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Review of monitoring uncertainty requirements in the CDM

Igor Shishlov[1] and Valentin Bellassen[2]

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Abstract

In order to ensure the environmental integrity of carbon offset projects, emission reductions certified under the Clean Development Mechanism (CDM) have to be 'real, measurable and additional', which is ensured through the monitoring, reporting and verification (MRV) process. MRV, however, comes at a cost that ranges from several cents to EUR1.20 and above per ton of CO_2e depending on the project type. This article analyzes monitoring uncertainty requirements for carbon offset projects with a particular focus on the trade-off between monitoring stringency and cost. To this end, we review existing literature, scrutinize both overarching monitoring guidelines and the 10 most-used methodologies, and finally we analyze four case studies. We find that there is indeed a natural trade-off between the stringency and the cost of monitoring, which if not addressed properly may become a major barrier for the implementation of offset projects in some sectors. We demonstrate that this trade-off has not been systematically addressed in the overarching CDM guidelines and that there are only limited incentives to reduce monitoring uncertainty. Some methodologies and calculation tools as well as some other offset standards, however, do incorporate provisions for a trade-off between monitoring costs and stringency. These provisions may take the form of discounting emissions reductions based on the level of monitoring uncertainty – or more implicitly through allowing a project developer to choose between monitoring a given parameter and using a conservative default value. Our findings support the introduction of an uncertainty standard under the CDM for more comprehensive, yet cost-efficient, accounting for monitoring uncertainty in carbon offset projects.

Keywords: climate policy, carbon offsets, CDM, monitoring, uncertainty.

JEL codes: Q50, Q54, Q58.

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[1] Researcher at CDC Climat Research | igor.shishlov@cdcclimat.com

[2] Researcher at French National Institute for Agricultural Research (INRA) | valentin.bellassen@dijon.inra.fr

Publication director: Benoît Leguet

To receive regular updates on our publications, send your contact information to research@cdcclimat.com

Press contact: Maria Scolan - +33 1 58 50 32 48 – maria.scolan@cdcclimat.com

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1. Introduction

The existing international climate regime, set up by the Kyoto Protocol in 1997, imposed quantitative limits on greenhouse gas (GHG) emissions of developed countries and economies in transition that are included in the Annex B to the Kyoto Protocol. These limits are enounced in countries' emissions quotas – Assigned Amount Units (AAU). The Kyoto Protocol incorporated four flexibility mechanisms that were designed to help governments maximize the economic efficiency of achieving their commitments:

- 'Bubbling' (article 4) permits a group of Annex B countries to redistribute their GHG emissions reduction commitments, as it was done by the European Union countries;
- Joint Implementation (article 6) permits Annex B countries to host emissions reduction projects that generate tradable Emission Reduction Units (ERU);
- The Clean Development Mechanism (article 12) permits non-Annex B countries to host emissions reduction projects that generate tradable Certified Emission Reductions (CERs);
- International Emissions Trading (article 17) permits Annex B countries to directly trade their Kyoto allowances (AAUs).

With over 7,500 registered projects and almost 1.5 billion tCO_2e of GHG emissions reduced in developing countries as of September 2014 (UNEP Risoe 2014), the CDM is the largest carbon offset scheme in the world. The mechanism raised over US$360 billion (UNEP Risoe 2014) of mostly private investments in climate change mitigation over 10 years. This figure is 10 to 20 times higher than the value of carbon assets generated. Indeed, the leverage effect of carbon finance enables to raise private investments in climate-friendly projects that may significantly exceed revenues from the sale of carbon credits (Shishlov and Bellassen 2013).

Being an offsetting mechanism, the CDM represents an environmental 'zero-sum' game, whereby emissions reductions generated in developing countries can be used for compliance by developed countries and private companies (Shishlov and Bellassen 2012). Therefore, in order to ensure that the overall magnitude of GHG abatement does not decrease, emissions reductions under the CDM have to be 'real, measurable and additional to any that would occur in the absence of the certified project activity' (UN 1998).

Past research has shown that a suboptimal monitoring, reporting and verification (MRV) framework may threaten environmental integrity of carbon offsetting. Wara (2008), Schneider (2009), and Haya and Parekh (2011) built evidence proving that non-additional projects had managed to be registered under the CDM, which might have effectively increased global GHG emissions. Haya (2009) demonstrated that some renewable energy projects in India had manipulated financial data in order to prove additionality. Schneider (2011) showed that many projects focused on destruction of HFC-23, a highly potent GHG, engaged in strategic production behavior until the loophole was closed by the CDM Executive Board.

While these studies pointed at too lenient an approach to MRV in the CDM, there was also evidence of excessively stringent MRV requirements that impeded implementation of projects in certain sectors. For instance, Michaelowa, Hayashi, and Marr (2009) demonstrated that excessively complex monitoring requirements were a major barrier for the implementation of household energy efficiency projects. Foucherot and Bellassen (2011) drew the same conclusion for most agricultural sub-sectors except bioenergy and waste management projects. Rogger, Beaurain, and Schmidt (2011) studied baseline and monitoring methodologies for the waste management sector and found that the methodology for the calculation of emission mitigation was the major barrier for composting projects.

While past research has identified flaws in the MRV framework that may threaten economic efficiency and environmental integrity of the CDM, they did not investigate the issue of monitoring uncertainty in carbon offsetting. Monitoring rules prescribed by the regulator come with an uncertainty range. As a result, the actual amount of emissions may differ from the reported amount even when agents abide by the rules. We believe that in light of the ongoing discussion about the MRV framework for new market mechanisms as well as the reform of the existing ones, there is a need to review the uncertainty requirements under the CDM framework and analyze their potential influence on the implementation of emissions reduction projects.

First, we briefly review the literature on monitoring uncertainty in climate policy and on monitoring costs particularly focusing on the trade-off between stringency and costs of monitoring. Second, we scrutinize the overarching CDM guidelines and their translation into sector-specific monitoring methodologies in order to understand whether the stringency-cost trade-off was taken into account in the CDM. Third, we review the 10 most-used methodologies in order to understand whether the monitoring uncertainty in addressed in a systematic manner. Finally, we analyze the impact of historical changes in monitoring requirements on feasibility of certain project types under the CDM through four case studies.

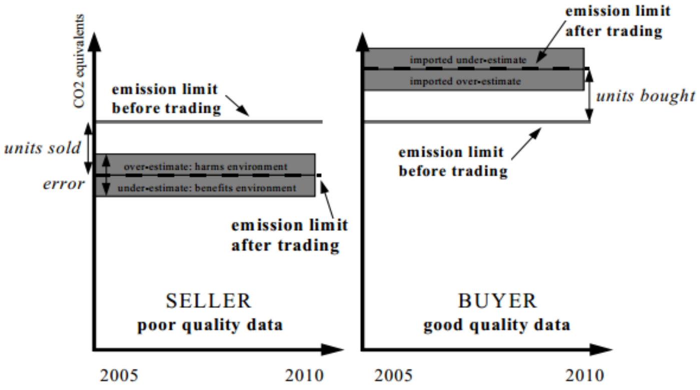
2. Monitoring uncertainty and costs in climate policy

This section reviews the existing literature on monitoring uncertainty and costs in climate policy. It is demonstrated that there is a natural trade-off between the uncertainty and the cost of monitoring and that monitoring uncertainty can be addressed by the regulator using ‘hard’ (uncertainty thresholds) or ‘soft’ (discount proportional to uncertainty) approaches.

2.1. Monitoring uncertainty in climate policy

Sectors vary significantly in terms of monitoring approaches depending on the nature of GHG emissions. This in turn explains the need for sector-specific methodologies that reflect the peculiarities of different project types and sub-types. In practice not all sectors have precise and affordable monitoring methods, therefore, any climate policy has to find a way to account for monitoring uncertainty. The OECD (1997) acknowledged that different countries or sectors may have different levels of GHG accounting uncertainty, which may result in inappropriate levels of exchange in emissions rights. For example, if an agent with poor data quality sells carbon credits to an agent with superior data quality, he is also exporting the emissions reduction uncertainty (Figure 1). In case the seller overestimates emissions reductions the overall level of emissions may effectively increase compared to a situation without carbon trading.

Figure 1 – The impact of monitoring uncertainty on emissions trading



Source: OECD (1997)

Monni et al. (2007) suggested three ways to deal with GHG monitoring uncertainty:

- allowing emissions trading only between sectors with comparable uncertainty levels, e.g. credits resulting from increasing carbon stocks in one country can be used to compensate reducing carbon stocks in another country, but not to compensate increased fossil fuel use;
- setting a maximum level of uncertainty allowed for a given sector to be eligible to participate in carbon trading, e.g. using the confidence intervals[3] approach;
- discounting the amount of carbon credits awarded for a given amount of emissions reduction based on the uncertainty of monitoring of these emissions reductions.

The first approach would result in a significant decrease in flexibility and therefore is not applied in the CDM. The second approach is the one most commonly used in the CDM probably due to its relative simplicity, while the third approach had seen limited use in some monitoring methodologies (see Section 3).

Another way of looking at monitoring uncertainty was suggested by Cantrell et al. (2012), who borrowed the logic of the insurance theory to assign a value to information uncertainty in climate policy. Similar to life insurance that takes into account distribution variance in life expectancy, a risk charge that accounts for uncertainty of GHG emissions is added to their valuation. If an insurance company does not charge a risk premium it will sooner or later go bankrupt due to the random pattern of indemnity payments. Conversely, if an insurer charges too high a risk premium, it will sooner or later be outcompeted by those insurers that can offer a better deal to their customers while keeping afloat themselves. Therefore, the better the company can estimate the uncertainty, the more competitive it becomes. Likewise, a climate regulator would charge a

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[3] A statistical measure of the reliability of an estimate, for example, 95/5 confidence/precision interval means that there is a 95% chance that the true value lies within +/-5% of the estimate.

risk premium in order to ensure that emissions remain under a defined cap; otherwise he will ‘go bankrupt on climate’. At the same time too large a premium may increase climate change mitigation costs unreasonably, rendering some emissions reductions unprofitable.

2.2. MRV costs in carbon offset projects

The CDM experience shows that MRV costs may vary significantly depending on project type and may be a major barrier for the implementation of projects in certain sectors. In addition to the usual upfront project development costs, transaction costs borne by CDM project developers include Project Design Document (PDD) development, validation costs (internal and auditing), UNFCCC registration fees and the cost of installing the monitoring system. These costs vary considerably depending on the project size and type and may range from EUR 37,000 for small-hydro projects to EUR 434,000 for very large adipic acid N_2O projects. The cost of monitoring equipment may range from zero – in case there is no additional CDM-specific equipment to be installed – to EUR 15,000 (Warnecke et al. 2013). Validation costs may also vary depending on the size and nature of a project. Programmes of Activities (PoAs) provide a framework for bundling several similar projects, thus reducing costs of registering each project. For example, a PoA focused on efficient cook stoves becomes less costly than a classic CDM as of the second project, while more complex project types may take 3-5 projects to justify the use of the PoA framework (Beaurain and Schmidt-Traub 2010).

The project developer is responsible for carrying out all monitoring activities, which is usually done either ‘in-house’ using the developer’s own resources or by a hired specialist consultant. This choice may significantly affect the actual monitoring costs: it was reported that the cost of the external consulting firm can exceed 1,000 euros per man-day, while internal costs may be considerably lower (Guigon, Bellassen, and Ambrosi 2009). The estimates of periodic monitoring costs usually fall in the range of 3,000 to 18,000 euros (Table 1).

Table 1 – Periodic monitoring costs in CDM projects

Cost estimate	Source
EUR10,000	Michaelowa and Stronzik (2002)
EUR9,600*	Krey (2005)
EUR5,000	Guigon, Bellassen, and Ambrosi (2009)
EUR1,500-5,000 for projects <50 kCER/year	Warnecke et al. (2013)
EUR3,000-10,000 for projects >50 kCER/year	Warnecke et al. (2013)
EUR5,000-18,000 for N_2O projects	Warnecke et al. (2013)

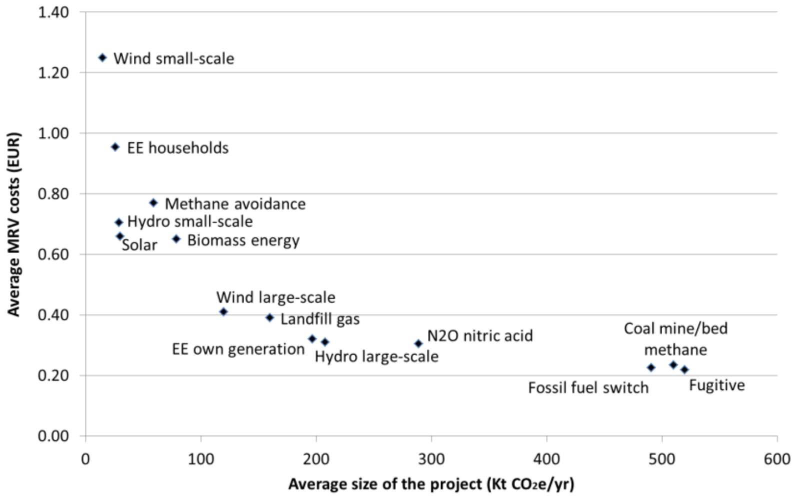
* *Converted from US dollars into euros using the average annual (respective publication year) exchange rate.*

Monitoring costs may also vary drastically depending on the project type. For example, in the case of transportation projects monitoring costs may be as high as EUR144,000 due to the requirements to conduct multiple surveys of passengers (Replogle and Bakker 2011). Besides the absolute figures, the relative importance of monitoring in the cost structure of a CDM project depends on the abatement cost, and hence the type of a project.

Furthermore, the cost of the periodic verification of monitoring reports under the CDM has been estimated in the range of EUR5,000-30,000 (Warnecke et al. 2013). Project participants may reduce verification costs per ton of CO_2e by increasing the duration of monitoring periods and decreasing the frequency of reporting. Periodic verification costs may also vary depending on the nature of a project. For example it is estimated that verification costs for PoAs can be significantly higher and reach EUR40,000 (IGES 2013a). Additional costs borne by project proponents are related to the UNFCCC fees and the internal time consumed in dealings with the Designated Operational Entity (DOE)[4]. UNFCCC fees can amount to EUR0.08-0.15 per CER in addition to the 2% of the issued CERs, which go to the climate change adaptation fund.

Total average MRV costs vary from few cents for HFC-23 and N_2O adipic acid projects to EUR1.20 and above per ton of CO_2e for diffused small-scale projects, often representing a significant share in the cost structure of an offset project (Figure 2).

Figure 2 – Average relative MRV costs for CDM projects[5]



Source: CDC Climat Research based on Warnecke et al. (2013)

2.3. Cost-stringency trade-off

More accurate monitoring usually comes at an increasing cost, which in some sectors may constitute a major barrier to the implementation of projects. For example, Pearson et al. (2013) quantified monitoring costs in carbon sequestration projects to be in the range of 3% to 42% of total project costs. Indeed, in forestry projects the cost and precision of monitoring carbon stocks may vary depending on the number of plots sampled (Figure 3).

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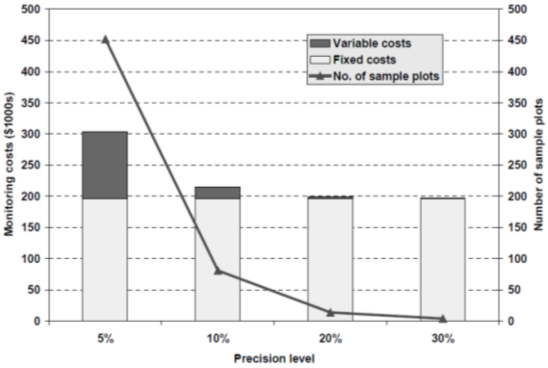
[4] DOEs are independent auditors accredited by the CDM Executive Board to perform validation of CDM projects and verify their emissions reductions.

5 The CDM Market Support Study (Warnecke et al. 2013) is retained here as the most reliable source for three main reasons. First, the data in this study is collected from a sample of DOEs and project developers in sectors, most represented in the CDM. Second, cost estimates of the study are consistent with previous research (Table 1). Finally, it is the latest study available to our knowledge.

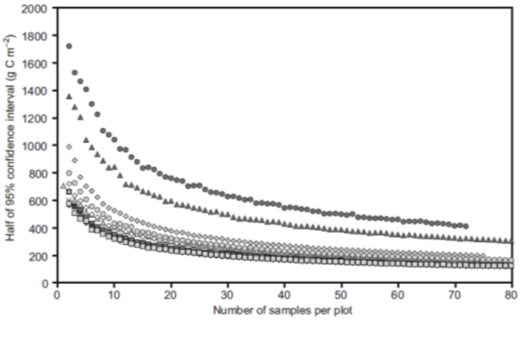
Figure 3 – Relationship between monitoring precision and costs for the Noel Kempff project



Source: OECD (2002)based on Powell (1999)

Although the CDM allows only afforestation and reforestation projects, this is a good example of the correlation between monitoring costs and precision. In this case achieving a high level of certainty may be prohibitively expensive, hence suboptimal. A similar issue arises when monitoring soil carbon stocks. In their model of contracts for carbon sequestration policies for agriculture Antle et al. (2003) showed that the monitoring costs to achieve a 10% sampling error are in the range of US$0.01-0.20, to achieve a 5% sampling error – in the range of US$0.04-1.06, while achieving lower error results in proportionally higher monitoring costs. Similarly, Mäkipää et al. (2008) demonstrated in practice that a relatively high level of precision can be achieved with 10-20 samples per plot. Further increases in the number of samples do not yield any significant monitoring improvements (Figure 4).

Figure 4 – Relationship between the level of soil carbon stock monitoring precision and number of samples per plot for 10 different plots in Norway



Source: Mäkipää et al. (2008)

These examples demonstrate that there is a trade-off between accuracy and costs of MRV in climate policy. Pearson, Walker, and Brown (2009) suggested the concept of 'maximizing return on investment in monitoring', which echoes this trade-off. According to the authors, a rational project developer would weigh the costs of improving monitoring against the potential amount of extra carbon credits generated. The intuitive view that reducing monitoring uncertainty pays off with extra carbon credits is commonly taken for granted by the industry (Cattaneo 2011). However, the reality of CDM rules often contradicts this view as explained in section 3.

Having reviewed the existing literature on monitoring uncertainty and costs, we can derive three key lessons for climate policy in general and carbon offset mechanisms in particular:

- monitoring uncertainty can be addressed through 'hard' (minimum thresholds) or 'flexible' (discounting) approaches;
- MRV costs in the CDM vary drastically depending on the project type and size;
- there is a trade-off between monitoring stringency and cost, which, if not addressed properly, may result in locking some low-cost abatement opportunities.

3. Analysis of monitoring stringency in carbon offset projects

This section examines whether the trade-off discussed above was incorporated in guidelines and methodologies for carbon offset projects under the CDM. To this end we will review overarching MRV guidelines, analyze how they are translated into sector-specific methodologies and examine how uncertainty is accounted for in monitoring rules under the CDM and in other carbon offset mechanisms. It is demonstrated that the CDM provides only limited incentives to reduce uncertainty through adjustment of certain variables and parameters and that overall the treatment of uncertainty is inconsistent across methodologies.

3.1. CDM monitoring guidelines

While the Kyoto Protocol set out general principles of flexibility mechanisms, it did not specifically address the issue of monitoring GHG emissions reductions. Technical details and procedures were elaborated through subsequent negotiations. The most notable package of rules was established at the seventh Conference of the Parties (COP7) to the UNFCCC (UNFCCC 2002) in Marrakech in 2001 (often referred to as the 'Marrakech Accords') and confirmed at the first Conference of the Parties serving as the meeting of the Parties (CMP1) to the Kyoto Protocol at Montreal in 2005 (UNFCCC 2006). COP7 established inter alia *Modalities and Procedures for the implementation of the CDM* (17/CP.7), marking the official birth of the mechanism. Overarching monitoring requirements, with which sector-specific methodologies must comply, are thus defined by the following documents:

- *Modalities and procedures for a clean development mechanism* (Decision 3/CMP.1) for general requirements for baseline and monitoring methodologies;
- *CDM Project Standard* (CDM-EB65-A05-STAN) for project design requirements including principles of monitoring;
- *CDM Project Cycle Procedure* (CDM-EB65-A32-PROC) for procedures for submission and publishing monitoring reports;
- *CDM Validation and Verification Standard* (CDM-EB65-A04-STAN) for procedures of validation and verification;
- *Standard for sampling and surveys for the CDM* (CDM-EB69-A04);

- *Guidelines for completing the proposed new baseline and monitoring methodology form* (CDM-EB66-A25-GUID);
- Other guidelines, clarifications and supporting documents by the CDM EB.

According to the *CDM Modalities and Procedures* (Decision 3/CMP.1), Project Design Documentation (PDD) must include a monitoring plan that provides for ‘the collection and archiving of all relevant data necessary for estimating or measuring anthropogenic emissions by sources of greenhouse gases occurring within the project boundary during the crediting period’. The *CDM Project Standard* further specifies that variables that continuously affect the amount of GHG emissions (reductions), such as the quantity of fuel input or the amount of gas captured have to be measured constantly, while variables that remain largely unchanged, e.g. emissions factors, have to be measured or calculated once a year (CDM-EB65-A05-STAN). Exceptions may be accepted on case-by-case basis during the review of methodologies.

With regards to data uncertainty, project developers have to ‘reduce bias and uncertainties as far as is practical/cost-effective, or otherwise use conservative assumptions, values and procedures to ensure that GHG emission reductions by sources or GHG removals by sinks are not over-estimated’ (CDM-EB65-A05-STAN). The same principle is applied to baselines: ‘the establishment of a baseline is considered conservative if the resulting projection of the baseline does not lead to an overestimation of emission reductions attributable to the CDM project activity’ (CDM-EB66-A25-GUID).

More specifically, ‘methodologies have to describe the uncertainty of key parameters and, where possible, provide an uncertainty range at 95% confidence level for key parameters for the calculation of emission reductions. Methodology developers are also encouraged to refer to chapter 6 of the *IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories* for more guidance on analysis of uncertainty’ (CDM-EB66-A25-GUID).

Quantification of monitoring uncertainty can be done in three different ways (CDM-EB68-A10):

- Using default values as provided in the 2006 IPCC guidelines; specifically, methodologies have to ‘describe the uncertainty of key parameters and, where possible, provide an uncertainty range at a 95% confidence level for key parameters for the calculation of emission reductions’ (CDM-EB66-A25-GUID)
- Using the confidence/precision concept for surveys and sampling; specifically, ‘project proponents shall use 90/10 confidence/precision as the criteria for reliability of sampling efforts for small-scale project activities and 95/10 for large-scale project activities’ (CDM-EB69-A4);
- Using manufacturer’s information for obtaining a meter’s uncertainty.

After the uncertainty is quantified, different methodologies use different approaches to include it into quantification of emissions reductions (see section 3.2). The overarching monitoring guidelines, however, provide no explicit incentives to reduce uncertainty and do not include explicit provisions regarding the possible trade-off between the stringency of monitoring and the amount of carbon crediting.

The CDM Executive Board nevertheless attempted to adapt the stringency of monitoring to the importance of information at stake via the *Materiality Standard*. A piece of information is considered material if its omission or misstatement may lead to an overestimation of emissions reductions by more than a defined threshold dependent on the project size: from 0.5% for projects with annual emissions reductions of over 500 Kt CO_2e to 10% for renewable energy projects of up to 5 MW and for energy efficiency projects of up to 20 GWh of energy savings per year (Decision 9/CMP.7).

Overall, provisions of the *Standard for Sampling and Surveys for the CDM* and the *Materiality Standard* demonstrate that the CDM Executive Board followed the concept of materiality, whereby the stringency of monitoring requirements depends on the amount of emissions reductions at stake. Indeed, the CDM rules provide for a clear differentiation between large-scale and small-scale projects. In some cases, such as HFC projects, the Executive Board adopted a 'case-by-case' approach imposing highly conservative emissions factors as a response to loopholes that had potentially created perverse incentives for developers to engage in strategic production behavior (Shishlov and Bellassen 2012).

3.2. CDM monitoring methodologies

Methodologies specific to a project type or sub-type must comply with the CDM guidelines. Since CERs are issued against emissions reductions realized by a project, the issue of monitoring is closely linked to the issue of baseline setting. This is the reason why all CDM methodologies include rules for both baselines setting and monitoring. Stringent monitoring requirements together with the need to establish a baseline resulted in complex sector-specific methodologies that are often costly to implement. Michaelowa, Hayashi, and Marr (2009) noted that the CDM Executive Board was initially very strict regarding the principles of data quality and conservativeness, which often resulted either in the rejection of newly proposed methodologies or the introduction of requirements to install prohibitively expensive monitoring equipment (such as in the case of the early methodology for landfill gas projects). Moreover, the bottom-up approach to developing methodologies resulted in multiple project-specific methodologies not tailored to be applied across all projects of the same type.

In light of this constraint, the CDM Executive Board attempted to consolidate methodologies to create a concise list of broadly applicable approaches and eliminate inconsistencies among them. As of September 2014 there were 208 active approved methodologies including 89 large-scale methodologies (AM), 23 large-scale consolidated methodologies (ACM), 92 small-scale methodologies (AMS), and 4 afforestation/reforestation (AR) methodologies (UNEP Risoe 2014). The 10 most commonly used methodologies, representing over 80% of registered projects and over a third of credits issued[6] as of September 2014, are analyzed in this paper (Annex 1). Three questions are asked about each methodology:

- what are the key variables or parameters to be monitored?

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[6] Top 10 methodologies do not include the methodology for HFC-23 projects, which account for 35% of all issued CERs. This project type has been extensively covered in the literature (e.g. in Schneider 2011) and is therefore not explicitly included in this analysis.

- what are the requirements regarding the calculation of uncertainty for these key variables or parameters and/or for the resulting estimate of emissions reduction?
- does this calculation impact the amount of credits issued to the project developer, through discounting or otherwise?

All top 10 methodologies allow for the use of some IPCC default values – namely through different CDM tools, such as for example the *Tool to calculate the Emission Factor for an electricity system*. These default values are provided by the IPCC with a 95% confidence interval and the choice of the uncertainty bound is in most cases done conservatively. This is an implicit discount for uncertainty. Nevertheless, most methodologies do not provide the possibility to reduce the discount with a more precise estimate. In addition, for default values from other sources than IPCC, methodologies do not use this conservativeness principle. As to measured variables, some of them are adjusted for uncertainty though a discount proportional to uncertainty or a default discount.

Most key parameters and variables in the 10 most commonly used methodologies (as of September 2014), however, are not adjusted for uncertainty (Table 2). There are therefore only limited incentives to reduce uncertainty below the minimum threshold. A detailed review of the 10 most commonly used methodologies is provided in the Annex 1.

Table 2 – Adjustment for uncertainty of key variables/parameters[7] in the 10 most-used CDM methodologies as of September 2014

Methodology	**No. of projects**	**Number of parameters/variables** to which an implicit (conservativeness factor) or explicit discount is applied[8]
ACM0002 (renewable power)	3 210	0.13 out of 3
AMS-I.D. (renewable power)	2 077	0.13 out of 4
AMS-I.C. (thermal energy)	253	0.13 out of 5
AMS-III.H. (wastewater)	225	1.13 out of 5
ACM0001 (landfill gas)	221	1 out of 4
AMS-III.D. (manure management)	179	0.25 out of 4
ACM0006 (biomass)	122	0.18 out of 7
ACM0012 (waste energy)	111	0 out of 2
ACM0008 (coal bed/mine methane)	82	0 out of 3
AM0022 (waste treatment)	61+6	0.25 out of 4

Source: authors based on the review of CDM methodologies and calculation tools

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[7] “Key variables/parameters” are those identified as such in the CDM Methodology Booklet (UNFCCC 2013a).

[8] When a “key variable/parameter” is itself composed of several calculation components (e.g. grid emission factor = f(OM vs BM weighting, amount of fuel, net calorific value of fuel, emission factor of fuel)), the number of these components for which a discount is applied is divided by the total number of calculation components. Hence the possibility of a discount being applied to 0.2 out of 4 key variables/parameters. This approach is clearly a coarse approximation of a thorough uncertainty analysis as defined by IPCC (2006) but the latter was beyond the scope of this paper.

Some other methodologies also use adjustment/discount factors to address uncertainty of measurements. For example:

- ACM0016 (mass rapid transport systems) uses the upper value of the 95% confidence interval for fuel consumption;
- ACM0014 (wastewater treatment), AR-ACM0003 and AR-AM0014 (forestry) use discount factors tied to different uncertainty ranges;
- AM0018 (steam optimization) uses the standard error to account for uncertainty;
- AM0034 (N2O nitric acid) explicitly included a provision for discounting carbon credits based on overall monitoring uncertainty. However, in June 2013, it was replaced by AM0019 with no explicit reference to monitoring uncertainty.

The analysis above demonstrates that the CDM monitoring requirements have partly followed the conservativeness principle, mainly through the conservative choice of lower/upper uncertainty bounds for some IPCC default values as well as for some monitored variables. Conservativeness however is not applied in a consistent manner within and between methodologies: not all parameters and variable come with an uncertainty estimate and not all those for which a confidence interval is provided use the conservative limit of the interval.[9]

Moreover, existing CDM guidelines and methodologies seem to lack the incentive to reduce uncertainty above the given confidence/precision threshold (e.g. 95/5 or 90/10). The flexibility option to choose the level of uncertainty based on the cost of monitoring has thus been largely omitted in monitoring guidelines and most methodologies.

The CDM Executive Board acknowledged that the rules regarding treatment of uncertainty apply only to selected variables and are not consistent across methodologies. At its 39th meeting in 2008 the Executive Board requested that the Methodology Panel work on the guidelines regarding treatment of uncertainty including the issue ‘flexibility to choose the level of uncertainty’ (CDM-EB39). However, the topic was not prioritized and was not further developed until CMP7 that took place in Durban in 2011 re-opened the issue and requested the Executive Board to ‘address the issue of uncertainties of measurements in baseline and monitoring methodologies, so that these types of uncertainties do not need to be considered in addressing materiality’ (9/CMP.7). Since 2012, the Executive Board has been working on developing a new standard (or amending the existing ones) to address the issue of monitoring uncertainty in a systematic way. The new rules ‘should provide flexibility in optimizing measurement instrumentation based on cost-benefit considerations’ (CDM-EB73-AA-A04).

3.3. Treatment of uncertainty in other carbon offset standards

Unlike the CDM, several voluntary offset standards provide explicit guidelines regarding the treatment of emissions reduction uncertainty. Notably, the largest voluntary offset standard – the

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[9] This is not saying that the conservative limit should always been used: if applied to estimates based on many parameters, the result would certainly be overly conservative. This is why IPCC provides methodologies to assess the overall uncertainty of the estimate.

Verified Carbon Standard (VCS) – explicitly incorporates the issue of monitoring uncertainty in its two main documents:

- *The VCS Program Guide* stipulates that 'all GHG emission reductions and removals must be quantifiable using recognized measurement tools (including adjustments for uncertainty and leakage) against a credible emissions baseline' (VCS 2012a).
- *The VCS Standard* stipulates that methodologies have to clearly explain uncertainties related to assumptions, parameters and procedures and how they are addressed. 90 or 95 percent confidence interval of parameters has to be estimated: 'where a methodology applies a 90 percent confidence interval and the width of the confidence interval exceeds 20 percent of the estimated value or where a methodology applies a 95 percent confidence interval and the width of the confidence interval exceeds 30 percent of the estimated value, *an appropriate confidence deduction shall be applied*' (VCS 2012b).

Uncertainty of carbon stocks is of particular concern in forestry projects. The Chicago Climate Exchange (CCX) Forestry Carbon Sequestration Project Protocol addresses this issue through discounting. Model estimates of net changes in carbon stocks are discounted by twice the reported statistical error at a 90% confidence interval. Moreover, CCX provides an explicit incentive to apply more accurate monitoring, as 'no discount will be applied for instances when in-field inventories are conducted on an annual basis'. It is also stipulated that 'in order to encourage high-quality inventories, smaller discounts are applied to projects with a higher degree of accuracy for a given level of precision' (CCX 2009). Another CCX methodology – for Avoided Emissions from Organic Waste Disposal – applies a default discount factor of 0.9 to baseline emissions to account for uncertainties.

The Climate Action Reserve (CAR) Program Manual provides for the principle of conservativeness similar to that of the CDM. At the same time 'the Reserve retains the right to reject a variance, request further documentation, or *impose additional constraints and/or discount factors* on the proposed monitoring or measuring methods' (CAR 2011). There is thus a legal window for the regulator to apply discounting for monitoring uncertainty.

The Japan Verified Emission Reduction (J-VER) scheme incorporated more flexible overall MRV requirements compared to the CDM. Notably, the additionality demonstration under J-VER is based on a 'positive list' of methodologies rather than project-by-project additionality demonstration. The monitoring process itself is also significantly simplified with a wide use of conservative default values to calculate emissions reductions (IGES 2013b).

Apart from carbon offsetting, some other policies may provide for a trade-off between monitoring costs and accuracy. For example, Vine and Sathaye (2000) noted that the US Environmental Protection Agency's Conservation Verification Protocols provide an incentive for more rigorous monitoring of energy efficiency improvements, whereby developers adopting more stringent monitoring with inspections are eligible for higher rewards, while those using default values can only claim a part of energy savings.

4. Case studies: monitoring stringency and feasibility of offset projects

This section reviews four case studies illustrating that monitoring requirements may become a major barrier for implementation of projects. It is demonstrated that the Executive Board adopted a 'case-by-case' approach to the treatment of uncertainty in some cases attempting to balance the cost and stringency of monitoring requirements.

4.1. Compact fluorescent lamps

Despite its emissions reduction potential, demand-side energy efficiency (with a notable exception of waste heat recovery projects) remains largely underrepresented in the CDM. In general, the main obstacles for energy efficiency projects include high technical and financial risk, imperfect information, hidden costs, access to capital, split incentives and bounded rationality (Sorrell, Mallett, and Nye 2011). Additionally, the diffuse nature of energy efficiency projects may result in prohibitively complex and/or expensive monitoring. Apart from cumbersome monitoring, energy efficiency projects under the CDM suffered from a very high methodology rejection rate due to issues with baseline conservativeness (Müller-Pelzer and Michaelowa 2005).

Michaelowa, Hayashi, and Marr (2009) analyzed two early methodologies (AM0046 and AMS-II.C) for projects focused on distribution of compact fluorescent lamps (CFLs) and concluded that they involved prohibitively complex and expensive monitoring and sampling requirements. Notably, developers were required to sample four groups of at least 100 households each – two participating in the projects and two reference groups. Moreover, the utilization of each lamp had to be directly measured using a meter attached to the lamp cable. Millard-Ball and Ortolano (2010) confirmed this finding, noting that two years after the approval of methodology AM0046 not a single project managed to get registered under the CDM due to excessively rigorous monitoring requirements.

In order to address this challenge, a new methodology (AMS-II.J) was developed and approved in 2008 that substituted certain monitoring requirements with the ex-ante calculation of 'deemed' parameters. Interestingly, the 'deemed savings' approach was *de facto* previously used in the project 0079: 'Kuyasa low-cost urban housing energy upgrade project' registered under the AMS-II.C methodology. Although this methodology required direct monitoring of power consumption and of operating hours, the developer managed to work around these requirements and to estimate these parameters in the PDD using manufacturer's data and an ex-ante study respectively (Niederberger, Limaye, and Brunner 2007).

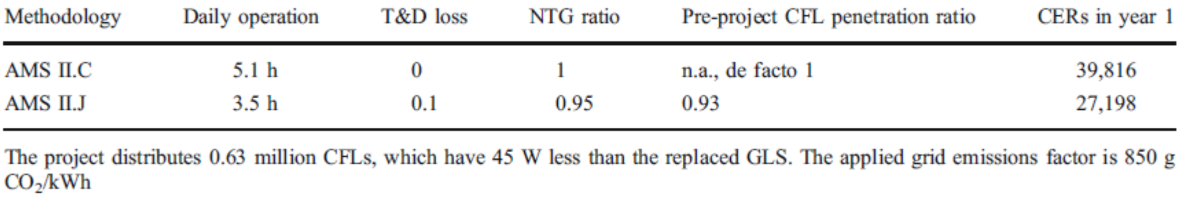
The new methodology AMS-II.J offered project developers a choice between direct measurement and applying a 'default value' for the following parameters (UNFCCC 2013b):

- Number of daily operating hours of a CFL: measured according to sampling requirements of the methodology or a default value of 3.5 hours;
- Average annual technical grid losses (transmission and distribution): data published either by a national utility or an official governmental body or a default value of 10% if data cannot be regarded as reliable;

- Net-to-gross adjustment factor (share of energy savings that can be attributed to the project): value based on a lighting use survey or a default value of 0.95.

Michaelowa, Hayashi, and Marr (2009) calculated that the reduced monitoring stringency in the AMS-II.J methodology may come at a cost of about 30% less CERs awarded compared to AMS-II.C due to highly conservative assumptions regarding deemed parameters (Table 3). Nevertheless, this methodology proved to be the most popular among projects focused on efficient lighting: it was used by 36 out of 42 registered CDM projects and 61 out of 71 registered CDM PoAs as of March 2013 (UNEP Risoe 2014).

Table 3 – CER calculation for the CDM project No. 1754: Visakhapatnam OSRAM CFL



Methodology	Daily operation	T&D loss	NTG ratio	Pre-project CFL penetration ratio	CERs in year 1
AMS II.C	5.1 h	0	1	n.a., de facto 1	39,816
AMS II.J	3.5 h	0.1	0.95	0.93	27,198

The project distributes 0.63 million CFLs, which have 45 W less than the replaced GLS. The applied grid emissions factor is 850 g CO_2/kWh

Source: Michaelowa, Hayashi, and Marr (2009)

The example of demand side energy efficiency projects thus shows that despite the absence of an explicit trade-off between monitoring precision and the amount of carbon credits awarded in the overarching CDM guidelines, this trade-off may nevertheless materialize in methodologies applying to the same project type that require different levels of precision balanced by an adjustment of carbon crediting. Moreover, the methodology AMS-II.J provided developers with a possibility to choose the level of monitoring stringency based on their cost considerations. Finally, the availability of different monitoring methodologies for the same sector provides for an implicit monitoring flexibility through the choice of methodology.

4.2. Efficient cook stoves

Another sub-sector where complex monitoring was perceived as a major barrier for implementation of projects is the distribution of efficient cook stoves. Due to the diffused nature of these projects, precise monitoring of emissions reductions is virtually impossible and, therefore, estimations based on samples, surveys and tests are warranted. Emissions reductions from the use of efficient cook stoves are calculated as a product of the amount of woody biomass saved, i.e. fuel consumption, the fraction that is considered non-renewable biomass (fNRB), the emission factor for the fossil fuel and the net calorific value (NCV) of the biomass (Lee et al. 2013). While the NCV is taken from the IPCC Emission Factor Database, the three other parameters must be estimated.

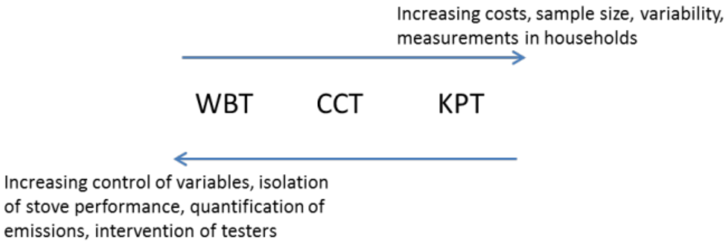
The main methodology used by over 90% of cook stove CDM projects and PoAs (AMS-II.G) allows developers to choose among three methods to measure fuel consumption:

- the Kitchen Performance Test (KPT), conducted in the field and aimed at observing real-life consumption behavior over several days;

- the Controlled Cooking Test (CCT), conducted in a laboratory or in the field and aimed at measuring fuel consumption in a representative cooking task performed by a local cook;
- the Water Boiling Test (WBT), conducted in a laboratory and aimed at measuring fuel consumption in a standardized setting (water-boiling).

These methods provide another example of a trade-off between cost and precision of monitoring (Figure 5). Although laboratory tests enable controlling for errors, which is not possible during field tests, they usually result in lower quality data. For example, Johnson et al. (2007) in their study of a project in Mexico found that using the WBT results in a significant underestimation of emissions reductions. At the same time, despite the fact that field tests may yield better quality data and potentially more carbon credits, most projects resort to simpler WBT in their CDM projects (Lee et al. 2013).

Figure 5 – Trade-offs in different methods to quantify cooking stove fuel consumption

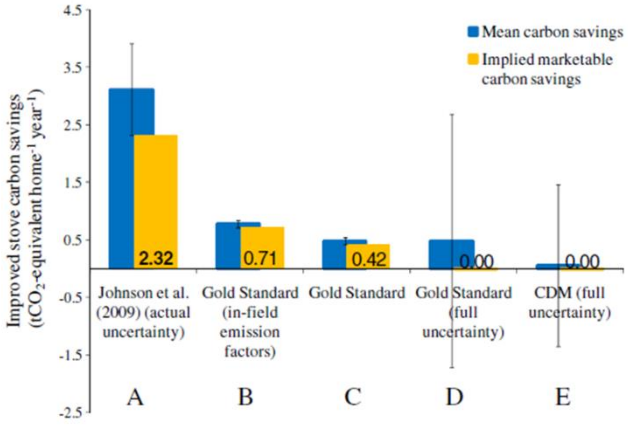


Source: Lee et al. (2013)

The trade-off between monitoring uncertainty and the amount of carbon credits can also be illustrated through differences in monitoring requirements in the CDM and the Gold Standard. Unlike the CDM methodology, the Gold Standard requires developers to conduct the KPT, while the two other methods are not allowed. In addition to monitoring requirements of the CDM, the Gold Standard methodology obliges developers to biennially check the fraction of non-renewable biomass and to conduct quarterly kitchen surveys, effectively increasing the cost of monitoring. At the same time, the Gold Standard in addition to carbon dioxide (CO_2) takes into account reduction in emissions of methane (CH_4) and nitrous oxide (N_2O), potentially enabling projects to claim more carbon credits (Blunck et al. 2011).

Neither the CDM nor the Gold Standard requires calculating uncertainty for the two other monitored parameters, namely the emission factor and the fraction of non-renewable biomass in fuel (fNRB). Johnson, Edwards, and Masera (2010) suggested that if this uncertainty is taken into account, offset projects would result in zero carbon crediting if the lower bound of the 95% confidence interval is applied (scenarios D and E on Figure 6). The authors also proposed their own monitoring approach based on 'local community sub sampling of emission factors and fuel consumption combined with spatially explicit community-level estimates of non-renewable fuel usage'. Although incurring higher monitoring costs, it allows project developers to claim larger amounts of carbon credits (scenario A on Figure 6).

Figure 6 – Emission reductions and 95% confidence intervals for carbon crediting for cook stove projects



Source: Johnson, Edwards, and Masera (2010)

Cook stove methodologies thus provide yet another example of an implicit trade-off between monitoring cost and stringency: a tradeoff between standards – the Gold Standard being more stringent but more lucrative as Gold Standard credits usually sell at a premium compared with CERs – and a trade-off between monitoring options within the CDM as less stringent options use more conservative values, potentially decreasing the amount of credits obtained.

4.3. Transportation

Transportation accounts for 13% of GHG emissions worldwide (IPCC 2007), yet the share of this sector in the CDM is miniscule. One of the commonly reported barriers to implementation of these projects is the complexity of monitoring of diffused emissions reductions. Millard-Ball and Ortolano (2010) conducted 29 interviews with project developers, consultants and members of the CDM Methodology Panel and identified three key groups of barriers that hamper the implementation of CDM projects in the transportation sector:

- inherent challenges of quantification of diffused emissions;
- stringency of the Methodology Panel regarding the approval of methodologies;
- stringent treatment of uncertainty in ‘leakage’ and ‘rebound’ effects for transportation methodologies compared to other sectors.

Romero (2012) noted that methodologies dealing with improved transportation energy efficiency include reasonable monitoring requirements. The methodology AMS-III.AA, for instance, requires monitoring of fuel efficiency in vehicles (baseline and project), annual average distance and the number of operating vehicles. Conversely, methodologies focusing on transportation mode shift – e.g. AM0031 for mass transport system – require monitoring of multiple parameters including transport modes in the absence of the project, fuel consumption of these modes, fuel types used by different modes, distance of travel with different modes, occupancy rate and number of new passengers.

The UNFCCC Practitioner Workshop on the Improvement of CDM Methodologies for Transportation highlighted that monitoring costs in existing transportation methodologies (AM0031 for bus rapid transit and ACM0016 for mass rapid transit) can be prohibitively high – up to EUR144,000 mainly due to multiple surveys required (Replogle and Bakker 2011). Similar to Millard-Ball and Ortolano (2010), Replogle and Bakker (2011) emphasized that the requirements to monitor leakage may be excessively stringent in transportation projects. For example, measurement of the occupancy rate may cost a project developer up to EUR18,000 per monitoring period, while according to the reports this parameter does not change significantly over time and hence only marginally improves monitoring precision. One can therefore conclude that the 'delicate balance between accuracy and practicality is necessary in designing the MRV framework' called for by IGES (2013) has not yet been reached in transportation methodologies.

Recognizing these challenges, the CDM Executive Board revised the methodology AM0031 to reduce the number of surveys necessary from annual to one every three years. Another proposed solution to the problem of high monitoring costs in transportation was to continue regular monitoring of activity until the observed emissions reductions per citizen stabilize within +/-10% range, after which the monitoring frequency, and hence costs, may be considerably reduced (Zegras, Chen, and Grütter 2009).

4.4. Buildings and construction

According to the IPCC (2007), the buildings sector offers the largest emissions reduction potential under US$20 per ton of CO_2e until 2030. Apart from more efficient lighting and cooking appliances discussed earlier, the buildings sector includes such GHG mitigation opportunities as more efficient electrical appliances, heating and cooling systems, upgraded insulation, solar-powered heating and cooling, etc. However, as of September 2014 there were only 10 projects in the buildings sector registered – excluding efficient lighting and improved cooking stoves (UNEP Risoe 2014). 8 of them employed the methodology AMS-II.E: 'Energy efficiency and fuel switching measures for buildings'.

Maximizing energy savings in buildings requires a holistic approach, whereby different measures are integrated in a single strategy (IGES 2013b). An integrated approach is also desirable from the economic point of view, as it allows project developers to reduce transaction costs. Although the methodology AMS-II.E can be applied to any type of efficient technology in buildings, it requires establishing a clear causality: '…applicable to project activities where the impact of the measures implemented (improvements in energy efficiency) by the project activity can be clearly distinguished from changes in energy use due to other variables not influenced by the project activity (signal to noise ratio)'. Besides, the methodology requires direct measurement of energy consumption reduction from each technology installed. Therefore, it is virtually impossible to apply this methodology to projects aiming at the 'whole-building' approach (Michaelowa and Hayashi 2011).

Another major issue that developers have to face is difficulties in establishing the baseline for emissions reduction calculation. This barrier becomes of a particular importance for projects focused on new buildings, since establishing a baseline requires the use of historical data from comparable buildings. This may prove to be cumbersome due to often unique design of buildings

(Cheng et al. 2008). As of September 2014 there were only 5 registered CDM projects focused on energy efficiency in new buildings – all of them in India (UNEP Risoe 2014).

The first large-scale methodology for the buildings sector – AM0091: 'Energy efficiency technologies and fuel switching in new buildings' – was approved in 2011. It addresses the issue of baseline setting through a benchmarking approach. Specifically, the methodology uses the benchmark at the level of 20% top performing buildings in a given municipality in the past 5 years. The benchmark is used both to establish the baseline and demonstrate additionality, while monitoring is simplified thanks to the whole-building approach. The methodology has a potential to unlock large-scale energy efficiency opportunities in buildings, however, its practical applicability is yet to be evaluated, since as of September 2014 there were no projects registered.

4.5. Case-by-case approach to monitoring stringency

These four case studies illustrate the case-by-case approach of the CDM with regards to the trade-off between monitoring stringency and monitoring costs. As the overarching CDM guidelines do not provide clear explicit guidance on this issue, the CDM Executive Board and the Methodology Panel tend to start with strong requirements. Yet, these instances prove flexible when they see, on a case-by-case basis, that the monitoring requirements prevent projects from emerging in a given sub-sector: the monitoring requirements may then be reduced in a new methodology, or a trade-off could be offered between the amount of credits and monitoring stringency to project developers.

The CDM Executive Board acknowledged that the uncertainty of monitoring has not been treated in a consistent manner across methodologies and in the overarching guidelines. The first draft standard on uncertainty of measures was therefore proposed by the Executive Board in May 2013 and included inter alia provisions for discounting carbon credits based on monitoring uncertainty: 'if the overall measurement uncertainty exceeds five per cent, the aggregated emission reductions shall be adjusted by the calculated overall uncertainty' (CDM-EB73-AA-A04). The draft also proposed specific formulas for calculating overall monitoring uncertainty of a project (Annex 2). Introducing such a standard would give project developers more flexibility in choosing their monitoring approach, which may help unlock previously untapped or under-represented sectors, while ensuring the environmental integrity through explicit uncertainty discounts. This 'learning-by-doing' approach is quite typical of the CDM, as demonstrated by Shishlov and Bellassen (2012) regarding other issues such as perverse incentives in HFC projects, materiality in verification, standardization of baselines etc.

5. Conclusions

This paper analyzed monitoring uncertainty requirements for carbon offset projects under the CDM scheme with a particular focus on the trade-off between monitoring stringency, particularly treatment of uncertainty, and costs. To this end, we reviewed existing literature, scrutinized overarching monitoring guidelines, the 10 most-used CDM methodologies and analyzed four case studies. We found that there is indeed a natural trade-off between the stringency and the cost of monitoring, i.e. reducing monitoring uncertainty is usually costly. If not addressed properly, this issue may become a major barrier for the implementation of carbon offset projects in some sectors, such as transportation or buildings.

We built evidence, both systematic – through the analysis of overarching CDM guidelines and the 10 most used CDM methodologies – and anecdotal – through four case studies – that the CDM monitoring requirements have partly followed the conservativeness principle, mainly through a conservative choice of lower/upper uncertainty bounds for some IPCC default values as well as for some monitored variables. At the same time, existing CDM guidelines and methodologies seem to lack the incentive to reduce uncertainty below the given confidence/precision threshold (e.g. 95/5 or 90/10). The flexibility option to choose the uncertainty based on the cost of monitoring has thus been so far largely omitted in monitoring guidelines and in most methodologies.

More generally, the issue of monitoring uncertainty has not yet been addressed in a systematic manner in the CDM. Some methodologies and calculation tools as well as some other offset standards, however, do incorporate provisions for a trade-off between the stringency and the costs of monitoring. These provisions may take the form of discounting emissions reductions based on the level of monitoring uncertainty or more implicitly allowing a project developer to choose between monitoring a given parameter and using a conservative default value. The CDM Executive Board acknowledged that monitoring uncertainty has not been treated in a consistent manner and the draft standard on uncertainty was subsequently presented in May 2013. Our findings support the implementation of this standard for more comprehensive, yet cost-efficient, accounting for monitoring uncertainty in carbon offset projects.

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7. Annexes

Annex 1 – Treatment of monitoring uncertainty in the 10 most commonly used CDM methodologies (as of September 2014)

Methodology	**Key variables/parameters (as per CDM Methodology Booklet as of November 2013)**	**Treatment of monitoring uncertainty in the methodology and relevant calculation tools**	**Explicit discount for uncertainty of key variables/parameters**
ACM0002 **Grid-connected electricity generation from renewable sources** (3,210 projects)*	**At validation:** • Grid emission factor (can also be monitored ex post). **Monitored:** • Electricity supplied to the grid by the project; • If applicable: methane emissions of the project.	**Methodology:** • baseline uncertainty: the power generation of renewable energy projects can vary significantly from year to year, due to natural variations in the availability of the renewable source (e.g. varying rainfall, wind speed or solar radiation). The use of few historical years to establish the baseline electricity generation can therefore involve a significant uncertainty. The methodology addresses this uncertainty by adjusting the historical electricity generation by its standard deviation. • default emission factor for emissions from reservoirs **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** • IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Tool to calculate the emission factor for an electricity system:** • IPCC default values at the lower limit of the uncertainty at a 95 per cent confidence interval • The results of the survey should be used to derive global estimates adjusted for their uncertainty at a 95 per cent confidence level in a conservative manner (using the upper or lower uncertainty bound whatever is conservative) • In certain cases (e.g. projects in LDCs) default CO2 emission factor (0.8 t CO2/MWh) and the default value of the electricity generated by the off-grid power plants can be applied for the first crediting period	<u>**0.13 of 3 key variables/parameters discounted for uncertainty:**</u> **Electricity supplied by the project**: measured with the electricity meter, no discount (0 of 1) **Grid emissions factor** consists of 5 key parameters (0.66 of 5 discounted): • *Amount of fuel consumed*: taken from utility records or official publications, no discount (0 of 1) • *Net calorific value (energy content) of fuel*: calculated using one of three options (1 of 3 discounted, i.e. 0.33): (i) fuel supplier data, no discount; (ii) regional or national average default values (no discount); or (iii) IPCC default values at the lower limit of uncertainty at 95% confidence (discount) • *Emission factor of fuel*: calculated using one of three options (1 of 3 discounted, i.e. 0.33): (i) fuel supplier data, no discount; (ii) regional or national average default values (no discount); or (iii) IPCC default values at the lower limit of uncertainty at 95% confidence (discount) • *Electricity generated*: utility or government records or official publications, no discount (0 of 1) • *Weighting of the operation margin and build margin emissions factor*: default value depending on the type of generation, no discount (0 of 1) **Emissions from reservoirs of hydro power plants** (if applicable): default emission factor for (EB23 decision), no discount (0 of 1)
AMS-I.D. **Grid connected renewable**	**At validation:** • Grid emission factor (can also be monitored ex post); • Moisture content of	**Methodology:** • baseline uncertainty: in the specific case of retrofit/capacity addition in hydro, solar, wind, geothermal, wave and tidal plants where power generation can vary significantly from year to year, due to natural	**0.13 of 4 key variables/parameters discounted for uncertainty:** **Grid emissions factor** consists of 5 key parameters (0.66 of 5 discounted): • *Amount of fuel consumed*: taken from utility records or official publications, no discount (0 of 1)

electricity generation (2,077 projects)	biomass of homogeneous quality shall be determined ex ante. **Monitored:** • Quantity of net electricity supplied to the grid; • Quantity of biomass/fossil fuel consumed; • Net calorific value of biomass shall be determined once in the first year of the crediting period.	variations in the availability of the renewable source (e.g. varying rainfall, wind speed or solar radiation), the use of few historical years to establish the baseline electricity generation can therefore involve a significant uncertainty. The methodology addresses this uncertainty by adjusting the historical electricity generation by its standard deviation. This ensures that the baseline electricity generation is established in a conservative manner and that the calculated emission reductions are attributable to the project activity. **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** • IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Tool to calculate the emission factor for an electricity system:** • IPCC default values at the lower limit of the uncertainty at a 95 per cent confidence interval • The results of the survey should be used to derive global estimates adjusted for their uncertainty at a 95 per cent confidence level in a conservative manner (using the upper or lower uncertainty bound whatever is conservative) • In certain cases (e.g. projects in LDCs) default CO2 emission factor (0.8 t CO2/MWh) and the default value of the electricity generated by the off-grid power plants can be applied for the first crediting period	• *Net calorific value (energy content) of fuel*: calculated using one of three options (1 of 3 discounted, i.e. 0.33): (i) fuel supplier data, no discount; (ii) regional or national average default values (no discount); or (iii) IPCC default values at the lower limit of uncertainty at 95% confidence (discount) • *Emission factor of fuel*: calculated using one of three options (1 of 3 discounted, i.e. 0.33): (i) fuel supplier data, no discount; (ii) regional or national average default values (no discount); or (iii) IPCC default values at the lower limit of uncertainty at 95% confidence (discount) • *Electricity generated*: utility or government records or official publications, no discount (0 of 1) • *Weighting of the operation margin and build margin emissions factor*: default value depending on the type of generation, no discount (0 of 1) **Quantity of biomass/fossil fuel consumed**: on-site measurements, no discount (0 of 1) **Moisture content of biomass**: on-site measurement, no discount (0 of 1) **Net calorific value of biomass:** measurement in laboratories according to relevant national/international standards. Measure quarterly, taking at least three samples for each measurement. The average value can be used for the rest of the crediting period, thus no discount (0 of 1)
AMS-I.C. **Thermal energy production with or without electricity** (253 projects)	**At validation:** • Grid emission factor (can also be monitored ex post). **Monitored:** • The moisture content of biomass of homogeneous quality may be fixed ex ante or monitored for each batch of biomass if the emission reductions are calculated based on energy input; • Thermal energy (mass flow, temperature, pressure for heat/cooling) delivered by the project and the amount of grid and/or captive electricity	**Methodology:** • for calculating thermal energy production with or without electricity to measure the quantity of hot air where it is not feasible (e.g. because of too high temperature), spot measurements can be used through sampling with a 90% confidence level and a 10% precision **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** • IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Tool to calculate baseline, project and/or leakage emissions from electricity consumption:** • IPCC default values at the upper or lower limit (whatever is more conservative)–of the uncertainty at a 95% confidence interval **Tool to determine the baseline efficiency of thermal or electric energy generation systems:** • the load-efficiency function derived using regression model shall be adjusted for uncertainty in a conservative manner, by considering the upper bound values of the range at 95% confidence level at the load	**0.13 of 5 key variables/parameters discounted for uncertainty:** **Grid emissions factor** consists of 5 key parameters (0.66 of 5 discounted): • *Amount of fuel consumed*: taken from utility records or official publications, no discount (0 of 1) • *Net calorific value (energy content) of fuel*: calculated using one of three options (1 of 3 discounted, i.e. 0.33): (i) fuel supplier data, no discount; (ii) regional or national average default values (no discount); or (iii) IPCC default values at the lower limit of uncertainty at 95% confidence (discount) • *Emission factor of fuel*: calculated using one of three options (1 of 3 discounted, i.e. 0.33): (i) fuel supplier data, no discount; (ii) regional or national average default values (no discount); or (iii) IPCC default values at the lower limit of uncertainty at 95% confidence (discount) • *Electricity generated*: utility or government records or official publications, no discount (0 of 1) • *Weighting of the operation margin and build margin emissions factor*: default value depending on the type of generation, no discount (0 of 1) **Moisture content of biomass**: on-site measurement, no discount (0 of 1) **Thermal energy supplied:** measured continuously, no discount (0 of 1)

	displaced; • Quantity of biomass and fossil fuel consumed; • Net calorific value of biomass shall be determined once in the first year of the crediting period.	point where efficiency is to be derived • default values can be used for load-efficiency **Methodological Tool 'Emissions from solid waste disposal sites':** • use of the calculation model correction factor to account for uncertainty of emissions from waste in different conditions *(either a default value or calculation)* **Methodological Tool 'Project emissions from flaring':** • the flare efficiency is determined for each minute m of year y based either on monitored data or default values	**Quantity of biomass/fossil fuel consumed**: on-site measurements, no discount (0 of 1) **Net calorific value of biomass:** measurement in laboratories according to relevant national/international standards. Measure quarterly, taking at least three samples for each measurement. The average value can be used for the rest of the crediting period, thus no discount (0 of 1)
AMS-III.H. **Wastewater treatment** (225 projects)	**At validation:** • COD removal efficiency of the baseline system. **Monitored:** • Flow of wastewater; • Chemical oxygen demand of the wastewater before and after the treatment system; • Amount of sludge as dry matter in each sludge treatment system; • Amount of biogas recovered, fuelled, flared or utilized (e.g. injected into a natural gas distribution grid or distributed via a dedicated piped network).	**Methodology:** • confidence/precision level of 90/10 for key monitored parameters has to be attained • Model correction factor to account for model uncertainties (0.89) • Methane Correction Factor depending on the type of wastewater treatment and discharge pathway or system **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** • IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Tool to calculate baseline, project and/or leakage emissions from electricity consumption:** • IPCC default values at the upper or lower limit (whatever is more conservative)–of the uncertainty at a 95% confidence interval **Methodological Tool 'Emissions from solid waste disposal sites':** • use of the calculation model correction factor to account for uncertainty of emissions from waste in different conditions *(either a default value or calculation)* **Methodological Tool 'Project emissions from flaring':** • the flare efficiency is determined for each minute m of year y based either on monitored data or default values	**1.13 of 5 key variables/parameters discounted for uncertainty:** **COD removal efficiency**: correction factor to account for model uncertainties is applied (1 of 1) **Volume of wastewater treated***:* measured on-site, 90/10 confidence/precision has to be attained, however no discount (0 of 1) **Chemical oxygen demand (COD)**: sampling, 90/10 confidence/precision has to be attained, however no discount (0 of 1) **Amount of dry matter in the sludge***: measurements, 90/*10 confidence/precision has to be attained, however no discount (0 of 1) **Methane captured and destroyed/gainfully used by the project activity** consists of 4 parameters (0.5 of 4 discounted): • Amount of biogas flared/combusted: monitored continuously, 90/10 confidence/precision has to be attained, however no discount (0 of 1) • Methane content of the biogas: measured with a continuous analyser or, alternatively, with periodical measurements at a 90/10 confidence/precision level, however no discount (0 of 1) • *Density of methane*: calculated using temperature and pressure that are measured continuously, no discount (0 of 1) • *Flare efficiency*: as per 'Tool to determine project emissions from flaring gases containing Methane' in case of the open flare default values are applied based on the presence of flare (which is monitored continuously with no discount); in case of an enclosed flare a fixed conservativeness discount is applied, therefore 0.5 out of 1 is discounted
ACM0001 **Flaring or use of landfill gas** (221 projects)	**Monitored:** • Amount of landfill gas captured; • Methane fraction in the landfill gas; • If applicable: electricity	**Methodology:** • CO2 emission factor of the fossil fuel type used for heat generation in the baseline is taken from 2006 IPCC Guidelines on National GHG Inventories. The lower limit of the 95% confidence interval shall be used **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:**	**1 of 4 key variables/parameters discounted for uncertainty:** **Amount of methane in the LFG that is flared/used**: measured according to the Tool to determine the mass flow of a greenhouse gas in a gaseous stream, no discount (0 of 1) **Fraction of methane in the LFG that would be oxidized**: default value as per Methodological Tool 'Emissions from solid waste disposal sites', no discount (0 of 1) **The model correction factor** (φy) depends on the uncertainty of the parameters used in the

	generation using landfill gas.	• IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Methodological Tool 'Emissions from solid waste disposal sites':** • use of the calculation model correction factor to account for uncertainty of emissions from waste in different conditions *(either a default value or calculation)* **Tool to calculate baseline, project and/or leakage emissions from electricity consumption:** • IPCC default values at the upper or lower limit (whatever is more conservative)–of the uncertainty at a 95% confidence interval **Methodological Tool 'Project emissions from flaring':** • the flare efficiency is determined for each minute m of year y based either on monitored data or default values **Tool to determine the mass flow of a greenhouse gas in a gaseous stream***:* • no reference to uncertainty **Tool to determine the baseline efficiency of thermal or electric energy generation systems:** • the load-efficiency function derived using regression model shall be adjusted for uncertainty in a conservative manner, by considering the upper bound values of the range at 95% confidence level at the load point where efficiency is to be derived • default values can be used for load-efficiency **Tool to determine the remaining lifetime of equipment:** • no reference to uncertainty **Methodological tool 'Project and leakage emissions from transportation of freight':** • estimate project and/or leakage CO2 emissions from road transportation of freight by vehicles. Two options are provided to determine these emissions: (a) Option A: Monitoring fuel consumption; or (b) Option B: Using conservative default values.	FOD model (1 of 1) **Electricity produced by the project**: measured with the electricity meter, no discount (0 of 1)

AMS-III.D.
Methane recovery in animal manure management systems
(179 projects)
	Monitored:
	• Amount of biogas recovered and fuelled, flared or used gainfully;
	• The annual amount of fossil fuel or electricity used to operate the facility or auxiliary equipment;
	• Fraction of the manure
		Methodology:
		• the fraction of methane in the biogas should be measured with a continuous analyser (values are recorded with the same frequency as the flow) or, with periodical measurements at a 90/10 confidence/precision level by following the 'Standard for sampling and surveys for CDM project activities and Programme of Activities', or, alternatively a default value of 60% methane content can be used. Option chosen should be clearly specified in the PDD
		• Default model correction factor to account for model uncertainties
			0.25 of 4 key variables/parameters discounted for uncertainty:
			Biogas volume: measured using the flow meter, no discount (0 of 1)
			CO2 emissions from fossil fuel combustion (if applicable) consists of 2 key parameters (0.13 of 2 discounted):
			• *Quantity of fuels combusted*: onsite measurements, no discount (0 of 1)
			• *CO2 emission coefficient of the fuel* is calculated using two options (0.13 of 1)
			  ▪ Option A (0 of 2): using *weighted average mass fraction of carbon in fuel* (no discount) and *weighted average density of fuel* (no discount)
			  ▪ Option B (0.5 of 2): using *weighted average net calorific value of the fuel*

	handled in the manure management system; • Proper soil application (not resulting in methane emissions) of the final sludge must be monitored.	(0.94) **Methodological Tool ‘Project emissions from flaring’:** • the flare efficiency is determined for each minute m of year y based either on monitored data or default values **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** • IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Methodological tool ‘Project and leakage emissions from anaerobic digesters’:** • Default value for the fraction of methane in the biogas (based on literature)	(0.25 of 1 discounted) and *weighted average CO2 emission factor of fuel* (0.25 of 1 discounted) **CO2 emissions from electricity consumption (if applicable)** consists of 3 key parameters (0.13 of 3 discounted): • *Quantity of electricity consumed:* measured with the electricity meter, no discount (0 of 1) • *Emission factor for electricity generation* (as per Tool to calculate the emission factor for an electricity system) consists of 5 key parameters (0.66 of 5 discounted) • *Average technical transmission and distribution losses*: different default values depending on the scenario, no discount (0 of 1) **Quantity of manure treated from livestock**: manure weight delivered to each system shall be directly measured or alternatively manure volume can be measured together with the density determined from representative sample (90/10 precision), no discount (0 of 1)
ACM0006 **Electricity and heat generation from biomass** (122 projects)	**At validation:** • Grid emission factor (can also be monitored ex post). **Monitored:** • Quantity and moisture content of the biomass used in the project activity; • Electricity and heat generated in the project activity; • Electricity and, if applicable, fossil fuel consumption of the project activity.	**Methodology:** • To determine the CH4 emission factor, project participants may undertake measurements or use referenced default values • The uncertainty of the CH4 emission factor is in many cases relatively high. In order to reflect this and for the purpose of providing conservative estimates of emission reductions, a conservativeness factor must be applied to the CH4 emission factor. The level of the conservativeness factor depends on the uncertainty range of the estimate for the CH4 emission factor. **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** • IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Methodological Tool ‘Emissions from solid waste disposal sites’:** • use of the calculation model correction factor to account for uncertainty of emissions from waste in different conditions *(either a default value or calculation)* **Tool to calculate baseline, project and/or leakage emissions from electricity consumption:** • IPCC default values at the upper or lower limit (whatever is more conservative)–of the uncertainty at a 95% confidence interval **Tool to calculate the emission factor for an electricity system:** • IPCC default values at the lower limit of the uncertainty at a 95 per cent confidence interval • The results of the survey should be used to derive global estimates adjusted for their uncertainty at a 95 per cent confidence level in a	**0.18 of 7 key variables/parameters discounted for uncertainty:** **Grid emissions factor** consists of 5 key parameters (0.66 of 5 discounted): • *Amount of fuel consumed*: taken from utility records or official publications, no discount (0 of 1) • *Net calorific value (energy content) of fuel*: calculated using one of three options (1 of 3 discounted, i.e. 0.33): (i) fuel supplier data, no discount; (ii) regional or national average default values (no discount); or (iii) IPCC default values at the lower limit of uncertainty at 95% confidence (discount) • *Emission factor of fuel*: calculated using one of three options (1 of 3 discounted, i.e. 0.33): (i) fuel supplier data, no discount; (ii) regional or national average default values (no discount); or (iii) IPCC default values at the lower limit of uncertainty at 95% confidence (discount) • *Electricity generated*: utility or government records or official publications, no discount (0 of 1) • *Weighting of the operation margin and build margin emissions factor*: default value depending on the type of generation, no discount (0 of 1) **Quantity of biomass:** on-site measurements, no discount (0 of 1) **Moisture content:** on-site measurements, no discount (0 of 1) **Quantity of electricity generated:** on-site measurements with a meter, no discount (0 of 1) **Quantity of heat generated:** on-site measurements, no discount (0 of 1) **CO2 emissions from fossil fuel combustion (if applicable)** consists of 2 key parameters (0.13 of 2 discounted): • *Quantity of fuels combusted*: on-site measurements, no discount (0 of 1) • *CO2 emission coefficient of the fuel* is calculated using two options (0.13 of 1) ○ Option A (0 of 2): using *weighted average mass fraction of carbon in fuel* (no discount) and *weighted average density of fuel* (no discount)

		conservative manner (using the upper or lower uncertainty bound whatever is conservative) • In certain cases (e.g. projects in LDCs) default CO2 emission factor (0.8 t CO2/MWh) and the default value of the electricity generated by the off-grid power plants can be applied for the first crediting period **Tool to determine the baseline efficiency of thermal or electric energy generation systems:** • the load-efficiency function derived using regression model shall be adjusted for uncertainty in a conservative manner, by considering the upper bound values of the range at 95% confidence level at the load point where efficiency is to be derived • default values can be used for load-efficiency **Tool to determine the remaining lifetime of equipment:** • no reference to uncertainty **Methodological tool 'Project and leakage emissions from transportation of freight':** • estimate project and/or leakage CO2 emissions from road transportation of freight by vehicles. Two options are provided to determine these emissions: (a) Option A: Monitoring fuel consumption; or (b) Option B: Using conservative default values.	Option B (0.5 of 2): using *weighted average net calorific value of the fuel* (0.25 of 1 discounted) and *weighted average CO2 emission factor of fuel* (0.25 of 1 discounted) **CO2 emissions from electricity consumption (if applicable)** consists of 3 key parameters (0.13 of 3 discounted): • *Quantity of electricity consumed:* measured with the electricity meter, no discount (0 of 1) • *Emission factor for electricity generation* (as per Tool to calculate the emission factor for an electricity system) consists of 5 key parameters (0.66 of 5 discounted) • *Average technical transmission and distribution losses*: different default values depending on the scenario, no discount (0 of 1)
ACM0012 **Consolidated baseline methodology for GHG emission reductions from waste energy recovery projects** (111 projects)	**Monitored:** • Quantity of electricity/ heat supplied to the recipient plant(s); • Quantity and parameters of waste energy streams during project.	**Methodology:** • IPCC default emission factors can be used for some parameters, no reference to uncertainty however **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** • IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Tool to determine the baseline efficiency of thermal or electric energy generation systems:** • the load-efficiency function derived using regression model shall be adjusted for uncertainty in a conservative manner, by considering the upper bound values of the range at 95% confidence level at the load point where efficiency is to be derived • default values can be used for load-efficiency **Tool to determine the baseline efficiency of thermal or electric energy generation systems:** • the load-efficiency function derived using regression model shall be adjusted for uncertainty in a conservative manner, by considering the upper bound values of the range at 95% confidence level at the load point where efficiency is to be derived	**0 of 2 key variables/parameters discounted for uncertainty:** **Electricity produced by the project**: measured with the electricity meter, no discount (0 of 1) **Net quantity of heat supplied to the recipient facility**: consists of two measured parameters with no adjustment for uncertainty (0 of 1)

		- default values can be used for load-efficiency **Tool to determine the remaining lifetime of equipment:** - no reference to uncertainty	
ACM0008 **Consolidated methodology for Abatement of methane from coal mines** (82 projects)	**Monitored:** • Methane destroyed or used; • Concentration of methane in extracted gas; • If applicable: electricity generated by project.	**Methodology:** - IPCC default values at the lower limit of the uncertainty at a 95 per cent confidence interval **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** - IPCC default values at the upper limit of the uncertainty at a 95% confidence interval **Tool to calculate baseline, project and/or leakage emissions from electricity consumption:** - IPCC default values at the upper or lower limit (whatever is more conservative)–of the uncertainty at a 95% confidence interval **Methodological Tool ‘Project emissions from flaring’:** - the flare efficiency is determined for each minute m of year y based either on monitored data or default values **Tool to calculate the emission factor for an electricity system:** - IPCC default values at the lower limit of the uncertainty at a 95 per cent confidence interval - The results of the survey should be used to derive global estimates adjusted for their uncertainty at a 95 per cent confidence level in a conservative manner (using the upper or lower uncertainty bound whatever is conservative) - In certain cases (e.g. projects in LDCs) default CO2 emission factor (0.8 t CO2/MWh) and the default value of the electricity generated by the off-grid power plants can be applied for the first crediting period	**0 of 3 key variables/parameters discounted for uncertainty:** **Methane captured and destroyed**: continuous measurement, no discount (0 of 1) **Methane concentration**: continuous measurement, no discount (0 of 1) **Electricity produced by the project**: measured with the electricity meter, no discount (0 of 1)
AM0025 (replaced by ACM0022 in September 2012) **Alternative waste treatment processes** (62 projects + 6 with	**ACM0022:** **Monitored:** • Weight fraction of the different waste types in a sample and total amount of organic waste prevented from disposal; • Electricity and fossil fuel consumption in the project site.	**Methodology:** - IPCC default values at the upper/lower limit8 of the uncertainty at a 95% confidence interval - fixed conservativeness factors for some values - Discount factor to account for the uncertainty of the use of historical data to determine the chemical oxygen demand (COD) of the wastewater that would enter the lagoon in the absence of the project activity **Tool to calculate project or leakage CO2 emissions from fossil fuel combustion:** - IPCC default values at the upper limit of the uncertainty at a 95%	**0.25 of 4 key variables/parameters discounted for uncertainty:** **Weight fraction of the different waste types:** sampled, no discount (0 of 1) **Amount of waste:** measured, no discount (0 of 1) **CO2 emissions from fossil fuel combustion (if applicable)** consists of 2 key parameters (0.13 of 2 discounted): - *Quantity of fuels combusted*: on-site measurements, no discount (0 of 1) - *CO2 emission coefficient of the fuel* is calculated using two options (0.13 of 1) ○ Option A (0 of 2): using *weighted average mass fraction of carbon in fuel* (no discount) and *weighted average density of fuel* (no discount) Option B (0.5 of 2): using *weighted average net calorific value of the fuel* (0.25 of 1

ACM0022)		confidence interval **Methodological Tool 'Emissions from solid waste disposal sites':** - use of the calculation model correction factor to account for uncertainty of emissions from waste in different conditions *(either a default value or calculation)* **Tool to calculate baseline, project and/or leakage emissions from electricity consumption:** - IPCC default values at the upper or lower limit (whatever is more conservative)–of the uncertainty at a 95% confidence interval **Methodological Tool 'Project emissions from flaring':** - the flare efficiency is determined for each minute m of year y based either on monitored data or default values **Tool to determine the mass flow of a greenhouse gas in a gaseous stream:** - no reference to uncertainty **Tool to determine the baseline efficiency of thermal or electric energy generation systems:** - the load-efficiency function derived using regression model shall be adjusted for uncertainty in a conservative manner, by considering the upper bound values of the range at 95% confidence level at the load point where efficiency is to be derived - default values can be used for load-efficiency **Methodological tool 'Project and leakage emissions from composting':** - default values with no reference to uncertainty **Methodological tool 'Project and leakage emissions from anaerobic digesters':** - default value for the fraction of methane in the biogas (based on literature)	discounted) and *weighted average CO2 emission factor of fuel* (0.25 of 1 discounted) **CO2 emissions from electricity consumption (if applicable)** consists of 3 key parameters (0.13 of 3 discounted): - *Quantity of electricity consumed:* measured with the electricity meter, no discount (0 of 1) - *Emission factor for electricity generation* (as per Tool to calculate the emission factor for an electricity system) consists of 5 key parameters (0.66 of 5 discounted) - *Average technical transmission and distribution losses*: different default values depending on the scenario, no discount (0 of 1)

**number of projects using the methodology (including single and combined with others) registered as of September 2014, source: UNEP Risoe*

Source: authors based on the key word search ('uncertainty', 'error', 'confidence', 'default', 'discount') in CDM methodologies and calculation tools

Annex 2 – Proposed formulas for calculating overall monitoring uncertainty in a CDM project

If $ER = A * B * C$, then $U= \surd\ [u(A)^2 + u(B)^2 + u(C)^2]$

If $ER = A * B/C$, then $U= \surd\ [u(A)^2 + u(B)^2 - u(C)^2]$

If $ER = A * B^2$, then $U= \surd\ [u(A)^2 + 2u(B)^2]$

If $ER = mA + nB$, then $U= \surd\ [u(A)^2 + (n/m * u(B))^2]$

where:

(a) u uncertainty (fraction)

(b) A B C … parameters

(c) m n ... constants

(d) U overall uncertainty

Source: CDM-EB73-AA-A04