Application of the Oeko-Institut/WWF-US/ EDF methodology for assessing the quality of carbon credits

This document presents results from the application of version 3.0 of a methodology, developed by Oeko-Institut, World Wildlife Fund (WWF-US) and Environmental Defense Fund (EDF), for assessing the quality of carbon credits. The methodology is applied by Oeko-Institut with support by Carbon Limits, Greenhouse Gas Management Institute (GHGMI), INFRAS, Stockholm Environment Institute, and individual carbon market experts. This document evaluates one specific criterion or sub-criterion with respect to a specific carbon crediting program, project type, quantification methodology and/or host country, as specified in the below table. Please note that the CCQI website Site terms and Privacy Policy apply with respect to any use of the information provided in this document. Further information on the project and the methodology can be found here: www.carboncreditquality.org

Sub-criterion:	1.3.2 Robustness of the quantification methodologies applied to determine emission reductions or removals
Project type:	Industrial biodigesters fed with livestock manure
Quantification methodology:	CDM ACM0010 – Version 8.0
Assessment based on carbon crediting program documents valid as of:	15 May 2022
Date of final assessment:	31 January 2023
Score:	3

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Assessment

Relevant scoring methodology provisions

The methodology assesses the robustness of the quantification methodologies applied by the carbon crediting program to determine emission reductions or removals. The assessment of the quantification methodologies considers the degree of conservativeness in the light of the uncertainty of the emission reductions or removals. The assessment is based on the likelihood that the emission reductions or removals are under-estimated, estimated accurately, or over-estimated, as follows (see further details in the methodology):

Assessment outcome	Score
It is very likely (i.e., a probability of more than 90%) that the emission reductions or removals are underestimated, taking into account the uncertainty in quantifying the emission reductions or removals	5
It is likely (i.e., a probability of more than 66%) that the emission reductions or removals are underestimated, taking into account the uncertainty in quantifying the emission reductions or removals OR The emission reductions or removals are likely to be estimated accurately (i.e., there is about the same probability that they are underestimated or overestimated) and uncertainty in the estimates of the emission reductions or removals is low (i.e., up to ±10%)	4
The emission reductions or removals are likely to be estimated accurately (i.e., there is about the same probability that they are underestimated or overestimated) but there is medium to high uncertainty (i.e., ±10-50%) in the estimates of the emission reductions or removals OR It is likely (i.e., a probability of more than 66%) or very likely (i.e., a probability of more than 90%) that the emission reductions or removals are overestimated, taking into account the uncertainty in quantifying the emission reductions or removals, but the degree of overestimation is likely to be low (i.e., up to ±10%)	3
The emission reductions or removals are likely to be estimated accurately (i.e., there is about the same probability that they are underestimated or overestimated) but there is very high uncertainty (i.e., larger than ±50%) in the estimates of the emission reductions or removals OR It is likely (i.e., a probability of more than 66%) or very likely (i.e., a probability of more than 90%) that the emission reductions or removals are overestimated, taking into account the uncertainty in quantifying the emission reductions or removals, and the degree of overestimation is likely to be medium (±10-30%)	2
It is likely (i.e., a probability of more than 66%) or very likely (i.e., a probability of more than 90%) that the emission reductions or removals are overestimated, taking into account the uncertainty in quantifying the emission reductions or removals, and the degree of overestimation is likely to be large (i.e., larger than ±30%)	1

Information sources considered

1 CDM ACM0010 – Version 8.0

2 CDM Methodological tool 14: Project and leakage emissions from anaerobic digesters – Version 2.0
3 CDM Methodological tool 13: Project and leakage emissions from composting – Version 01.0.0
4 CDM Methodological tool 06: Project emissions from flaring – Version 4.0
5 IPCC 2006 Guidelines for National Greenhouse Gas Inventories. Volume 4, Chapter 10 Emissions from livestock and manure management.
6 IPCC 2019: Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4, Chapter 10 Emissions from livestock and manure management.
7 IPCC 2006 Guidelines for National Greenhouse Gas Inventories. Volume 4, Chapter 11 Emissions from livestock and manure management. N_2O emissions from managed soils, and CO_2 emissions from lime and urea application
8 Duren et al. 2019: California's methane super-emitters, Nature volume 575, pages180–184. https://doi.org/10.1038/s41586-019-1720-3
9 Zhang et al. 2013: Carbon emission reduction potential of a typical household biogas system in rural China, Journal of Cleaner Production, Volume 47, May 2013, Pages 415-421. https://doi.org/10.1016/j.jclepro.2012.06.021

Assessment outcome

The quantification methodology is assigned a score of 3.

Justification of assessment

Project type

This assessment refers to the project type "Industrial biodigesters fed with livestock manure". The project type is characterized as follows:

"Generation of biogas by anaerobic digestion of livestock manure. The biogas is combusted for the generation of power and/or heat, which can be fed into the grid or used on-site. A smaller fraction of the gas may be flared. The project type reduces emissions by (i) avoiding methane emissions from the uncontrolled decomposition of livestock manure and (ii) by displacing more greenhouse gas intensive energy generation based on fossil fuels."

Under ACM0010, projects are applicable if in the baseline manure management system[1] the manure is treated and stored partly under anaerobic condition, which leads to methane emissions. More specifically, projects are applicable if the depth of the lagoons used for manure management under the baseline scenario is at least 1 m, the retention time is greater than one month, and the average annual temperature is greater than 5°C. Livestock has to be managed under confined conditions (no free roaming). Applicable are existing as well as greenfield livestock facilities (if they can demonstrate that an uncovered anaerobic lagoon is the most plausible baseline scenario).

[1] Manure management system is the general term ACM0010 uses for methods to treat the manure.

The focus of the following assessment is on elements with the potential for over- and underestimation of emission reductions and on elements that introduce uncertainty. These elements are numbered and summarized in Table 5. Elements that we assume to be neutral are not further discussed.

Emission sources considered in calculating emission reductions

Table 1 lists the emission sources included in ACM0010 and compares them with methodologies adopted under the CAR and the CDM. Under ACM0010, all major emission sources are included. ACM0010 differs from the CAR methodology mainly because it accounts for emission reductions associated with the utilization of methane from the biodigesters (in most projects the methane is used for electricity generation). ACM0010 also considers changes in nitrous oxide (N_2O) emissions, whereas CAR does not include N_2O emissions.

Table 1 Comparison of emissions sources considered in manure management methodologies

Emissions from	CDM ACM0010 (v8)	CAR Livestock (USA v4.0 and Mexico v2.0)	CDM AMS-III.D (v21)
Baseline Emissions			
Baseline waste treatment processes	CH_4: Yes N_2O: Yes	CH_4: Yes **N_2O: No**	CH_4: Yes **N_2O: No**
Electricity or thermal energy generation or use of natural gas in the baseline scenario	CO_2: Yes	**No**	CO_2: Yes[2]
Upstream emissions of fossil fuels used in the baseline scenario	No	No	No
Project Emissions			
Project waste treatment processes / Effluent treatment system	CH_4: Yes N_2O: Yes[3]	CH_4: Yes **N_2O: No**	CH_4: Yes[4] **N_2O: No**
Physical leakage or venting of gas from the biodigester	CH_4: Yes (phys. leakage)	CH_4: Yes (**venting** and phys. leakage)	CH_4: Yes (phys. leakage)
Incomplete destruction of methane from combustion or flaring of the biogas	CH_4: Yes	CH_4: Yes	CH_4: Yes
Electricity and thermal energy use	CO_2: Yes	CO_2: Yes	CO_2: Yes
Project construction and decommissioning	No	No	No
Leakage Emissions			
Disposal of treated manure on land	CH_4: Yes N_2O: Yes[5]	**CH_4: No** **N_2O: No**	**CH_4: No** **N_2O: No**

2 AMS-III.D refers to AMS-III.H, where utilization of the recovered biogas is eligible.
3 Direct and indirect N_2O emissions
4 The effluent from the biodigester shall be handled aerobically, otherwise the related emissions shall be taken into account as per relevant procedures of “AMS-III.AO Methane recovery through controlled anaerobic digestion". In the case of soil application, proper conditions and procedures (not resulting in methane emissions) must be ensured.
5 Incl. application, leaching and run-off

Storage of liquid or solid[6] effluent (outside project boundary)	CH_4: Yes	CH_4: Unclear	CH_4: Yes
Composting of the digestate	CH_4: Yes N_2O: Yes	CH_4: Yes **N_2O: No**	CH_4: Yes N_2O: Yes
Leakage only considered if in total positive	Applied	Not applied	Not applied
Overall emission reductions			
Minimum value of modelled and measured emission reduction	Applied	Applied	Applied

OE1 Project construction and decommissioning

ACM0010 does not account for project emissions due to the construction and decommissioning of the project equipment, arising mainly from the emissions embodied in steel and cement. There are few studies that quantify the impact. For household scale biodigesters in China, Zhang et al. 2013 calculate that the impact is equivalent to 1.8 years of emission reductions, which would correspond to 12% over a lifetime of 15 years. As industrial biodigesters are much larger and thus require significantly less steel and cement per volume of manure, we assume that a much smaller fraction applies for industrial scale digesters.

UE1 Neglecting upstream emissions from fossil fuels used in the baseline scenario

ACM0010 does not account for the upstream emissions associated with production of fossil fuels used in the baseline scenario for electricity or thermal energy generation. According to the World Resources Institute, upstream emissions account for 5-37% of fossil fuel's emissions, depending on the type and origin of the fossil fuel.[7] CO_2 emissions from fossil fuel combustion account for approximately 10-15% of total baseline emissions. Overall, neglecting upstream emissions from the associated fossil fuel productions thus underestimates overall emission reductions but to a relatively small extent (up to about 5%, depending on the type and origin of the fossil fuels).

Determination of baseline emissions

Baseline emissions are modelled using a variety of default parameters as well as data on the average population of livestock per category (corresponding mostly to the Tier 2 approach in the 2006 IPCC Guidelines for national GHG inventories and their 2019 Refinement). Baseline emissions arise from:

- Methane emissions from the baseline manure management system
- Nitrous oxide emissions from the baseline manure management system
- CO_2 emissions from electricity and/or heat generation using fossil fuels (which are being replaced by electricity and/or heat generated using biogas)

The following table lists the relevant parameters and provides a brief assessment of the uncertainty and the overall impact.

[6] Solid effluent usually in a solid waste disposal site.
[7] https://www.wri.org/data/upstream-emissions-percentage-overall-lifecycle-emissions (17 October 2022). This number does not include refining. Furthermore, the construction of electricity generation plants etc. is not accounted for.

Table 2 Baseline emissions: relevant parameters

Element	Usual Source[8]	Example	Uncertainty of element	Overall impact on under- or overestimation
Methane emissions from the baseline manure management system				
Average population of livestock category	Measured	100 market swine	Small	Small
Volatile solids[9] (VS) produced by livestock category	IPCC default values for different categories and regions[10]	0.3 kg VS/day/head (market swine in Asia)	Medium-High ±25% (IPCC 2006, Table 10A-7)	Medium-High
Percent of manure managed in manure management system	Measured	90%	Small	Small
Maximum methane producing capacity of manure for livestock category (B_o)	IPCC default values for different livestock categories and regions	0.29 m^3 CH_4/kg VS (market swine in Asia)	Medium ±15% (IPCC 2006, Table 10A-7)	Medium
Methane conversion factor (MCF) of the baseline manure management system[11]	IPCC default values for different systems and temperatures	78% (uncovered anaerobic lagoon at 20°C)	High[12] Depending on temperature, retention time, cover, etc.	High

8 For many parameters the methodology allows to (a) use IPCC default values, (b) measure the parameter, or (c) use country-specific data (if available). We assume that projects use IPCC default values (which seems to be the case in most projects).

9 Volatile solids (VS) are organic material in livestock manure and consist of both biodegradable and non-biodegradable fractions. The value needed is the total VS (both degradable and non-biodegradable fractions) as excreted by each animal species since the B_o (the maximum methane producing capacity of manure for livestock category) values are based on total VS entering the system.
Note that IPCC2019 does not provide per head estimates but per 1000kg animal mass and in addition the average per animal mass. For example, 6.8 kg VS per (1000 KG animal mass) per DAY and 49 kg animal mass for mean “finishing swine in Asia”. This results in 0.33 kg VS per head per day

10 To determine volatile solids, ACM0010 offers four option, with different complexity. For the assessment we assume that Option 4 is being used, which allow using IPCC default values.

11 The MCF represents the degree to which B_0 is achieved.

12 IPCC 2006 table 10.17, chapter 10, volume 4 notes for MCF values: “Judgement of IPCC Expert Group in combination with Mangino et al. (2001). Uncovered lagoon MCFs vary based on several factors, including temperature, retention time, and loss of volatile solids from the system (through removal of lagoon effluent and/or solids).” Based on this citation and our own judgment, we assume that the uncertainty of the MCF is high. Further note that IPCC 2019 has revised the data for MCF slightly and provides an excel tool that replaces the parameters with a more sophisticated modelling approach. It considers that taking yearly average temperature does not account for the fact that methane emissions depend nonlinearly on temperature (see 10B.5). Default parameters for Tier 1 are however still available. And ACM0010’s most current Version 8 (valid from 4 October 2013 onwards) still refers to IPCC 2006.

Conservativeness factor applied to methane conversion factor	Fixed	0.94[13]	-	6% underestimation
Nitrous oxide emissions from the baseline manure management system				
Annual average nitrogen excretion per head of a defined livestock population	IPCC default values for different livestock categories and regions	0.42 kg N/1000kg animal/day (market swine in North America or Asia)	High ±50% (IPCC 2006: Judgement by IPCC Expert Group)	Medium
Direct N_2O emission: emission factor of manure management system	IPCC default values for different systems	0 kg N2O-N per kg N excreted (Uncovered anaerobic lagoon)	High	Medium
Indirect N_2O emission: Nitrogen loss due to volatilization of NH3 and NOx from manure management	IPCC default values for different livestock categories and management systems	40% for Swine in Anaerobic lagoon	High IPCC 2006 refers to 25%-75%	Medium
Indirect N_2O emission: Emission factor from atmospheric deposition of nitrogen on soils and water surfaces	IPCC default value	0.010 kg N_2O-N / kg N	High IPCC 2006 refers to 0.002-0.05	Medium
CO_2 emissions from electricity generation				
Generated electricity in project	Measured	MWh/a	Small	Small
Grid emission factor	Determined project specific	tCO_2e/MWh	Medium	Small
CO2 emissions from heat generation				
Produced heat in project	Measured	MWh/a	Small	Small
Emission factor of fuel	Default value	tCO2e/MWh	Small	Small

U1 Modelled baseline emissions

In general, methane emissions from manure management in the baseline are uncertain, as they arise from complex biological processes. These depend on many factors, including animal species,

[13] The method reads: “A conservativeness factor should be applied by multiplying MCF values (estimated as per above bullet) with a value of 0.94, to account for the 20 per cent uncertainty in the MCF values as reported by IPCC 2006” (ACM0010 v 8, page 31).

climate, region, livestock productivity system, the extent of anaerobic conditions, or the retention time of the organic materials.

For ACM0010, the preferred option is in most cases to use regional or even project-specific data. Project owners can, however, always use default values from the IPCC Guidelines, which is done in most projects. IPCC default values are often based on rather old data or on expert judgment. It is beyond the scope of this assessment to evaluate the appropriateness and uncertainty of each parameter in detail. Table 2 summarizes available information and shows that several parameters have considerable uncertainty. If available, the table shows the quantitative uncertainty estimates as provided in the IPCC Guidelines.

To assess the overall uncertainty of baseline methane emissions, we apply a gaussian propagation of uncertainty for the three parameters that we assess in Table 2 to have medium or have high uncertainty: (a) the volatile solids produced by livestock category, (b) the maximum methane producing capacity of manure for livestock category (Bo), and (c) the methane conversion factor (MCF) of the baseline manure management system. For the first two parameters, we use the uncertainty band indicated by the IPCC. For the methane conversion factor, we estimate the uncertainty to be at least ±30%. This simplified calculation results in an overall uncertainty of at least 40% for methane emissions alone.[14] As the IPCC ranges are expert judgements and the uncertainty of the MCF is our own judgement (i.e., these values are not derived from data), this uncertainty estimate is to be understood as a rough approximation.

To account for the uncertainty, the methodology uses two safeguards: it applies a discount factor (discussed below under UE2) and requires that the following two values be determined for any given year and the lower value be used for quantifying emission reductions:

- The modelled methane baseline emissions subtracted by the project emissions due to physical methane leakage from the anaerobic digester; and
- The quantity of methane produced in the biodigester. This is determined based on the (i) quantity of produced biogas (which has to be measured) and (ii) the fraction of methane in the biogas (which can either be measured or a default value of 60% can be used).

The intent of this approach is using the measured methane generation under the project activity to cap the modelled baseline emissions. However, it seems likely that methane generation under the project is larger than in the baseline scenario, as a biodigester's purpose is to produce as much methane as possible. This approach is thus primarily a safeguard against significant overestimation of modelled baseline emissions. We do not have data with respect to how often this cap is applied. Assuming that a project biodigester has a methane conversion factor of 90%, whereas it is 60-80% in the baseline manure management system[15], the cap would only apply if the overestimation was approximately 12%-50%. The approach is therefore not deemed as an element that contributes to underestimating emission reductions but could reduce the degree of any overestimation.[16]

[14] Based on the three identified parameters the uncertainty is: (0.25^2+0.15^2+0.30^2)^0.5 = 42%. The contribution of other components is considered to be minor. We say "at least", as we did not quantify all uncertainty sources.

[15] Values loosely based on IPCC 2019, table 10.17

[16] The safeguard is the less effective the lower the methane conversion factor of the baseline manure management system.

Nitrous oxide emissions are calculated distinguishing between direct and indirect emissions and using IPCC default values. There is even more uncertain than for methane emissions (see ranges provided by IPCC 2006). However, the absolute contribution to baseline emissions is smaller — at least according to the default values.[17]

For both methane and nitrous oxide baseline emissions, ACM0010 allows project owners to use either measurements or default values. We are however not aware of any project pursuing measurements, possibly due to the associated costs and the risk that this might result in lower emission reductions compared to the default values.

To sum up element U1: Considering the uncertainty for methane emissions alone (more than 40%) as well as the other uncertainty sources, we assume that the overall uncertainty is at least 50%. However, the impact of this uncertainty might be mitigated to some extent due to the safeguard of using the lower value between the modelled methane emissions and actual methane generation under the project, as described above.

UE2 6% discount of methane emissions from the baseline manure management system

To mitigate the uncertainty in the estimates of baseline methane emissions, ACM0010 prescribes a conservativeness discount of 6% to be applied to the baseline methane emissions from the manure management system. As these emissions are usually higher than claimed emission reductions (due to project and leakage emissions), the impact of this element on overall emission reductions is likely to be higher than 6%.

U2 Greenfield Facilities

The methodology also covers greenfield livestock facilities if they can proof that the most plausible baseline scenario is using an uncovered anaerobic lagoon. The fact that greenfield facilities are allowed introduces additional uncertainty: while for existing facilities it can be empirically observed whether an anaerobic lagoon was in place, for new facilities this cannot be observed but would need to be assessed based on other information.[18] However, we assume that greenfield facilities make up a small fraction of projects such that the impact on overall emission reduction across all projects is not large.

Determination of project emissions

Project emissions arise from

- Methane emissions from physical leakage from biodigesters and from flare inefficiency

[17] For example, Gold Standard project GS 2561 provides an excel file of its emission reduction calculation using default values. For this project, nitrous oxide baseline emissions are about 20 times smaller than methane baseline emissions.

[18] There are several options how an anaerobic lagoon could be designed, including the depth and surface area of the anaerobic lagoon or the residence time of the organic matter. Those design options result in different methane emissions. The available default values largely differentiate between those design options.

- Methane emissions from the effluent of the biodigester (also called digestate[19]); this depends on the post digester manure management system[20]
- Nitrous oxide emissions from the effluent of the biodigester, also depending on the post digester manure management system
- CO_2 emissions from electricity and fossil fuel consumption to operate the manure management system

Project emissions are again determined based on models with various input parameters that are either measured parameters or default values. The following table lists relevant parameters.

Table 3 Project emissions: relevant parameters

Element	Usual Source	Example	Uncertainty of element	Overall impact on under- or overestimation
Physical leakage emissions from biodigester and flare inefficiency				
Produced methane	Amount of Biogas: Measured Fraction of methane: measured or default	x m^3/yr Fraction of methane: 60%	Small	Small
Methane: physical leakage from the biodigester[21]	Three default values for different types of biodigesters[22]	2.8%, 5% or 10% tCH4 leaked / tCH4 produced	High	Medium-High
Methane flare efficiency (for emergency flaring)	CDM Tool 06	95%	Small to Medium	Small
Methane emissions from the effluent treated in the project manure management system				
Fraction of volatile solids degraded in anaerobic biodigester	IPCC default values	40-70% (heated digestor)	High	Small
Methane conversion factor effluent (sludge)	IPCC default values for different systems and temperatures	4% Solid Storage at 20°C	High	Medium
Nitrous oxide emissions from the effluent treated in the project manure management system				
Average population of livestock category	See baseline	-	Small	Small
Annual average nitrogen excretion per head of a defined livestock	See baseline	-	Medium	Small
Direct N_2O emission: emission factor of	IPCC Default per system (often emission factor is	0.005 kg N2O-N per kg	High IPCC 2006	Medium

[19] Effluent or digestate are the spent contents of an anaerobic digester. Digestate may be liquid, semi solid or solid.

[20] Digestate may be further stabilized aerobically, applied to land, sent to a solid waste disposal site (SWDS) or kept in a storage or evaporation pond.

[21] Physical leaks through the roof and side walls, and release through safety valves due to excess pressure in the digester

[22] See CDM TOOL14 for definition of digester types and their leakage rates.

manure management system	zero)	N excreted Liquid/Slurry with natural crust	refers to “Factor 2”	
Indirect N_2O emission: Nitrogen loss due to volatilization of NH3 and NOx from manure management	IPCC Default per animal and manure management system	48% Swine and liquid/slurry	High IPCC 2006 refers to 15%-60%	Medium
Indirect N_2O emission: Emission factor from atmospheric deposition of nitrogen on soils and water surfaces	IPCC Default	0.010 kg N2O–N per N lost	High IPCC 2006 refers to 0.002 - 0.05	Medium-High
		CO_2 emissions		
From additional electricity and fossil fuel consumption			Small to Medium	Small

U3 Modelled project emissions

Analogous to the determination of baseline emissions, ACM0010 considers various project emission sources and uses a mix of measured parameters and default values. A detailed assessment of the individual elements is beyond the scope of this document. Regarding default values, it is again in most cases the preferable option to use regional defaults (or even project specific data) but there is always the option to use IPCC default values, which is done in most projects.

We assume that a key parameter affecting overall emission reductions is methane that physically leaks from the biodigester. In this respect ACM0010 refers to Tool 14, which suggests using “manufacturer information” but also provides default values for three types of digesters (see Table 3). Provided that a biodigester is well-maintained, these default values seem plausible (yet no source is provided in the tool). However, if biodigesters are not well-maintained or frequently vented, actual physical leakage rates might be higher. Duren et al. 2019 used airborne imaging spectrometer to detect methane plumes in California. They found that emissions are not equally distributed among installations but that certain installations are super emitters. While their focus was methane emitters in general, they explicitly mention manure management and anaerobic digesters as potential problems. There is however no data which would allow us to quantify the uncertainty of this element.

The approach to calculate project nitrous oxide emissions is the same as for the baseline. There are however different emissions factors (as the manure management system changes). Using default values, information from one project suggests that the nitrous oxide emission in the project case are in the same order of magnitude as the methane emissions from physical leakage (in terms of CO_2 equivalents).[23]

Determination of leakage emissions

On top of project emissions, the methodology also covers leakage emissions outside the project boundary due to final disposal of treated manure (which is spread on land). It distinguishes between nitrous oxide and methane emissions in the baseline scenario and under the project:

[23] Gold Standard project GS 2561.

- Nitrous oxide emissions arise from the remaining nitrogen content after the project and baseline manure management system, respectively. Firstly, the methodology applies a reduction factor that estimates by how much nitrogen is reduced through the manure management system. Secondly, nitrous oxide leakage emissions from the remaining nitrogen are subdivided into (i) land application, (ii) leaching & run-off and (iii) volatilisation, each having an emission factor.
- Methane emissions arise from the remaining volatile solid content under the baseline and the project. There is again a reduction factor that estimates by how much volatile solids are reduced. The remaining volatile solid is multiplied with the methane generation potential and a 100% conversion factor to determine methane emissions.

In both cases the only difference between project and baseline calculations are the remaining nitrogen or volatile solids after treatment. According to the default values used in the methodology, leakage emissions in the project are usually higher than in the baseline. And methane emissions are usually higher than nitrous oxide emissions.

In addition, the methodology covers potential leakage due to CH_4 emissions of storage of liquids or solids in a solid waste disposal site as well as due to CH_4 and N_2O emissions from composting of the effluent. These emissions are again determined using default values. We assume, however, that the influence of these emission sources on the overall emission reductions is small for the majority of projects.

Table 4 Leakage: relevant input parameters

Element	Usual Source	Example	Uncertainty of element	Impact on overall under- or overestimation
Nitrous oxide emissions from disposal of treated manure (land application, leaching & run-off and volatilisation)				
Annual average nitrogen excretion per head of a defined livestock	See baseline	-	Medium	Small-Medium
Nitrogen reduction factor in baseline or project	IPCC default values for different manure management system	60% (one cell lagoon)[24]	High	Medium
Application of manure on land: emissions factor	IPCC default value	=0.02 kg N2O-N/kg N (for cattle or pigs)	Very High (IPCC2006, table 11.1: 0.007 – 0.06)	Medium
Leaching&run-off: emissions factor times leached fraction	IPCC default value	=0.0075*0.3 kg N2O-N/kg N and	Very High (IPCC2006, table 11.3: for 0.0075: 0.0005–0.025)	Medium
Volatilisation: emissions factor times volatized fraction	IPCC default value	=0.01*0.2 kg N2O-N/kg N	Very High (IPCC2006, table 11.3: for 0.01: 0.002–0.05)	Medium
Methane emissions from disposal of treated manure				
Amount of input volatile solids and methane generation potential	See baseline	-		
Baseline volatile solid reduction factor (input vs. output of treatment system)	IPCC default values for different treatment system	85% (on cell lagoon)	High	Medium-High
Project volatile solid reduction factor (input vs. output of treatment system)	IPCC default values for different treatment system	80% (covered cell of two cell lagoon) 20% (underfloor pit storage)	High	High
MCF = 1	Fixed value		Medium	Medium
CH_4 emissions from storage of liquids or solids in solid waste disposal sites				
Monitoring or IPCC default values (rarely relevant)				
CH_4 and N_2O emissions from composting of the digestate				
Applying CDM tool 13: Project and leakage emissions from composting (rarely relevant)				

U4 Modelled leakage emissions

Disposal of treated manure causes significant nitrous oxide and methane emissions outside the system boundary. Due to the changes in the manure management, there might be significant changes in those emission sources between the baseline and the project case. For example, in a project where the detailed calculations are publicly available[25], leakage emission from treated manure for a monitoring period are determined as follows:

- Leakage in the baseline: Methane: 93'777 tCO_2eq; Nitrous oxide: 3'754 tCO_2eq
- Leakage in the project: Methane: 219'031 tCO_2eq; Nitrous oxide: 14'076 tCO_2eq
- This compares to overall baseline emissions of 446'019 tCO_2eq and project emissions of 18'103 tCO_2eq

The complex processes involved are captured by simplified default values that are associated with considerable uncertainty. The overall uncertainty of leakage emissions is thus high. For that reason, ACM0010 only considers leakage if the difference is positive such that leakage can only decrease emission reductions but cannot increase them. This is in principle a conservative requirement but only has impact in case leakage would increase emissions reductions but not in case it decreases emission reduction. We thus consider this as a uncertain element.

Summary and conclusion

Table 5 summarizes the assessment. For each of the previously discussed elements it estimates the potential impact on emission reduction quantification.

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24 Another example: 25-35% (covered first cell of 2 cell lagoon)

25 Gold Standard project GS 2561

Table 5 Relevant elements of assessment and qualitative ratings

Element	Fraction of projects affected by this element[26]	Average degree of under- or overestimation where element materializes[27]	Variability among projects where element materializes[28]
Elements likely to contribute to overestimating emission reductions			
OE1 Project construction and decommissioning	All	Low	Low
Elements likely to contribute to underestimating emission reductions			
UE1 Neglecting upstream emissions from fossil fuels used in the baseline scenario	All	Low	High
UE2 6% discount of methane emissions from the baseline manure management system	All	Low-Medium	None
Elements with unknown impact			
U1 Modelled baseline emissions	All	High	High
U2 Greenfield Facilities	Low	Low	Low
U3 Modelled project emissions	All	Medium	High
U4 Modelled leakage emissions	All	Medium-High	High

26 This parameter refers to the likely fraction of individual projects (applying the same methodology) that are affected by this element, considering the potential portfolio of projects. “Low” indicates that the element is estimated to be relevant for less than one third of the projects, “Medium” for one to two thirds of the projects, “High” for more than two third of the projects, and “All” for all of the projects. “Unknown” indicates that no information on the likely fraction of projects affected is available.

27 This parameter refers to the likely average degree / magnitude to which the element contributes to an over- or underestimation of the total emission reductions or removals for those projects for which this element materializes (i.e., the assessment shall not refer to average over- or underestimation resulting from all projects). “Low” indicates an estimated deviation of the calculated emission reductions or removals by less than 10% from the actual (unknown) emission reductions or removals, “Medium” refers to an estimated deviation of 10 to 30%, and high refers to an estimated deviation larger than 30%. “Unknown” indicates that it is likely that the element contributes to an over- or underestimation (e. g. overestimation of emission reductions in case of an omitted project emission source) but that no information is available on the degree / magnitude of over- or underestimation. Where relevant information is available, the degree of over- or underestimation resulting from the element may be expressed through a percentage range.

28 This refers to the variability with respect to the element among those projects for which the element materializes. “Low” means that the variability of the relevant element among the projects is at most ±10% based on a 95% confidence interval. For example, an emission factor may be estimated to vary between values from 18 and 22 among projects, with 20 being the mean value. “Medium” refers to a variability of at most ±30%, and “High” of more than ±30%.

Baseline, projects and leakage emissions are determined using a staggering amount of default values. There is no obvious omission of emissions sources and the default values are chosen based on differences between the type of livestock, technical systems, regions and temperatures. The reference for most default values are the 2006 IPCC Guidelines and the 2019 IPCC Refinement. These default values are often based on scare data in combination with expert judgment. As methane and nitrous oxide emissions arise from very complex biological processes, even the methodology's rather comprehensive approach cannot account for the variety of influencing factors. For many elements, we could therefore not identify whether the approach leads to an under- or overestimation. The modelling of baseline, project and leakage emissions is, however, identified to involve high uncertainty (U1, U3 and U4). For U1 alone, it plausible to assume that the uncertainty could be at least about ±50%. The uncertainties arising from U2-U4 increase that range.

There are elements that lead to overestimation and underestimation, with the latter having more impact. Thus, the methodology might lead to some underestimation overall. Whether and in how many instances such an underestimation will occur, is uncertain, due to the large uncertainties in the overall emission reductions. We thus do not assume that underestimation is *likely* to occur (i.e., with a probability of 67%), which would qualify for a score of 4. If there would be no bias towards over- or underestimation of emission reductions, the methodology would qualify for a score 2, as we estimate the uncertainty in overall emission reductions to be larger than ±50%. However, noting the slight tendency towards underestimation, we here assign an overall score of 3.