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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:	Household Biodigesters
Quantification methodologies:	CDM AMS-I.C, Version 21.0 CDM AMS-I.E, Versions 12.0 and 13.0 CDM AMS-III.R, Version 4.0 GS TPDDTEC, Version 3.1 GS AMB, Version 1.0
Assessment based on carbon crediting program documents valid as of:	15 May 2022
Date of final assessment:	31 January 2023
Score:	See page 2

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Scores

Project subgroups and methodologies	Score
Household biodigesters where emission reductions are claimed from reducing the consumption of non-renewable biomass (all applicable methodologies: CDM AMS-I.E with or without CDM AMS-III.R, GS TPDDTEC, GS AMB).	1
Household biodigesters where no emission reductions are claimed from reducing the consumption of non-renewable biomass (but from reducing fossil fuel consumption) for:	
• CDM AMS-I.C with or without CDM AMS-III.R	1
• GS TPDDTEC	2
• GS AMB	2

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 AMS-III.R (v4)

2 CDM AMS-I.E (v12 and v13)

3 CDM AMS-I.C (v21)

4 GS Technologies and Practices to Displace Decentralized Thermal Energy Consumption (TPDDTEC) v3.1

5 Methodology for animal manure management and biogas use for thermal energy generation (AMB), v1.0

6 CDM Tool 30 (v4)

7 CDM Tool 33 (v2)

8 Ballis et al 2015: The carbon footprint of traditional woodfuels, nature climate chage, 5, pages266–272 (2015) https://doi.org/10.1038/NCLIMATE2491

9 Bailis et al. 2020: Fraction of non-renewable biomass in emission crediting in clean and efficient cooking projects, a review of concepts, rules, and challenges; a report prepared for the world bank.

10 Brunn et al. 2014: Small-scale household biogas digesters: An option for global warming mitigation or a potential climate bomb? Renewable and Sustainable Energy Reviews, Volume 33, May 2014, Pages 736-741 https://doi.org/10.1016/j.rser.2014.02.033

11 Cames et al. 2016, Öko-Institut “How additional is the Clean Development Mechanism?”

12 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

13 Revised IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual (1996): Energy Chapter, page I.46, https://www.ipcc-nggip.iges.or.jp/public/gl/guidelin/ch1ref3.pdf.

14 Rogner et al. in Climate Change 2007: Mitigation of Climate Change (eds Metz, B. et al.) 95–116 (IPCC, Cambridge Univ. Press, 2007).

15 IPCC 2006 Guidelines for National Greenhouse Gas Inventories. Volume 4, Chapter 10 Emissions from livestock and manure management.

16 IPCC 2019: Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4, Chapter 10 Emissions from livestock and manure management.

17 CDM Methodologies Panel 2022: Review of default baseline assumptions applied in AMS-I.E, AMS-II.G and TOOL30. https://cdm.unfccc.int/sunsetcms/storage/contents/stored-file-20220713221018839/MP88_EA19_CN_Cookstove%20default%20values.pdf

Assessment outcome

The quantification methodologies are assigned the scores as provided on page 2.

Justification of assessment

Project type

This assessment refers to the project type “Household biodigesters”. The project type is characterized as follows:

“Generation of biogas by anaerobic digestion of livestock manure, and possibly other household waste such as kitchen waste, through household size biodigesters (e.g., with a capacity of 2 m^3). The biogas is used by households for cooking. The project type may include a compost unit that utilizes the fermented sludge from the biodigester to produce organic fertilizer. The project type reduces emissions by (i) avoiding methane emissions from the uncontrolled decomposition of livestock manure and (ii) by reducing the use of firewood or fossil fuels for cooking activities. Projects are located in rural areas in developing countries.”

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 7. Elements that we assume to be neutral are not further discussed.

Methodologies

This assessment covers the methodologies (and combinations thereof):

- CDM methodologies (combinations):
  - For claiming emission reductions from methane avoidance from uncontrolled decomposition of livestock manure (methane avoidance):
    - AMS-III.R
  - For claiming emission reductions from fuel switch (fuel switch):
    - AMS-I.E if firewood/charcoal (wood fuels) are the baseline fuels; and/or
    - AMS-I.C if fossil fuels are the baseline fuels.
- TPDDTEC v3.1[1]: Gold Standard’s methodology that was valid until August 2022, with a rather broad focus that covers emission reductions from both methane avoidance and fuel switch.
- Methodology for animal manure management and biogas use for thermal energy generation (AMB), v1.0: Gold Standard’s methodology that is valid since August 2022, with a focus on this project type, also covering emission reductions from both methane avoidance and fuel switch.

In the following, we assess all these methodologies, considering differences in the approaches used by those methodologies. Some findings only concern a subset of projects under this project type. In particular, we distinguish the following two subgroups of projects:

- Projects that claim emission reductions from methane avoidance (all projects claim fuel switch).

[1] There is a Version 4.0, which however does not cover biodigesters anymore.

- Projects that claim emission reductions from reducing the consumption of non-renewable biomass (firewood and/or charcoal).

The methodologies' scopes differ on details but is in generally similar.

Emission sources for calculating emission reductions

Table 1 lists the emission sources included under the different methodologies.

Table 1 Emissions sources included under the different methodology

Emissions from	CDM AMS-III.R (v4) AMS-I.C (v21) AMS-I.E(v12)	Gold Standard TPDTDEC v3.1	Gold Standard AMB
Baseline emissions: methane avoidance			
Emissions from the baseline waste treatment processes	CH_4: Yes N_2O: No	CH_4: Yes N_2O: No	CH_4: Yes N_2O: No
Baseline emissions: fuel switch			
CO_2 emissions from fuel consumption in the baseline scenario	Yes	Yes	Yes
CH_4 and N_2O emissions from fuel consumption in the baseline	No	Yes	Yes
Upstream emissions of fossil fuels used in the baseline scenario	No	No	No
Project emissions			
Project waste treatment processes / effluent treatment system	No[2]	No	Yes
Physical leakage or venting of methane from the biodigester	Yes (Physical leakage only)	No	Yes (Physical leakage only)
Incomplete destruction of methane from combustion of the biogas	Yes	No	No
Project construction and decommissioning	No	No	No
Leakage emissions			
Due to biomass usage and installation of thermal appliances	Partly	Yes	Yes
Changes of methane and nitrous oxide emissions outside the project boundary due the changes in the animal waste management system	No	No	Yes (CDM Tool14)

2 This is taken into account in AMS-III.D (which is very similar to AMS-III.R) but not in AMS-III.R.

OE1 Omissions of several emission sources (relevant for all methodologies)

Table 1 shows that there are several emission sources that are not considered in the methodologies. The most relevant ones are

- Leakage due to biomass usage and installation of thermal appliances: all methodologies provide guidance to identify possible leakage effects (CDM methodologies AMS-III.R and AMS-I.C refer to Tool22, AMS-I.E refers to Tool16). However, the CDM methodologies and the GS methodology AMB allow for an “all-inclusive” deduction of 5% to account for leakage, without requiring further justification. TPDDTECv3.1 does not provide the option to apply such a 5% discount. Under the methodology, project owners must investigate potential sources of leakage every two years. Yet, if leakage risks are deemed very low, they can be ignored in the quantification of emissions reductions.
- Project emissions from project waste treatment processes / effluent treatment system and leakage emissions due to changes in the animal waste management system: The biodegradable material in the biodigester never decomposes completely such that the effluent (also called digestate) still has the potential to emit methane. The effluent may be applied to land, further stabilized aerobically, or kept in a storage or evaporation pond. Especially the last option may lead to methane emissions. CDM methodologies and TPDTDEC v3.1 neglect these emissions from post treatment which may lead to overestimation of emission reductions. AMB seems to consider them.
- The projects produce organic fertilizer that may replaces synthetic fertilizer, which may have an impact on N_2O emissions.

It is beyond the scope of this assessment to quantify the impact of neglecting these emission sources differentiated by the various methodologies. We assume that a more detailed analysis would not impact the overall soring of the methodologies. Such an analysis is thus deferred to subsequent work.

OE2 Project construction and decommissioning (relevant for all methodologies)

The methodologies do not mention or account for project emissions due to construction and decommissioning of 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.

UE1 Neglecting upstream emissions from fossil fuels used in the baseline scenario (relevant if fossil fuels are replaced)

The methodologies do not account for upstream emissions associated with production of fossil fuels used in the baseline scenario. 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.[3] Neglecting upstream emissions thus underestimates overall emission reductions, if fossil fuels are replaced.

[3] 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.

Determination of baseline emissions (Methane avoidance)

Methane emissions from manure treatment in the baseline are calculated using a variety of default values (corresponding mostly to the Tier 2 approach in the 2006IPCC Guidelines and the 2019 IPCC Refinement).

Table 2 lists relevant parameters and provides a brief assessment of the uncertainty and the overall impact.

Table 2 Baseline emissions: Relevant parameters for quantifying methane avoidance (Example)

Element	Usual Source	Example	Uncertainty of element
Average population of livestock category	Survey	3 swine	Small
Volatile solids[4] VS produced by livestock category	IPCC default values for different categories and regions[5]	0.3 kg VS/day/head (market swine in Asia)	Medium-High ±25% (IPCC 2006, Table 10A-7)
Percent of manure managed in manure management system	Survey/estimated	90%	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)
Methane conversion factor (MCF) of the baseline manure management system[6]	IPCC default values for different systems and temperatures	35% (Liquid slurry without natural crust cover at 18°C annual average temperatures)	High Depending on temperature, retention time, cover, etc.
Adjustment factor to account for uncertainties	Fixed	0.89 AMS-III.R (v4)	-

U1 Methane emissions from baseline manure treatment (relevant if avoided methane emissions are claimed)

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, climate, region, livestock productivity system, the extent of anaerobic conditions, or the retention

[4] 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

[5] 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.

[6] The MCF represents the degree to which B_0 is achieved.

time of the organic materials. All methods use basically the same approach to quantify these emissions: Projects may use a set of default values from the IPCC Guidelines, which 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.

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.[7] 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.

UE2 Methane emissions from the baseline manure treatment not claimed (relevant if avoided methane emissions are not claimed)

Some projects do not claim avoided methane emissions in calculating overall emission reductions. The reason for this is unclear. One possible explanation is that in these cases the baseline treatment of manure is aerobic. To the extent that methane emissions occur in the baseline, neglecting them would lead to an underestimation of emission reductions.

UE3 Conservativeness discount (relevant under AMS-III.R)

AMS-III.R requires applying a conservativeness discount of 11% to the calculation of avoided methane emissions. The impact of this discount on overall emission reductions depends on the level of other emission sources. Methane avoidance represents only one baseline emission source (the other being fuel switch); in addition, there are several project emission sources. As the level of these emission sources differ among projects, the overall impact of the discount also differs among projects.

Determination of baseline emissions (Fuel switch)

All household biodigester projects claim emission reductions from fuel switch because the digesters' biogas allows reducing the consumption of baseline fuels. The baseline fuels can include firewood, charcoal or fossil fuels. The authors assessed the top 10 projects in the voluntary market (based on credits issued). For all projects, fuel switch is more important than methane avoidance (for most projects, the fuel switch's contribution to overall emission reductions is more than 80%).

In the following, we discuss different components that are relevant for baseline emissions from fuel switch. The brackets indicate whether the components are relevant for all or only for a subgroup of projects.

<u>Discussion on the determination of the baseline fuel consumption (all projects)</u>

[7] 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.

The assessed methodologies provide the following options to determine the consumption of the baseline fuel:

- For all baseline fuels
  - Under all methodologies: A one-time, ex-ante baseline survey of baseline fuel consumption may be conducted (potentially repeated at crediting period renewal).
- Further alternative options for firewood/charcoal
  - Under all methodologies, except Version 13.0 of AMS-I.E: A default value of 0.5 tonnes of woody biomass per person per year may be used. This has to be complemented by the number of persons per household which may be taken from surveys or the literature.
  - Under AMS-I.E, Version 13.0: In this version of the methodology, the default value for the woody biomass per person per year was lowered from 0.5 to 0.4 tonnes, following a literature review by the Methodologies Panel.
  - Under AMB: A default value of 0.13 tonnes of charcoal per person per year may be used. This has to be complemented by the number of persons per household which may be taken from surveys or the literature.
  - Under AMS-I.E: Country- or region-specific data may be used.
- Further alternative option for fossil fuels (mainly coal)
  - Under AMS-I.C: The methodology does not require to measure the baseline consumption. Instead baseline emissions from thermal energy displaced by the project activity are derived from the net quantity of heat supplied by the project activity and the efficiency of the baseline stoves. However, none of the projects we analysed measured the supplied heat. Instead, many projects derived the supplied heat from the efficiency and thermal capacity of the biogas stoves (fixed ex-ante using information provided by the project proponent) and the operating hours of the biogas stoves (monitored), assuming that during all operating hours the stoves are used at maximum capacity. This allows to derive the amount of fossil fuels being replaced (instead of separately determining baseline and project emissions).

OE8 Baseline fuel consumption (relevant for all methodologies)

All analysed methodologies allow determining the baseline fuel consumption based on surveys or using default values. Based on our assessment of about 15 randomly selected projects, no projects used the default value but use surveys to determine the baseline fuel consumption. This suggests that most projects use the surveys rather than the default values.

The default value in the assessed methodologies is 0.5 tonnes/capita/year. In 2022, the Methodologies Panel of the CDM conducted a literature review which analysed the annual average firewood consumption per capita and found that the average value is about 0.62 tonnes/capita/year (with a standard deviation of 0.45), based on data from the United Nations and Demographic and Health Surveys (DHS) (CDM Methodologies Panel 2022). It is also identified that the average values for over half of countries for which data is available were equal to or lower than 0.5 tonnes/capita/year and recommended that the value be lowered to 0.4 tonnes/capita/year in order to ensure that it is conservative. This is because project owners can "pick and choose" between using the default value and undertaking surveys. There is a risk that projects conduct sampling but only use the sampling results of these are higher than the default value. A value of 0.5 has thus a higher risk to leading to overestimation of emission reductions than a value of 0.4. The value of 0.4 was adopted by the CDM Executive Board is included in version 2.0 of TOOL33.

All methodologies provide detailed requirements for surveys. Nevertheless, there are some indications that the surveys might lead to inflated estimates. The above-mentioned literature review of the Methodologies Panel of the CDM finds that the annual average firewood consumption per capita of 109 projects is 0.74 tonnes/capita/year (CDM Methodologies Panel 2022). This is higher than the average value of 0.62 determined by the Methodologies Panel based on data from the United Nations and Demographic and Health Surveys (DHS). This difference could be explained in different ways: one possible explanation is that the surveys might not be conducted properly, leading to a bias towards overestimation of emission reductions. Another explanation could be the uncertainty in the data (the uncertainty ranges of the two values overlap) and that the regions considered in the two data sources do not exactly match.

To further analyse this matter, we conducted the following plausibility test for five randomly chosen projects: We compared (i) the level of end-energy (e.g., heat transferred to the cooking device) that can be expected to be provided from using the project's biodigester based on the project's data on the manure quantities with (ii) the claimed level of end-energy provided as per the quantification of baseline emissions from the displacement of fossil fuels, firewood or charcoal. We found that the level of end-energy from (ii) is approximately 1.5 to 3 times higher than the level from (i). Even though there are also other explanations that could (partly) explain this difference[8], this finding indicates that the surveys might be biased and thus result in too high amounts of baseline fuel consumption.

Given that there are two indications of over-estimation (the calculations by Methodologies Panel using UN data and our plausibility test for five projects), we assume that there is a risk for a systematic bias in the baseline surveys. We therefore conclude that baseline surveys may lead to overestimation of overall emission reductions. This is particularly relevant for firewood, as usually the baseline consumption is based on rough estimates of the amount of firewood that has been collected by the households. For coal consumption, we assume that the surveys are more accurate, as coal has to be bought and one can check the receipts.

Note that for efficient cookstove projects, a further source of uncertainty are the adoption rates of the cookstoves. We assume that for biodigesters this is a less relevant source of uncertainty, as adoption rates can be monitored straightforwardly and should also be reflected in project fuel consumption data.

OE3 AMS-I.C's approach to determine baseline consumption of fossil fuels *(relevant for AMS-I.C)*

The approach applied under AMS-I.C to determine the baseline consumption of fossil fuels (see above) is likely to lead to overestimation of baseline emissions, because the assumption is that baseline stoves are used at maximal capacity all the time. In addition, this would lead to over-estimation of baseline emissions if stoves are used more under the project as compared to the baseline (such an overestimation of baseline emissions is not possible if the baseline fuel is

[8] Some households may use organic material other than manure, such as kitchen waste, in the biodigesters, which would increase the methane generation under the project. Moreover, the calculation of baseline methane emissions for (i) is based on default values, which are associated with significant uncertainties.

determined via a baseline survey). Both issues may lead to significant overestimation of emission reductions.

Approach to determine baseline firewood and charcoal consumption (relevant for AMB)

AMB introduces a threshold of 0.75 tonnes firewood per person per year or 0.195 tonnes charcoal per person per year. If these thresholds are crossed, the project has to "further substantiate" its results by independent third-party studies. AMB also introduces a cap of 0.95 tonnes firewood per person per year or 0.25 tonnes charcoal per person per year. A value above the cap shall not be applied. We assume that this element reduces the potential for over-estimation but does not lead to any underestimation of emission reductions. We thus rather consider it as a neutral element.

OE4 Suppressed demand (relevant for TPDDTECv3.1)

The project type grants access to cheap energy which could have the rebound effect of enabling households to increase their energy consumption. In this context, TPDDECTv3.1 allows using a suppressed demand baseline. Roughly speaking, suppressed demand means that it is allowed to set the baseline higher than the most likely scenario, if the realistic baseline is below a minimum threshold deemed necessary to meet human development needs. While it is an important development goal to provide energy access to poor, rural households, this approach nevertheless leads to significant overestimation of the actual emission reductions.

Suppressed demand seems to only apply to few projects, however. TPDDECTv3.1 covers several projects types and suppressed demand seems not to be commonly applied for household biodigesters: In our sample of biodigesters projects that apply TPDDTECv3.1 we have not found a single project that uses a suppressed demand baseline. The baseline consumption is either based on a baseline survey or on default values. Note that the other methodologies (AMB, AMS-I.C, and AMS-I.E) do not allow to use a suppressed demand baseline.

Discussion on the fraction of non-renewable biomass f_{NRB} (relevant if firewood/charcoal is replaced)

If biogas replaces firewood or charcoal (which is made from firewood), this eases the pressure on local forests, which may lead to less degradation or deforestation. The calculation of these emission reductions is on determining the fraction of non-renewable biomass (f_{NRB}). This is a simplistic and methodologically questionable way to estimate the impact of firewood gathering on long-term changes in carbon stocks and to quantify the corresponding emissions reductions. It is notoriously uncertain and has several limitations (see e.g. Bailis et al. 2020 for a recent overview).

Because it is methodologically challenging to determine f_{NRB}, the CDM has in 2012 provided country specific default values for many countries. They range from 50% to nearly 100%, with values above 80% for the large majority of countries. These values have been criticized as being overestimated.[9] High f_{NRB} values over a sustain period would imply that forests would be entirely lost in a relatively short period, which seems unrealistic. The CDM has therefore withdrawn these default values, which become are invalid by 2020. A large majority of projects still use these outdated f_{NRB} values. In

9 At a global level, f_{NRB} is estimated by the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC) to be 10% (IPCC Guidelines (2006) and Rogner et al. (2007)), Bailis et al. 2015 estimated country specific values between 27% and 34%, and Miranda et al. 2013 between 20% to 30%. Bailis et al. 2020 (figures at pages 25ff) show the discrepancy between the values used in carbon crediting projects and the authors' WISDOM model.

addition, f_{NRB} are often national values that — in large countries— may not appropriately reflect the local context of projects.

The specific requirements regarding the f_{NRB} differ among the methodologies:

- AMS-I.E (v12) does not use the above-mentioned country-specific CDM default values but refers to CDM Tool 30, which provides a procedure for determining f_{NRB} values. The tool is rather complex to implement, requiring input parameters from several sources. It is beyond the scope of this assessment to assess the details of Tool 30. Given that many assumptions need to be made in applying TOOL30, we assume that the tool still allows to determine unrealistically high f_{NRB} values.[10]
- AMS-I.E (v13) introduces a global default value for f_{NRB} of 30% (referring to Tool 33 v2).[11] However, AMS-I.E (v13) still allows project developers to determine their own values using Tool 30. Therefore, we assume that the default value of 30% will not be widely adopted.
- TPDDTECv3.1 allows to use CDM approaches (such as from AMS-I.E v12 or earlier versions) or other project-specific approaches. De-facto, the same high f_{NRB} values have been uses as under the CDM projects.
- AMB also refers to CDM Tool 30 and does not provide any default value.

OE5 Overestimation of the fraction of non-renewable biomass (relevant if firewood/charcoal is replaced)

The above discussion shows that most project's f_{NRB} values are very likely to be significantly overestimated. Assuming that the default value of 30% in TOOL30 is a realistic average estimate and considering that most projects use values above 80%, the overestimation of the f_{NRB} value would be above 150%.[12]

Discussion on the baseline emission factors for firewood and charcoal (if firewood/charcoal is replaced)

Table 3 shows the emission factors according to IPCC 2006 for different fuel types. The CO_2 emission factor is 112 t CO_2/TJ for wood and charcoal, which is substantially higher than emission factors of fossil fuels.

Table 3 IPCC default emission factors (EF) for common household fuels

FUEL	Emission factor CO_2 (t/TJ)	Emission factor CH_4 (t/TJ)	Emission factor N_2O (t/TJ)
Liquefied petroleum gas (LPG)	63.1	0.005	0.0001

10 See for example, CDM project "PoA 10576 : Ghana Improved Cookstove Project by EWP in Republic of Korea" (https://cdm.unfccc.int/ProgrammeOfActivities/poa_db/ZYM1P30K5WINT7AFXVEBQJU6CRGO24/view) It applies Tool 30 to obtain a value for f_{NRB} of 79.8%. In contrast, Ballis et al 2015 have used the "Woodfuels Integrated Supply/Demand Overview Mapping" (WISDOM) method to estimate the f_{NRB}. They derive much lower values for Ghana (between 0% and a bit more than 30% depending on the region).

11 Both AMS-I.E (v13) and Tool 33 (v2) are valid as of 8 September 2022.

12 80%/30%-1=1.66

Kerosene	71.9	0.01	0.0006
Coal	94.6	0.3	0.0015
Wood	112	0.3	0.004
Charcoal	112	0.2	0.001

Table 4 and Table 5 show that the methodologies use the same net caloric values (NCV) but differ with respect to the choice of the emission factors.

Table 4 Default net caloric values (NCV) and emission factors applicable to firewood under different methodologies

Methodology (Version)	**NCV** (TJ/t)	**Emission factor CO_2** (tCO_2/TJ)	**Emission factor non-CO_2** (tCO_2eq/TJ)
AMS-I.E v7	0.015	81.6	-
AMS-I.E v8-v9[13]	0.0156	63.7	-
AMS-I.E v10-13	0.0156	Regional defaults (see Table 5)	-[14]
TPDDECT v3.1	Refers to “IPCC defaults, credible published literature, project-relevant measurement reports, or project-specific field tests prior to first verification”		
AMB – Firewood	0.0156	112	8.692 or 9.46
AMB – Charcoal[15]	0.0295	112	5.865 or 5.298

Table 5 Default regional emission factors (EF) for AMS-I.E v10-13

REGION	**DEFAULT EF** ($t CO_2e/TJ$)
Europe and Central Asia	57.8
Middle East and North Africa	63.9
South Asia	64.4
Latin America and the Caribbean	68.6
Sub-Saharan Africa	73.2
East Asia and the Pacific	85.7

13 Excluding coal from the baseline mix. Unfortunately, this major change has not been documented in the “document information” in the Annex of the AMS-I.E.

14 The non-CO_2 emissions factors related to fossil fuels are minuscule. The methodology provides regional default values which seem not to include non-CO_2 emissions. Project participants may also derive project-specific emission factors which may include non-CO_2 emissions factors. In any case, the impact is negligible.

15 Emission factors are for combustion only. The methodology also provides default emission factors that include production emissions. This is, however, discussed in the section on the wood to charcoal conversion factor.

UE4 Baseline emission factor based on fossil fuels (relevant under AMS-I.E if firewood/charcoal is replaced)

AMS-I.E's emission factors (and in related CDM methodologies like AMS-II.G) are based on the assumption that, in the absence of the project, cooking would take place using fossil fuels. This is incongruent with the scope of AMS-I.E which is to "displace the use of non-renewable biomass by introducing renewable energy technologies". As noted in page 137 of Cames et al. 2016, this was the CDM Executive Board's "solution" to the fact that the CDM does not allow avoiding forest loss or degradation as a project type (only afforestation and reforestation are allowed). For projects using wood or charcoal as a baseline fuel, AMS-I.E thus determines the emission factor as the average of a selected mix of fossil fuels deemed appropriate for the project location. This purposefully wrong approach leads in any case to an emission factor below 112 tCO_2/TJ and thus underestimates baseline emissions by 23 to 48%, depending on the fossil fuel based baseline emission factor assumed, which depends on region of the project (see Table 5) and the version of the methodology.

UE5 Determination of non-CO_2 baseline emissions (relevant under AMS-I.E if firewood/charcoal is replaced)

The combustion of firewood or charcoal leads to non-CO_2 greenhouse gas emissions (methane and nitrous oxide).[16] TPDDECTv3.1 and AMB use the IPCC default value of 112 t CO_2/TJ for CO_2 emissions from firewood or charcoal. In addition, they allow to account for non-CO_2 emissions, using IPCC default values for emission factors for firewood and charcoal, which increases emission reduction claims by approximately 5 to 8%. We assume that this is relatively accurate and thus does not contribute to under- or overestimation of emission reductions.

In contrast to TPDDECTv3.1 and AMB, the methodology AMS-I.E determines the non-CO_2 emission factors based on fossil fuels, which are much smaller than factors for firewood and charcoal. Based on the non-CO_2 emission factors used under AMB, this effect leads to an underestimation of baseline emissions by approximately 5% for charcoal and 8% for firewood.

<u>Discussion on charcoal to wood conversion factor (if charcoal is replaced)</u>

In case a project replaces charcoal, the charcoal consumption has to be multiplied by a wood-to-charcoal conversion factor. This is a measure for how much kg firewood (wet basis) is being used to produced one kg of charcoal (dry basis). All methodologies allow using project specific values. In addition, they allow using the default values shown in Table 6.

[16] While CO_2 emissions depend on the properties of the firewood, non-CO_2 emissions depend on the properties of the fire (methane emissions arise from incomplete combustion).

Table 6 Default values for the wood-to-charcoal conversion factor

Methodology (Version)	Wood-to-charcoal conversion factor [kg firewood (wet basis) per kg charcoal (dry basis)]
AMB (v1.0)	2.6 (default) 3.1 (cap)[17]
TPDDECTv3.1	None[18]
AMS-I.E (v12)	6
AMS-I.E (v13)	4[19]

In 2022, the Methodologies Panel of the CDM conducted a literature review and concluded that a value of 4 represents the lower end of the range indicated in most literature reviewed.[20] Indeed, the available literature often indicates higher values, depending on the kiln type and moisture content. Based on this analysis, we conclude that

OE6 / UE6 Charcoal to wood conversion factor (if charcoal is replaced under TPDDECTv3.1)

- *UE6 Charcoal to wood conversion factor (if charcoal is replaced under* AMB or AMS-I.E, Version 13): The default values of 2.6 (as used by AMB) or 4 (as used by AMS-I.E, Version 13) likely underestimate the baseline emissions.
- *OE6 Charcoal to wood conversion factor (if charcoal is replaced under TPDDECTv3.1 or* AMS-I.E, Version 12 and older*).* AMS-I.E, Version 12 and earlier versions as well as TPDDECTv3.1 use a default value of 6, which introduces risks for overestimation also due to a potential selection bias, given that project developers may use this default value, or their own values from measurements, or values from the literature.

Based on the authors analysis of a limited number of projects, only a minority involves charcoal.

Determination of project emissions

Project emissions arise inter alia from methane emissions from the biodigester's physical leakages or biogas venting, as well as from the remaining fuel consumption (of the baseline fuel).

Remaining fuel consumption under the project is captured using repeated surveys, which seems adequate. Usually, consumption under the project is small as compared to consumption under the baseline. The calculation of project emission from any remaining fuel consumption is identical to the baseline approach. For these reasons, this aspect is not discussed any further.

Physical leakage and intentional releases of methane (venting) could significantly reduce overall emission reductions. The methane production in the biodigester is usually higher than methane

[17] The methodology does not directly state the conversion factor but prescribes the following parameters (see TPDDECT v4.0, p. 26) which imply the stated conversion factor:
- Firewood: EF = 112 tCO_2e/TJ and NCV=0.0156TJ/ton
- Charcoal: EF =165.22 tCO_2e/TJ (default); EF 197.15 tCO_2e/TJ (cap) and NCV=0.0295TJ/ton

[18] TPDDECT v3.1 refers to "IPCC, credible published literature, project-relevant, measurement reports, or project-specific monitoring"

[19] AMS-I.E (v13) refers to Tool 33, which in Version 2 prescribes a value of 4. This value is based on a detailed review of the Methodologies Panel (see CDM Meth Panel 88, Annex 19)

[20] See CDM Meth Panel 88, Annex 19.

generation from manure treatment in the baseline. This holds in particular if other wastes, such as kitchen wastes, supplement the use of manure in the biodigester. Therefore, if a substantial fraction of the methane produced in the biodigester leaks into the atmosphere, the overall emission reductions may even become negative. The break-even point depends on the difference between methane formation in the baseline and the biodigester's methane production as well as on the emission factors of the replaced fuels. Brunn et al. 2013 estimate that the break-even point where overall emission reductions would be zero is between leak rates of 3% and 51%. The lower value stems from a case where sustainably harvested wood is being replaced (i.e. f_{NRB}=0).

There is no data regarding real-word leakage rates. We assume that those are highly dependent on the maintenance frequency and training of users. None of the methodologies requires or fosters measures to decrease leakage rates.

OE7 Physical methane leakage considered inappropriately (relevant for all methodologies)

All methodologies set a default value of 10% for the physical methane leakage based on the maximum methane production potential (i.e. setting MCF=1, which per se is conservative). Brunn et al. 2013 estimate that emissions from inlets, outlet and other leaks may be up to 10%. In addition, there are intentional releases which may be up to 30%. Furthermore, as discussed above, it is likely that organic material other than manure will be digested as well, which would lead to additional leakage but is not considered when quantifying project emissions. Given that actual methane generation may be larger due to the use of other wastes and noting that intentional releases constitute a further risk, we assume that on average there could be an overestimation of emission reductions, which may be substantial in isolated cases.

Summary and conclusion

Table 7 summarizes the assessment. For each of the previously discussed elements it estimates the potential impact on the emission reduction quantification.

Table 7 Relevant elements of assessment and qualitative ratings

Element	Fraction of projects affected by this element[21]	Average degree of under- or overestimation where element materializes[22]	Variability among projects where element materializes[23]
Elements likely to contribute to overestimating emission reductions			
OE1 Omissions of several emission sources (relevant for all methodologies)	All	Medium	High
OE2 Project construction and decommissioning (relevant for all methodologies)	All	Low to Medium	Low
OE3 AMS-I.C's approach to determine baseline consumption of fossil fuels (relevant for AMS-I.C)	High (For AMS-I.C)	Medium	Medium
OE4 Suppressed demand (relevant for TPDDECT Version 3.1)	Low (For TPDDECT3.1)	Medium to High	Medium
OE5 Overestimation of the fraction of non-renewable biomass (relevant if firewood/charcoal is replaced)	All (For subgroup replacing firewood or charcoal)	High	High
OE6 Charcoal to wood conversion factor (relevant for AMS-I.E, Version 12 or earlier, and TPDDECTv3.1)	Low (For subgroup replacing firewood or charcoal when using either AMS-I.E,	Unknown	High

21 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.

22 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.

23 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%.

	Version 12 or earlier, or TPDDECT v3.1)		
OE7 Physical methane leakage considered inappropriately (relevant for all methodologies)	All	Low to Medium	High
OE8 Baseline surveys to determine baseline consumption (relevant for all methodologies)	High	Medium	Medium
Elements likely to contribute to underestimating emission reductions			
UE1 Neglecting upstream emissions from fossil fuels used in the baseline scenario (relevant if fossil fuels are replaced)	All (For subgroup not replacing firewood or charcoal)	Medium	High
UE2 Methane emissions from the baseline manure treatment not claimed (relevant if avoided methane emissions are not claimed)	All (for subgroup not claiming methane avoidance)	Low	Medium
UE3 Conservativeness discount (relevant under AMS-III.R)	All (For subgroup claiming methane avoidance when using AMS-III.R)	Low to Medium	None
UE4 Baseline emission factor based on fossil fuels (relevant under AMS-I.E if firewood/charcoal is replaced)	All (For subgroup replacing firewood or charcoal when using AMS-I.E)	Medium to High	Medium
UE5 Determination of non-CO_2 baseline emissions (relevant under AMS-I.E if firewood/charcoal is replaced)	All (For subgroup replacing firewood or charcoal when using AMS-I.E)	Low	Medium
UE6 Charcoal to wood conversion factor (relevant for AMS-I.E, Version 13, and AMB)	Low (For subgroup replacing firewood or charcoal when using either AMS-I.E, Version 13, or AMB)	Unknown	High
Elements with unknown impact			
U1 Methane emissions from baseline manure treatment (relevant if avoided methane emissions are claimed)	All (For subgroup claiming methane avoidance)	High	High

From this analysis we derive the following scores, differentiated by subgroups of project types and methodologies.

For the subgroup of projects displacing firewood or charcoal we assign a score of 1. For this group, the element OE5 leads to a very likely overestimation that is larger than 30%. Although the methodologies differ on other key factors affecting baseline emissions – the CO_2 emission factors for biomass (UE4), the consideration of non-CO_2 emissions (UE5) and the wood-to-charcoal conversion factors (OE6 and UE6) – these factors do not change the result in any plausible scenario.

For all other projects (i.e., projects that displace fossil fuels) the score is 2, with the exception of projects that use AMS-I.C, for which the score is "1". This is justified as follows:

- For projects that claim emission reductions from methane avoidance and *do not use* the combination of AMS-I.C and AMS-III.R, the main sources of overestimation are elements OE1, OE2 and OE7, with the latter element also introducing considerable uncertainty. This over-estimation is unlikely to be compensated by element UE1 alone. Moreover, element U1 introduces considerable uncertainty. We therefore estimate the overall uncertainty, mainly arising from elements U1, U2 and OE7, to be larger than ±50%. At the same time, there is likely some overestimation of overall emission reductions, which is, however, deemed lower than ±30%. This corresponds to a score of 2.
- For projects that claim emission reductions from methane avoidance and *use* the combination of AMS-I.C and AMS-III.R, the conservativeness discount of AMS-III.R introduces a source of underestimation (UE3), but the approach of AMS-I.C to determine baseline fossil fuel consumption assuming that stoves always operate their maximum capacity introduces a significant source of overestimation (OE3). Overall, we estimate that the latter element could have relatively strong effect, such that in aggregate the overall overestimation of emission reductions is likely to be larger than ±30%. This corresponds to a score of 1.
- For projects that do not claim emission reductions from methane avoidance for all relevant methodologies, element UE2 leads to a small underestimation but UE3 is missing such that we assume a score of 2 (same as for first bullet).