upon collection (often weekly or bi-weekly)
QA/QC procedures:	Annual calibration of scale
Any comment:	

Type of human waste	Wet weight (kg/p/d
Excreta	0.13
Faecal material (source-separated)	0.13 + 1.4 = 1.53
Urine (source-separated)	1.4

7 ASSOCIATED PROJECTS AND EMISSION REDUCTION POTENTIAL

Mosan is a CBS project operating in Guatemala, more precisely in the region of the lake Atitlán. This lake is exposed to substantial pollution, largely due to direct sewage discharge (Basterrechea Dáz et al., 2020). There is a general lack of access to safe sanitation as well as to running water in the predominantly indigenous villages around this lake (Basterrechea Dáz et al., 2020), where the people generally live in poverty, some with wages below the national minimal income (López Ramírez et al., 2010). There are seven wastewater treatment plants with effluent discharge to the lake, but they are often poorly managed and effluent pollutant and nutrient concentrations often exceed regulation values (Barreno Ortiz & Reyes Morales, 2019). Household on-site sanitation facilities are generally large and rarely emptied. Emptied faecal sludge from septic tanks or lined pit latrines are disposed of in the valleys at some distance to the villages. Leakage to the ground from unlined or semi-lined pits is likely, as emptying frequencies are reported to be virtually non-existent in household sanitation containment facilities.

Mosan is operating a pilot CBS in the village of Santa Catarina Palopó at the shore of lake Atitlán. Mosan offers a decentralized, modular and replicable sanitation solution meant for marginalized communities with limited access to sanitation facilities. Mosan has been serving over 150 people in over 40 households since its inception in 2018. The dry toilets Mosan provides come with two containers for source-separation of urine and faeces. Faeces are mixed with sawdust as a cover material after each use. The containers are collected twice a week and brought to a transformation facility. Faecal matter is pyrolyzed to render biochar after an initial open drying. Urine is stored for a month and then precipitated with Magnesium oxide (MgO) to form struvite. Both of these products could potentially be used in agriculture or gardening as soil conditioner and natural fertilizer, respectively. Mosan is currently seeking to expand to the further communities in order to increase its impact and ensure sustainable operation.

The current aggregate baseline scenario was assessed via key informant interviews and from official sanitation usage data by the National Institute of Statistics in Guatemala (INE). Direct baseline emissions for one CBS toilet unit per year were determined according to this methodology concept note and can be summarized as follows:

Sanitation Pathway	Usage [%]	Methane [kg CO_2-eq]	Nitrous Oxide [kg CO_2-eq]	Pathways GHG [kg CO_2-eq/unit/a]
Lined pit with flush toilet	20%	132	14	146
Unlined pit above groundwater table	6%	15	4	19
Unlined pit with flush water	47%	202	31	233
Sewered sanitation to lake	16%	34	34	67
Aerobic WWTP	8%	23	16	24
Open Defecatio	3%	3	3	6
Sum	100%	4	102	**496**

With an average of 2.5 kg LPG per unit and month used for pyrolysis, and negligible direct methane and nitrous oxide emissions, yearly CO_2 emissions from fuel combustion necessary for the transformation of human waste from one toilet unit is calculated as follows:

$$87\ kg\ CO_2 = 2.5\ {}^{kg\ LPG}/_{month} \cdot 12 \cdot 2.9\ {}^{kg\ CO_2}/_{kg\ LPG}$$

The CO_2 emission factor for LPG was chosen from the IPCC 2006 Guidelines on Energy (Garg, Kazunari, & Pulles, 2006).

For direct emissions during pyrolysis:

Wet weight of faeces: $\mathrm{m_{in,w}} = \frac{130g}{p \cdot d} \cdot 365\ \mathrm{d}\ \cdot 5\ \mathrm{p} \cong 240\frac{\mathrm{kg}}{\mathrm{a}}$

$$0.0015\ \mathrm{kg\ CH_4} = 240\frac{\mathrm{kg}}{\mathrm{a}} \cdot 5.8 \cdot 10^{-6}\ \mathrm{kg\ waste/kg\ CH_4}$$

$$0.0043\ \mathrm{kg\ N_2O} = 240\frac{\mathrm{kg}}{\mathrm{a}} \cdot 1.7 \cdot 10^{-5}\ \mathrm{kg\ waste/kg\ N_2O}$$

$$1.3\ \mathrm{kg\ CO_2 - eq}\ = (0.0015\ \mathrm{kg\ CH_4} \cdot 34\ \mathrm{kg\ CO_2eq/kg\ CH_4} + 0.0043\ \mathrm{kg\ N_2O} \cdot 298\ \mathrm{kg\ CO_2/\ kg\ N_2O})$$

For an average emission avoidance of 496 kg CO_2-eq per toilet unit per year, emission savings for one CBS unit amount to:

$$396\ ^{kg\ CO_2 - eq}/_{year} = 496\ kg\ CO_2 - 89\ kg\ CO_2 - 1\ kg\ CO_2$$

Depending on size of the project (=employed units) and the carbon price per ton of emission savings, carbon credit revenues could cover up to 5% – 15% of direct running costs.

Globally, there are seven organizations operating CBS projects. These are located in Kenya (Sanergy, Sanivation), Ghana (Clean Team toilets), Haiti (SOIL), India (Sanitation First), Madagaskar (Loowatt) and Peru (X-runner). First implementations of CBS were established more than ten years ago. Since the transformation processes and aggregate baseline scenarios differ significantly from region to region, overall emission savings cannot be easily estimated. The container-based sanitation alliance (CBSA) reports a combined growth rate for four projects (Sanergy, SOIL, Clean Team, x-runner) of 15 to 20 toilets per month (World Bank, 2019). This number is expected to grow in the next years, but new ways of financial revenues are needed, as currently, only 10% to 20% of total service costs are covered by revenues (World Bank, 2019). Further revenue streams, e.g., from carbon crediting may support this approach to scale and thus reduce greenhouse gas emissions from sanitation facilities and most importantly, provide people in low-income settings access to safe sanitation.

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APPENDIX

A. Demonstration of Additionality of a CBS Project

Additionality is proved for the case of the CBS project Mosan in Guatemala by providing evidence from official and government-backed sources:

- AMSCLAE (2020). Plan de Manejo Integrado : no mention of container-based sanitation or other mobile or dry toilet solutions in the watershed (or target region) of the Mosan project around the lake Atitlán, and mention of capacity building in the sewage sector (Basterrechea Dáz et al., 2020)
- INE (2019): CBS is not listed as a part of sanitation coverage in the country of Guatemala (INE, 2019)
- World Bank Group (2018) Identifies sanitation as one of the major challenges in Guatemala's development, with 47% of the population having access to an improved sanitation facility. CBS is not named as a possible solution to this issue but mentions capacity building in the sewage sector to improve the sanitation situation. (World Bank, 2018)
- International Human Rights Clinic (2012): Guatemala is in violation of people's rights to clean water and sanitation. This shows lack of access to sanitation services due to missing regulations and governmental support in the sanitation sector. (Skinner, Kueny, & Guildner, 2012)

It can be concluded that significantly less than 5% of the population in Guatemala currently have access to a CBS service, as it is not mentioned in any official literature or statistics about sanitation in Guatemala. Furthermore, this assessment shows the wide-spread lack of access to safe sanitation solutions.

B. Definitions for Sanitation Categories

Table 16: Categories of on-site sanitation

OSS No.	Definition
1.	Lined pit latrine which are effectively sealed, connected to individual household toilet facilities and emptied once full.
2.	Lined pit latrine which are effectively sealed, connected to individual household toilet facilities and to have never been emptied. Lower rates of greywater discharge than in shared facilities, greywater largely retained
3.	Lined pit latrine connected to flush toilet. More water content, which is largely retained. With the higher moisture content, more anoxic conditions are assumed
4.	Unlined pit latrine below the groundwater table. Infiltration of groundwater make conditions anaerobic.
5.	Unlined pit latrine above the groundwater table, little greywater is discharged
6.	Unlined pit latrine connected to a flush toilet. More water content, which can infiltrate to the ground
7.	Septic tank connected to flush toilets with two or three lined compartments, with an outlet for effluent water that infiltrates to the ground. Often also discharge of greywater.

Table 17: Categories of wastewater or faecal sludge discharge or treatment sites

No.	Name	Explanation
1.	Aquatic environments	In general, if no information available on type of water body, otherwise categorization into water body 2 or 3
2.	Lentic water bodies	Reservoirs, lakes and estuaries; eutrophic
3.	Rivers	
4.	Discharge to soil	Based on emission factors of open dump/unmanaged landfill
5.	Land application	Application of wastewater or sewage sludge in agriculture, but could also be applied for dumping of faecal sludge more spread out than in category 3.
6.	Stagnant sewer	Disposal of faecal matter in a sewer where transport water is not sufficient. For nitrous oxide emissions, this category is assumed to resemble conditions in a eutrophic lake, based on considerations made in (Doorn & Liles, 1999)
7.	Anaerobic shallow lagoon (< 2 m depth), facultative lagoon	Shallow lagoons or waste ponds

8.	Anaerobic deep lagoon (> 2 m depth)	Deep lagoon or waste ponds
9.	Anaerobic reactor (w/o methane recovery)	Controlled anaerobic digestion of secondary sludge or faecal sludge
10.	Constructed wetlands (three types, see draft methodology)	Based on three categories described on the 2013 IPCC Supplement for Wetlands
11.	Aerobic treatment plant	Entails biological aerated treatment. Three types with different considerations of the degree of treatment (see separate elaboration and Appendix).
12.	Drying bed	No distinction is made here between planted and unplanted drying bed
13.	Thickening tank	Settling and thickening tank for sludge
14.	Faecal sludge storage	Similar assumption to drying bed, relatively dry conditions or not piled but spread out (allowing for more oxygen supply)

C. Decision Tree to categorize Sanitation Pathways in Baseline Assessment