Visibility of carbon market approaches in greenhouse gas inventories

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ABSTRACT

Under the Paris Agreement, Parties must track the implementation and achievement of their nationally determined contributions (NDCs). In many cases, NDC targets are expressed as a greenhouse gas (GHG) emissions level and their implementation and achievement is tracked through national GHG inventories. To achieve their targets, it is thus essential for countries that the effects of mitigation measures are visible in their inventories. Inventory visibility is understood as the degree to which a change in GHG emissions or removals resulting from mitigation actions is reflected in GHG inventories. Inventory visibility can be assessed by identifying which emission sources and gases are affected by a mitigation action, determining the minimum inventory methods required for reflecting the related emission reduction, and identifying the completeness of and methods used by the current GHG inventory. In addition, it is useful to identify potential differences with the quantification approaches used under carbon market mechanisms. Inventory visibility is found to be generally high for measures that reduce CO2 emissions from fossil fuel combustion, while in parts of the industrial processes sector and in the forestry sector there is a higher risk that emission reductions are not visible. An analysis of the portfolio of Clean Development Mechanism projects shows that for most projects this risk is low; only 8% of the carbon credit supply potential is assessed to have a medium risk and 5% is assessed to have a high risk. However, as future carbon market mechanisms under Article 6 of the Paris Agreement may need to tap more into project types with medium to higher risk of non-visibility, national GHG inventory systems may need to be strengthened to assure visibility of mitigation projects.

KEYWORDS

GHG inventories; market-based mechanisms; GHG accounting; clean development mechanism; nationally determined contributions

Introduction

The Paris Agreement requires its Parties to regularly communicate nationally determined contributions (NDCs) in which they specify their climate change mitigation targets.

The Agreement also establishes an enhanced transparency framework which requires Parties to track ‘progress made in implementing and achieving their NDCs’. Progress is tracked through relevant ‘indicators’ [1, paragraph 67]. Which indicator is best suited depends on the type of mitigation target. In the case of greenhouse gas (GHG) emissions targets, emissions taken from national GHG inventories are the most suitable indicator to track progress.

To achieve their NDCs, it is essential for Parties that the outcome of mitigation actions is reflected in the indicators used to track progress. An important question is therefore under which conditions and how accurately the outcome from mitigation actions is visible in national GHG inventories or other relevant indicators to track progress towards NDCs. This mainly depends on whether the methods, data sources and assumptions used to estimate GHG inventories (or other relevant indicators) have sufficient accuracy and granularity to pick up the emission reductions (or other relevant outcomes) resulting from the mitigation actions. This issue has been referred to as the ‘inventory visibility’ of mitigation actions [2] – a term also used in this paper.

Inventory visibility is relevant, and has been discussed, in various contexts. Inventory visibility is an issue for all types of indicators used to track progress towards NDCs. In practice, it is most relevant for GHG inventories, because many countries have communicated GHG emissions targets in their NDCs and estimating GHG emissions can be more complex than tracking other types of indicators. This paper therefore assesses inventory visibility in the context of national GHG inventories.

Inventory visibility is relevant for all types of mitigation actions, but gained particular attention...
in the context of international carbon markets [2–5], for two reasons: First, the methods used to quantify emission reductions under carbon market approaches can differ from those used for national GHG inventories. Under crediting mechanisms, for example, projects flaring landfill gas determine the emission reductions based on measurements, while national GHG inventories often estimate emissions from landfills based on the amount of waste dumped [6, Vol. 5, p. 3.6].

Second, inventory visibility is an important consideration for accounting for internationally transferred mitigation outcomes (ITMOs) under Article 6 of the Paris Agreement. Article 6.2 requires Parties to ‘apply robust accounting to ensure, inter alia, the avoidance of double counting’. Double counting could occur if a mitigation outcome is used more than once towards NDCs or towards other relevant purposes, such as under the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) established under the International Civil Aviation Organization (ICAO) [7]. Under the Paris Agreement, double counting between countries is avoided through the application of ‘corresponding adjustments’ to reported GHG emissions. Corresponding adjustments are to be applied and reported in the form of a ‘structured summary’ in which additions to NDC covered emissions are made for ITMOs first transferred and subtractions for ITMOs used towards an NDC. The additions and subtractions give an adjusted emissions balance that can be compared to the target level [1, 8]. If countries account in this way for the international transfer of mitigation outcomes under carbon market approaches, but do not observe the associated emission reductions in their national GHG inventories, they may face a shortfall in emission reductions in their structured summary and hence difficulties in achieving their mitigation target.

Inventory visibility has been identified in several papers [2–5, 9–11], but the risks relating to inventory visibility and means to address them have not yet been investigated in more detail. Prag et al. [2] argue that the risk of a lack of inventory visibility may be higher for crediting mechanisms than for emissions trading systems (ETSSs). Herold and Böttcher [9] find a particularly high risk of a lack of inventory visibility in the land-use, land-use change and forestry (LULUCF) sector and recommend steps to identify relevant gaps and improve GHG inventories accordingly. The most comprehensive available evaluation of inventory visibility was conducted for the Kyoto Protocol’s Joint Implementation (JI) mechanism [4, 12]. The evaluation reveals considerable differences and inconsistencies between national GHG inventories and emission reduction claims by JI projects. In some instances, emissions addressed with JI projects were not included in the national GHG inventory, such as for projects avoiding uncontrolled fires at coal waste piles in Ukraine; in other instances, the emission reductions claimed by JI projects were inconsistent with those reported in national GHG inventories, such as for the abatement of HFC-23 emissions in Russia.

Building on this earlier work, this paper systematically assesses for which type of mitigation actions and under which conditions a lack of inventory visibility is a risk, which inventory methods are required to ensure inventory visibility of mitigation actions, and what implications arise when using international carbon market approaches. Understanding these matters can help inventory compilers in improving their greenhouse gas inventories and in making them fit for the purpose of tracking progress in implementing and achieving their country’s NDCs.

**Methods**

**Defining inventory visibility**

In this paper, inventory visibility is understood as the degree to which a change in GHG emissions or removals resulting from mitigation actions is reflected in national GHG inventories, keeping all other factors constant. In other words, inventory visibility refers to the ability of these inventories to pick up changes in emissions or removals resulting from mitigation actions. This may include mitigation implemented through carbon market approaches.

Inventory visibility is different from inventory accuracy and precision. Inventory visibility refers to whether changes in emissions resulting from mitigation actions are visible, whereas accuracy is a measure of the agreement between the true value and the average of repeated measured observations or estimates, and precision is a measure of the agreement among repeated measurements of the same variable [6, Vol. 1, p. 3.7]. Inventory uncertainty is the lack of knowledge of the true value of a variable that can be described as a probability density function characterising the range and likelihood of possible values [6, Vol. 1, p. 3.8]. A high inventory visibility does not
necessarily mean that the inventory has high accuracy or low uncertainty. For example, if a policy reduces the amount of fertilizer applied to fields, this measure may be visible in the GHG inventory if the inventory is based on robust data on fertilizer application, while the overall uncertainty of N₂O emissions from fertilizer application may still be high due to the uncertainty of emission factors.

Furthermore, inventory visibility does not mean that the GHG inventory can necessarily be used to estimate the emission reduction of a specific mitigation action. Assume, for example, that a city introduces a measure which shifts transportation from cars to public buses. This measure decreases fuel consumption in the transport sector which mainly affects CO₂ emissions. If the country’s national GHG inventory estimates CO₂ emissions from transport accurately, the impact from this measure is visible in its GHG inventory; the aggregated CO₂ emissions from this sector will be lower. The national GHG inventory, however, does not provide the emission reductions of the specific measure, because emissions from transportation are also influenced by factors not related to the mitigation action, such as changes in fuel prices (Figure 1).

**Methodology for assessing inventory visibility**

Assessing inventory visibility of mitigation actions requires the following four steps to be undertaken:

**Step 1: Identification of emission sources and gases affected by the mitigation actions**

Mitigation actions often affect several emission sources and gases in national GHG inventories. The construction of a wind power plant, for example, mainly reduces CO₂ emissions from fossil fuel combustion in the electricity sector, but also affects several other emission sources, such as emissions from cement and steel produced to build the wind power plant. A full life-cycle analysis would identify many emission sources to be affected by a mitigation measure. In practice, often only one or few emission sources make up the bulk of emission reductions. In the example of the wind power plant, the reduced fossil fuel combustion in power plants connected to the same electricity grid is the main emission source affected.

A first step for assessing the inventory visibility of mitigation actions is therefore identifying the main emission sources and gases affected by the mitigation action [9]. This step can be straightforward for some mitigation actions, such as flaring landfill gas, but can be complex for actions that affect multiple emission sources, such as the production and use of biofuels. For activities in the LULUCF sector this also requires identifying the relevant carbon pools and activities. Life-cycle assessments or methodological standards to quantify emission reductions, such as baseline and monitoring methodologies under crediting mechanisms, can assist in identifying the main emission sources and gases.

Once these sources and gases are identified, a second step is identifying whether they are mainly affected in the country where the mitigation action is implemented or in other countries. The international trade of fuels, electricity or other commodities usually impacts emissions in other countries. If countries import biomass, this could lead to deforestation in other countries. If they import fossil fuels, upstream emissions associated with fossil fuel production may occur in other countries.

![Figure 1. Relationship of inventory visibility with other concepts.](https://example.com/figure1.png)
Lastly, to assess the impact of mitigation actions on progress towards NDCs, it is important to understand which emissions are covered by the NDC. If a country’s NDC covers only CO₂ emissions, for example, a project using thermal oxidation of N₂O waste gas emissions would decrease emissions outside the scope of its NDC but lead to an increase of CO₂ emissions within its scope. Such cross-effects between emissions could have two different impacts:

- If emissions decrease outside the scope of the country’s NDC but increase within the scope, the ability of the country to achieve its NDC could be undermined.
- If the emissions decrease within the scope of the country’s NDC but increase outside the scope, environmental integrity could be undermined; emissions within the NDC are reduced at a cost of an increase outside its scope and aggregated global GHG emissions could increase.

Understanding inventory visibility is thus not only important for the purpose of ensuring that countries can use the outcomes from mitigation actions to achieve their NDC but also to identify any cross-effects and risks for environmental integrity.

**Step 2: Identification of minimum inventory methods required to ensure inventory visibility**

The IPCC Guidelines for national GHG inventories provide different methods to estimate emission sources, referred to as tiers [6]. Tier 1 methods provide a simple approach, whereas higher tiers require more sophistication but also lead to more accurate estimates. To assess inventory visibility, it is necessary to identify for each main emission source and gas which tier is necessary to achieve inventory visibility. For some emission sources, a Tier 1 approach may suffice to achieve inventory visibility, whereas for other emission sources higher tiers may be needed. In some cases, the mitigation outcomes could be ‘approximately’ visible with a lower tier, while a higher tier may provide for a larger degree of visibility. Lastly, given that the IPCC Guidelines sometimes provide liberty within a certain tier on how to calculate emissions, in some instances a certain way of applying a tier may be necessary to achieve inventory visibility.

Mitigation actions can affect emissions or removals in GHG inventories in three different ways, by changing:

- Activity data (e.g., by reducing the amount of fossil fuels combusted);
- Emission factors (e.g., the installation of a catalyst reduces the rate of emissions per unit of product);
- Other parameters used to estimate emissions or removals (e.g., the ‘recovery factor’ used to estimate the amount of landfill gas captured).

To assess inventory visibility, it is thus necessary to identify, for each of the emission sources identified in Step 1, which of these elements are mainly affected by the mitigation action and which tier is necessary to ensure that changes to these elements are picked up in the GHG inventory. In many cases, this can be easily and objectively determined, for example if a mitigation measure reduces the emissions intensity of production and the IPCC Tier 1 approach uses a default emission factor based on the amount of production. In some instances, the assessment may require expert judgment, for example if the GHG inventory visibility hinges on the quality of underlying data used.

**Step 3: Identification of completeness and methods applied in the national GHG inventory**

A prerequisite for ensuring inventory visibility is that the relevant emission source and gas is estimated in the national GHG inventory. In practice, some GHG inventories are not complete; they do not estimate specific emission sources or gases. Another step is thus assessing whether the relevant source and gas is included in the GHG inventory.

Next, any gaps need to be identified by comparing the current method applied in the GHG inventory with the method that has been identified in Step 2 as the minimum requirement to ensure inventory visibility.

**Step 4: Identification of potential differences in quantification approaches between national GHG inventories and carbon market approaches**

Inconsistencies between the quantification under carbon market mechanisms and national GHG inventories could have two effects:

- If the transferring country has an ambitious mitigation target and the actual emissions
reductions observed in the GHG inventory are smaller than the mitigation outcomes internationally transferred, the country would face a mitigation gap and would need to implement more mitigation actions in order to achieve its NDC [13].

- If the transferring country has a loose NDC target (which it will overachieve without implementing mitigation actions) and the emission reductions as observed in the GHG inventory are smaller than the mitigation outcomes internationally transferred, the country would not face a mitigation gap and global emissions may increase as a result of the transfer.

It may thus be helpful for countries to identify any inconsistencies between the methods applied under carbon market approaches and the methods used in national GHG inventories.

**Assessment of inventory visibility for selected mitigation actions**

Here we apply the method described above to assess whether and under which conditions the emission reductions resulting from mitigation actions are typically reflected in GHG inventories. Towards this end, we select six categories of mitigation actions, focusing on those that have often been implemented under crediting mechanisms (see Table 1 below).

In order to identify the main emission sources and gases, as described in Step 1 above, we evaluate which emission sources and gases are considered in the determination of emission reductions under the CDM. We use CDM methodologies because they typically aim to simplify the calculation by including only the major emission sources and gases affected by a project activity. This simplifies the analysis but still enables a good understanding whether the main outcomes from mitigation actions are reflected in GHG inventories. CDM methodologies are also available for a broad range of mitigation actions and represent a global standard for quantifying emission reductions that has served as a blueprint for most other crediting programs [14].

In order to identify, for each selected mitigation action, the minimum inventory methods required to ensure inventory visibility, as described in Step 2 above, we derive a classification for the risk of a lack of inventory visibility, as follows:

- **Low risk:** We deem that there is a low risk if at least 80% of the mitigation outcomes are visible with the application of Tier 1 inventory methods.
- **Medium risk:** We deem that there is a medium risk if 20%–80% of the mitigation outcomes are visible with the application of Tier 1 inventory methods. We also deem that there is a medium risk if a larger proportion is visible with Tier 1 methods, but Tier 1 methods are challenging to implement (e.g., because they require data that may not be readily available).
- **High risk:** We deem that there is a high risk if at least 80% of the mitigation outcomes are only visible if Tier 2 or 3 inventory methods are applied.

To determine the exact risk, each specific mitigation action would need to be assessed, since the risk depends on the relative size of each emission source affected, and the methodological approaches used in the national GHG inventory of the relevant country. To assess the ‘typical’ risk, we deploy expert judgment, drawing on the experience with carbon crediting activities on the relative size of the main emission sources affected. For example, in landfill gas utilization projects, typically more than 80% of the emission reductions stem from reducing methane emissions at the landfill and less than 20% from using the captured landfill gas to displace fossil fuel use.

Furthermore, we do not assess the risks in the context of any specific country, as described in Step 2 above. We also do not consider whether the emission reductions occur domestically or in other countries, and whether they are covered by NDCs. However, we provide some information on what tiers are typically applied by countries or whether relevant data is typically available. This information is, however, mostly available for developed countries.

Lastly, we point to potential differences between the application of CDM methodologies and national GHG inventories, as described in Step 4 above.

**Results**

Table 1 summarizes the findings from the application of the method to the selected types of mitigation actions. For each type of mitigation action, the table specifies:

- which emission sources, gases and parameters used in GHG inventories are mainly affected by the mitigation action, based on an evaluation
| Mitigation action                                                                 | Main GHG | Effect (in brackets: codes of CRF sources) | Parameters                                                                 | Minimum method required to provide for inventory visibility | Risk of a lack of inventory visibility | Key issues and uncertainties                          |
|---------------------------------------------------------------------------------|----------|--------------------------------------------|---------------------------------------------------------------------------|-------------------------------------------------------------|----------------------------------------|--------------------------------------------------------|
| **A: Measures to reduce fossil fuel combustion (renewable energy, energy efficiency and fuel switch measures)** |          |                                            |                                                                           |                                                             |                                        |                                                        |
| Energy efficiency improvements at power plants                                  | CO₂      | Reduced fossil fuel use (1A1a, 1A2)        | AD                                                                        | Tier 1                                                      | Low                                    | Robustness of energy balances                         |
| Fuel switch from coal to gas in power plants                                    | CO₂      | Reduced fossil fuel use (1A1a, 1A2)        | AD                                                                        | Tier 1                                                      | Low                                    | Robustness of energy balances                         |
|                                                                                    | CH₄      | Change in upstream emissions from fuel production (1A1b; 1A1c; 1A3e; 1B1; 1B2b) | AD                                                                        | Tier 1                                                      |                                        |                                                        |
| Hydropower production                                                           | CO₂      | Reduced fossil fuel use (1A1a, 1A2)        | AD                                                                        | Tier 1                                                      | Low                                    | Robustness of energy balances                         |
|                                                                                    | CH₄      | Increased emissions from hydro reservoirs compared to baseline (4D2) | AD                                                                        | Tier 1 (2019 Refinement)                                    |                                        |                                                        |
| Wind or solar powered production                                                 | CO₂      | Reduced fossil fuel use (1A1a, 1A2)        | AD                                                                        | Tier 1                                                      | Low                                    | Robustness of energy balances                         |
| Residential sector energy efficiency or fuel switch measures                     | CO₂      | Reduced or changed fossil fuel use (1A4a)  | AD                                                                        | Tier 1                                                      | Low                                    | Robustness of energy balances                         |
|                                                                                    | CH₄      | Change in upstream emissions from fuel production (1A1b; 1A1c; 1A3e; 1B1; 1B2b) | AD                                                                        | Tier 1                                                      |                                        |                                                        |
| Demand-side energy efficiency improvement                                        | CO₂      | Reduced fossil fuel use (1A1)              | AD                                                                        | Tier 1                                                      | Low                                    | Robustness of energy balances                         |
| Transport sector energy efficiency, fuel switch and E-mobility measures          | CO₂      | Reduced fossil fuel use (1A3)              | AD                                                                        | Tier 1                                                      | Low                                    | Robustness of energy balances                         |
|                                                                                    | CH₄      | Change in upstream emissions from fuel production (1A1b; 1A1c; 1A3e; 1B1; 1B2b) | AD                                                                        | Tier 1                                                      |                                        |                                                        |
| **B: Reduction of emissions in cement production**                              |          |                                            |                                                                           |                                                             |                                        |                                                        |
| Use of alternative raw materials in clinker production                           | CO₂      | Reduced process emissions from calcination process (2A1) | EF                                                                        | Tier 2                                                      | High                                   | Availability of data on use of alternative raw materials |
| Increased use of blending materials (e.g., fly ash, gypsum, slag)                | CO₂      | Reduced amount of clinker needed per produced unit of cement (2A1) | AD                                                                        | Tier 2                                                      | High                                   | Availability of data on use of blending materials      |
| Energy efficiency measures in cement production                                  | CO₂      | Reduced fossil fuel use (1A2f)             | AD                                                                        | Tier 1                                                      | Low                                    | Robustness of energy balances                         |
| **C: N₂O abatement from nitric and adipic acid production**                     | N₂O      | Reduced N₂O emissions (2B2)                | EF                                                                        | Tier 2                                                      | High                                   | Availability of data on abatement technologies         |
| Abatement of N₂O from nitric acid production                                     | N₂O      | Reduced N₂O emissions (2B3)                | EF                                                                        | Tier 2                                                      | High                                   | Availability of data on abatement technologies         |
| **D: Avoidance of CH₄ emissions from waste and manure**                          | CH₄      | Reduced emissions from wastewater treatment sites (SD) | EF                                                                        | Tier 1                                                      | Medium                                 | Availability of data on abatement technologies         |
| Use of aerobic wastewater treatment systems                                      | CH₄      | Reduced emissions from wastewater treatment sites (SD) | EF                                                                        | Tier 1                                                      | Medium                                 | Availability of data on abatement technologies         |
| Use of aerobic manure management systems                                          | CH₄      | Reduced emissions from manure management (3B) | EF                                                                        | Tier 1                                                      | Medium                                 | Availability of data on abatement technologies         |

(continued)
of the emission sources considered in the respective CDM methodologies;

- which IPCC methods are required to reflect the related emission reductions in GHG inventories according to the 2006 IPCC Guidelines [6], based on an evaluation of the respective IPCC inventory approaches and relevant literature; and

- what risk category is assigned to each identified emission source, gas or parameter, based on the tier needed in accordance with the risk categorization above and, where applicable, the relative size of the emission sources identified above.

The following sections analyse these matters for each of the mitigation actions.

**Category A: Measures to reduce fossil fuel combustion**

Many mitigation actions reduce or change the quantity of fossil fuels combusted. This includes the generation of renewable energy, energy efficiency improvements, and switching to less carbon intensive fossil fuels.

For these mitigation actions, CO$_2$ from fossil fuel combustion (reported in the common reporting format (CRF) under source categories 1A) is the main emission source in all relevant CDM methodologies.

In GHG inventories, these measures have an impact on the amount of fossil fuels combusted, which constitutes the activity data used for estimating GHG emissions. According to the IPCC Tier 1 method, the amount of fuel combusted is multiplied by a default emission factor, whereas under the Tier 2 and 3 methods, country and technology specific emission factors are used, respectively [6, Vol. 2, p. 2.11]. Independent of the methodological tier, a comprehensive energy balance is required and has to serve as basis for the GHG inventory. An energy balance compiles data on all energy products (imports, exports and use) in the territory of a country. If a robust energy balance is available, the impact of these mitigation measures on the activity data is automatically reflected in the GHG inventory and the Tier 1 approach for the collection of activity data in the 2006 IPCC Guidelines is, in principle, sufficient to reflect the impact of the mitigation measures. The extent to which emission reductions from the...
reduction or substitution of fossil fuels show up in GHG inventories thus largely depends on the robustness of the national energy balance. This also holds for indirect effects on fossil fuel consumptions, such as re-bound effects.

Challenges arise, however, for countries with power grids that are connected through international transmission lines. Here, mitigation measures implemented in one country may lead to emission reductions in other countries.

For some mitigation measures, CDM methodologies consider also other emission sources. For fossil fuel switch measures, upstream emissions from the production and transportation of fossil fuels are considered, mainly CH₄ emissions from coal mining (CRF: 1B1) and the exploration, processing, transportation and distribution of oil and natural gas (CRF: 1A1b 1A1c; 1B2; 1A3e). Upstream emissions usually make up only a small part of the overall emission reductions and can broadly be reflected in national GHG inventories through the use of respective Tier 1 approaches of the 2006 IPCC Guidelines [6, Vol. 2, p. 4.41].

In the case of hydropower, CH₄ emissions from the reservoir are accounted for in relevant CDM methodologies in a simplified manner. These emissions are usually not estimated in GHG inventories, although guidance is available in an annex to the 2006 IPCC Guidelines and in the 2019 Refinement [15] to these guidelines. Moreover, the magnitude of these emissions depends strongly on the circumstances of the hydropower plant and is uncertain. However, it is small in many instances (e.g., in colder climates).

As the reduction of fuel combustion is reflected in energy balances and hence becomes visible in GHG inventories when applying the Tier 1 inventory methods and as other relevant emission sources typically make up a much smaller share than CO₂ emission reductions and are also broadly visible with Tier 1 methods, we rate the risk of a lack of inventory visibility as low for all mitigation actions in this category.

The consistency of methodologies and data used in national GHG inventories and in the CDM methodologies can, however, be an issue. For renewable electricity generation projects, for example, the CDM establishes an algorithm that aims to model which power plants are displaced by renewable electricity generation. The resulting grid emission factor involves considerable uncertainty [16]. In the case of energy efficiency measures, rebound effects are often not considered in CDM methodologies, but would be captured in national energy balances. The amount of emission reductions estimated in CDM projects could thus differ significantly from the impact observed in GHG inventories based on robust energy balances. Differences between GHG inventories and the quantification in CDM methodologies could also occur due to the selection of net calorific values and CO₂ emission factors.

**Category B: Reduction of emissions in cement production**

In cement production, energy efficiency measures can be applied to reduce the amount of heat required for clinker production and for the blending process. The inventory visibility of these measures is covered under category A above. In addition, CO₂ process emissions from the calcination process can be reduced by using alternative raw materials or by increasing the share of blending material and lowering the amount of clinker for producing a specific amount of cement. Here we focus on this latter measure.

The relevant CDM methodologies² for process emissions from cement production consider mainly CO₂ emissions from clinker production. According to the 2006 IPCC Guidelines [6, Vol. 3, p. 2.8], the Tier 1 approach makes use of cement production data, Tier 2 makes use of clinker production data, and Tier 3 takes carbonate input data into account. As this mitigation measure does not affect the amount of cement produced but lowers the amount of clinker used, at least a Tier 2 approach is needed to reflect the reduced emissions in GHG inventories [6, Vol. 3, p. 2.9], including an emission factor that accounts for the amount of non-carbonate raw materials used during clinker production. We therefore rate the risk of a lack of inventory visibility as high in this category.

The methodologies concerning activity data collection and emission calculation used in GHG inventories and in the CDM are similar and should not lead to consistency issues in general. However, if the baseline assumed in CDM methodologies is different from the true (unknown) emissions that would occur without the mitigation measure, the number of credits issued under the CDM differs from the emission reduction reflected in the GHG inventory. Differences could also occur due to the selection of CO₂ emission factors.

**Category C: N₂O abatement from nitric and adipic acid production**

An important mitigation measure in the chemical industry is the reduction of N₂O emissions from nitric or adipic acid production.³ These emissions
can be abated through the installation of a catalytic or thermal N₂O destruction equipment or, in the case of adipic acid, through the recovery and use of N₂O. This reduces the N₂O emission factor (defined as N₂O emissions per ton of acid produced), while the activity data (the amount of acid produced) is not affected.

Under the 2006 IPCC Guidelines [11, Vol. 3, p. 3.19] Tier 1 approach, a default N₂O emission factor assuming no abatement is applied. Under the Tier 2 approach, default emission factors are classified by abatement technology type. If plant-level data on the type of abatement technologies is available, a Tier 2 approach would allow reflecting the effect of the measure in the GHG inventory. A Tier 3 approach for N₂O emissions from nitric acid production is based on plant-level measurement data. If the mitigation measure is implemented under carbon market approaches, a Tier 3 approach would also ensure full consistency of the mitigation outcomes with GHG inventories.

As inventory visibility of these measures is given only if at least Tier 2 methods are used, we classify them to have a high risk of a lack of inventory visibility.

**Category D: Avoidance of CH₄ emissions from waste and manure**

Landfill sites, wastewater treatment plants and manure management systems under anaerobic conditions emit gas which contains a high share of CH₄. The formation of this gas can be (partially) prevented by using an aerobic treatment system, and the gas can be captured and either flared or used for energy production.

Here we focus on the avoidance of CH₄ emissions. The impact from using captured CH₄ for energy generation purposes is similar to the impact of fossil fuel substitution as discussed for category A above. This substitution only contributes to a smaller extent to the overall mitigation impact, compared to the prevention of CH₄ emissions (as a result of the higher global warming potential of CH₄).

All relevant CDM methodologies[4] include CH₄ emissions from the respective sites as a major emission source.

For CH₄ emissions from landfills, the 2006 IPCC Guidelines provide a first order decay (FOD) model under Tier 1. Tiers 2 and 3 make use of the same model, but take into account country-specific data/parameters. The model is based on the amount of degradable organic carbon (DOC) in the disposed waste, a CH₄ correction factor (MCF⁵) and a recovery factor. The MCF differs depending on the fraction of aerobic decomposition. If data exists on the fraction of waste treated aerobically and corresponding MCF values are chosen, the Tier 1 approach is in principle sufficient to reasonably reflect the mitigation action in GHG inventories. This is because even the Tier 1 approach is based on the three parameters (DOC, MCF and recovery factor) which are affected by mitigation measures. However, the use of a higher tier may further enhance the degree of GHG inventory visibility.

In practice, the Tier 1 method is challenging to implement due to the data requirements and uncertainty (e.g., with regard to operation of CH₄ capture systems). We therefore rate the risk of a lack of inventory visibility as medium.

The consistency between GHG inventory methodologies and the CDM is generally assured for those CDM methodologies that apply the same FOD model. This typically holds for projects preventing the disposal of waste on anaerobic sites. For CH₄ capturing projects, however, the amount of CH₄ captured is directly measured and may substantially differ from inventory estimates based on the FOD model.

For CH₄ emissions from wastewater treatment, the 2006 IPCC Guidelines provide default factors for calculating the emission factor [6, Vol. 5, p. 6.10], including a factor for estimating the amount of degradable organic material in the wastewater and a methane correction factor (MCF) describing the fraction of aerobic decomposition. Default factors for various treatment methods are provided for the Tier 1 approach. For the Tier 2 and 3 approaches, country-specific factors and bottom-up data are required, respectively. Mitigation outcomes are visible when applying Tier 1 and using appropriate factors for the treatment system. However, there may be differences between the default factors used under Tier 1 and the factors that appropriately describe the mitigation actions. Hence, we rate the risk of a lack of inventory visibility as medium for the reduction or change in CH₄ emissions from aerobic systems in wastewater treatment.

Similarly, for manure management, the 2006 IPCC Guidelines provide default MCF for different manure management systems and average annual temperatures. However, they specify that for countries with livestock species representing a significant share of emissions, at least a Tier 2 approach...
should be applied. As mitigation outcomes are only partially visible with the application of Tier 1 methods, we rate the risk of a lack of inventory visibility as medium.

**Category E: Use of biomass or biofuels**

Biomass can substitute fossil fuels in the power, heat and transport sectors and thus mainly reduces CO₂ emissions from fossil fuel combustion, as covered in category A above.

In terms of emissions impacts, the case of biomass is more complex than most other measures. The production of biomass or biofuels can be associated with substantial upstream emissions (see Table 2) which can be significantly higher than for fossil fuels. In contrast, when waste or biomass residues are used, only some of these upstream emissions are relevant, since waste and biomass residues are by-products from other processes.

Accordingly, more emission sources are significant than for other mitigation measures. The CDM TOOL16 specifies procedures to estimate the main emissions from biomass production.

The use of biomass can affect CO₂ emissions from changes in above-ground and below-ground carbon stocks which are treated in Volume 4 of the 2006 IPCC Guidelines. The type of biomass (e.g., forest, crop), the way the biomass is cultivated and harvested, and the way the soil is treated all affect emissions. The Tier 1 approaches provide default values for how a carbon stock in a specific system changes over time. If applied thoroughly and based on country-specific land-use statistics, including on the types of crop cultivated as well as the soil and crop management applied, the Tier 1 approach is sufficient to reflect CO₂ emissions from biomass use in GHG inventories.

If the use of biomass for a mitigation project leads to increased pressure on land-use in general, this may be reflected in CDM methodologies as leakage emissions. To reflect these emissions in the GHG inventory, any change to associated land use must be adequately reflected, e.g., land-use statistics (including land-use changes) must be in place.

In terms of mitigation actions based on the use of forest biomass, category F, below gives further information.

The use of biomass can also lead to a diversion of biomass from other uses to the project activity which may result in an increase in fossil fuel use elsewhere (leakage emissions). These emissions fall under category A and are likely covered by GHG inventories.

Biomass or biofuel production can involve the use of N fertilizer, leading to energy-related emissions from fertilizer production (covered under category A above) and N₂O emissions from nitric acid production (covered under category D above), and from fertilizer application. With regard to fertilizer application, the Tier 1 approach of the 2006 IPCC guidelines provides default emission factors. This is sufficient for reflecting this emission source in the GHG inventory, as long as country-specific nitrogen fertilizer application data is available.

Upstream emissions from the production of fuels from biomass are usually reflected by a Tier 1 approach of the IPCC Guidelines, similar as described for categories A, B and C. Note that they are only reflected in the GHG inventory when occurring within the country.

Finally, when looking at biomass use for transportation, or for electricity and heat production, the reduction of the amount of fossil fuels combusted is typically reflected in GHG inventories with the Tier 1 approach of the IPCC Guidelines (see category A, above).

If emission reductions are claimed due to avoidance of biomass otherwise left to decay, the same may need to be reflected in the waste section of the GHG inventory. If biomass were otherwise dumped on landfills and left to decay under anaerobic conditions, this would be considered in the estimation of emission reductions from the project activity. In order for these emissions to be reflected in the GHG inventory, sound waste statistics would be required.

| Source of emissions | IPCC Volume | Waste or biomass residues | Other biomass |
|---------------------|-------------|----------------------------|---------------|
| CO₂ from cultivation of biomass | AFOLU | X | |
| CO₂ from loss of soil organic carbon | AFOLU | X | |
| CO₂ from soil management | AFOLU | X | |
| CO₂ from land-use change | AFOLU | X | |
| CO₂ from fertilizer production | IPPU | X | |
| N₂O from fertilizer application | AFOLU | X | |
| CO₂ from clearance or burning of biomass | AFOLU | X | |
| CO₂ from combustion of fossil fuel derived methanol in the biodiesel ester | Energy | X | X |
| CO₂ from energy consumption (for thermal and mechanical processing of biomass) | Energy | X | X |
| CO₂ and CH₄ from transport & distribution of biomass | Energy | X | X |

Abbreviations: AFOLU = Agriculture, Forestry and Other Land-Use; IPPU = Industrial Processes and Product Use.
The use of biomass residues from annual crops does not lead to a ‘net accumulation of biomass carbon stocks’ [6, Vol. 4, p. 5.7], hence the consideration as carbon neutral fuel in the project corresponds to the reflection in the inventory. In case of biomass from perennial crops (such as from oil palms or coconut palms), it needs to be ensured that the GHG inventory uses parameters for, inter alia, biomass carbon stock at harvest, harvest/maturity cycle or biomass accumulation which correspond to the amount of biomass residues used for the mitigation project.

To summarise, the use of biomass or biofuels is associated with diverse emission sources, including from changes in carbon stocks, from leakage, and from fertilizer production and use. Reflecting changes in these emissions in GHG inventories requires applying complex methods and sufficiently granular data sources. We therefore rate the risk of a lack of inventory visibility for this category as medium to high, depending on the type of activity and associated upstream emission sources.

**Category F: Land-use related activities**

Land-use related mitigation actions address different land categories, including forests, grasslands and cropland, and involve mitigation measures such as reducing deforestation or forest degradation, afforestation, improved forest management or wetland restoration.

The visibility of these measures in GHG inventories is more complex than for other sectors, for several reasons. First, Parties account for the sector in different ways in their GHG inventories and in accounting for NDCs, depending on the approach the Party pursues in accounting. This relates to what activities or land-use categories are covered, which pools are accounted for, how ‘forests’ are defined, whether the age structure of forests is reflected, or how harvested wood products are accounted for.

A second challenge is that quantifying carbon stocks can be associated with significant uncertainties, depending on methods and data used. Traditional approaches include the use of land-use statistics. Some Parties combine them with field sampling and remote sensing data. The uncertainty of such combined approaches is relatively low. However, they might involve infrequent assessments, e.g., forest inventories being carried out only every ten years. The largest uncertainties are associated with soil carbon reporting. There is a risk that changes in soil carbon are not detected by inventories using default methods. Another key question is whether data is available at the necessary temporal and spatial resolution to observe the impact of smaller forestry mitigation actions. Lastly, it is important that GHG inventories continue to have the necessary quality over time in order to detect possible reversals in carbon stocks.

Under the CDM, methodologies are only available for afforestation and reforestation activities. The methodologies determine the amount of removals based on the size of the relevant area and the carbon stocks on the land. Key parameters include the diameter and height of sample trees, biomass expansion factors, wood densities or pre-project crown cover of trees and shrubs. These parameters are typically included in national GHG inventories of developed countries. For countries lacking inventory data a combination of satellite information for land stratification and targeted field sampling would be granular enough to reflect single afforestation or reforestation projects.

There may be granularity issues between the smaller-scale intervention from a CDM project and the large-scale approach of national inventories. The extraction of biomass from forests, harvest of forest biomass through thinning or final cut, is typically not causing land-use changes. Therefore, land-use statistics alone are not sufficient to capture the mitigation impact from measures such as improved forest management. This would require the inventory to be detailed enough to also reflect management changes within land-use categories, such as species change, changes in rotation lengths, etc. This can be achieved by stratifying the forests by species and age-classes.

Based on this general assessment, forest-related activities are here classified to have a high risk of a lack of inventory visibility.

**Assessment of inventory visibility in the context of the CDM**

This section briefly illustrates the findings from an assessment of inventory visibility in the context of the CDM project portfolio. The CDM is used here as an example because it was the largest international carbon market mechanism, operational from 2008 to 2020, and because it included a broad range of mitigation projects. It is, however, important to bear in mind that mitigation outcomes that are internationally transferred under the Paris Agreement or used under CORSIA could stem from a different portfolio of activities and
could therefore also have different risks of a lack of inventory visibility.

To assess the findings in the context of the CDM, the results of a detailed model for estimating the CDM carbon credit supply potential [17, 18] are combined with the findings on the risk of a lack of inventory visibility as described in this paper.

Figure 2 illustrates the risk of a lack of inventory visibility with regard to the CDM supply potential for the period 2013–2020. The figure shows that for most of the supply potential the risk of a lack of inventory visibility is low. About 8% of the supply potential is assessed to have a medium risk, whereas only 5% is assessed to have a high risk.

Discussion

The above analysis shows that many mitigation actions are automatically reflected in national GHG inventories, even if simple Tier 1 approaches are used. This holds for all mitigation actions that primarily reduce CO₂ emissions from fossil fuel combustion. A key prerequisite is, however, the availability of robust national energy balances. A large share of informal economies and poor statistics can diminish the ability of GHG inventories to pick up the emission reductions.

For some mitigation actions more advanced methods are necessary to ensure that their outcome is visible in GHG inventories, in particular for the abatement of non-CO₂ gases and mitigation actions in the LULUCF sector. Here, Tier 2 methods often ensure visibility to some degree, whereas Tier 3 methods reflect the impacts of mitigation actions more accurately.

Uncertainty in assessing inventory visibility and estimating GHG inventories

The application of the methodology to different types of mitigation actions showed that assessing inventory visibility can be straightforward in some instances, whereas it can be complex and require expert judgment in other instances. In these latter cases, there may be considerable uncertainty whether or not emission reductions are visible, and the outcome may depend on the specific granularity of the inventory of the country concerned. As GHG inventories are improved over time, with countries moving towards higher tiers and collecting more accurate data, the risk of inventory visibility may also decrease over time.

National GHG inventories involve considerable uncertainties around single estimates. However, the uncertainty in the change of emissions over time is lower. The same holds for inventory visibility, which relates to the changes in emissions from mitigation measures. Changes in activity data (e.g., due to fuel savings) or changes in emission factors (e.g., due to the installation of a catalyst) lead to a direct change in overall estimated emissions if the appropriate tiers are used. For these reasons, a higher degree of inventory visibility does not necessarily imply a lower uncertainty in the GHG inventory.

Lastly, it is important to bear in mind that GHG inventories capture the net effect of mitigation actions and other factors influencing emissions, such as economic and technological development, weather effects, or fuel prices, and irrespective of whether or not the mitigation actions were implemented in response to specific policies.
Implications for the preparation and improvement of GHG inventories

A lack of inventory visibility undermines the ability of Parties to use the emission reductions from mitigation actions to achieve their NDCs. It could also undermine transparency and environmental integrity if inventory visibility is not ensured for sources at which emissions increase as a side effect of a mitigation action.

It is thus important to improve GHG inventories over time with the view to ensuring that mitigation actions are reflected in tracking progress made in implementing and achieving NDCs. We therefore recommend that countries assess the inventory visibility at least with regard to their most important mitigation actions. Such an assessment can serve to identify gaps and improve the GHG inventory over time. While the improvement of GHG inventories should be mainly guided by the magnitude of emission sources – based on the analysis of ‘key categories’ – gaps with regard to inventory visibility of mitigation actions can further inform the prioritization of improvements.

Although a lot of capacity has been built over the last decades, some developing countries need financial and capacity building support to create sound national inventory systems and visibility of their mitigation actions. In addition, many countries realize that the availability of robust energy balances and comprehensive national greenhouse gas emissions inventories benefits not only their climate policy, but energy and transport policy in general.

Implications for the implementation of international carbon market approaches

Our findings suggest that mitigation outcomes from carbon market approaches are in many but not all cases visible in GHG inventories. This raises questions with regards to the accounting for international transfers of mitigation outcomes, the ability of countries to achieve their NDCs, and environmental integrity risks.

Application of corresponding adjustments

In international negotiations under Article 6 of the Paris Agreement, some Parties and stakeholders argued that corresponding adjustments are not necessary on the side of the transferring country if the emission reductions are not visible in GHG inventories used to track progress towards NDCs [3]. In this case, double counting would not occur because the transferring country would not observe the mitigation outcomes in tracking progress towards its NDC and could thus not use them to achieve its own NDC. Several issues are, however, important to consider:

- Enhanced transparency framework: The modalities, procedures and guidelines for the enhanced transparency framework under Article 13 of the Paris Agreement will lead to more accurate and complete GHG inventories. They require, for example, all countries to apply the 2006 IPCC Guidelines and to conduct a key category analysis to identify which tiers should be used to estimate emissions. In most sectors, Parties will have to apply tiers that ensure visibility of mitigation actions in GHG inventories.
- Recalculations: Improved reporting over time is an important principle of the transparency framework. Improvements commonly include recalculations of emissions from past years. Even if mitigation outcomes from carbon market approaches are currently not reflected in GHG inventories, Parties could recalculate the emissions in the future, such that the mitigation outcomes are reflected. This means that a lack of quality of current GHG inventories does not rule out that emission reductions are claimed by the Party towards its NDC in future.
- Disincentives for improvements: Not requiring corresponding adjustments in instances where mitigation outcomes are not visible in GHG inventories would provide perverse incentives for Parties not to improve their GHG inventories, in order to continue to be able to transfer mitigation outcomes without applying corresponding adjustments.

At COP26, held in Glasgow in November 2021, Parties adopted guidance under Article 6 of the Paris Agreement that requires transferring Parties to apply corresponding adjustments for all transfers of carbon market units, regardless of whether the emission reductions are (already) visible in GHG inventories [8]. This effectively provides incentives for countries to improve their GHG inventories in order to ensure that mitigation outcomes from carbon market approaches are visible.

Consistency in methods between carbon market approaches and GHG inventories

Consistency in the methods between carbon market approaches and GHG inventories can help to
reduce the risk for a Party that it may not achieve its NDC and help ensure environmental integrity.

When addressing consistency, it is important to bear in mind how emissions are determined. Under crediting mechanisms, such as the CDM, emission reductions are usually determined in a conservative manner, meaning that they tend to be underestimated. Various concepts and methodological tools for applying the conservativeness principle also exist in UNFCCC decisions, especially for sectors with high uncertainties, such as the land use and forestry sector [8, 19, 20]. Under GHG inventories, the purpose is to estimate emissions accurately, meaning to arrive at the best estimate within an uncertainty range. Hence, data generated under carbon market approaches may not always be suitable for national GHG inventories. It is important, however, that the methodological approaches and the choice of key parameters are consistent. For example, the use of methane conversion factors for wastewater treatment methods should be consistent between national GHG inventories and crediting mechanisms, although the values could differ.

In many instances, GHG inventories may more accurately reflect the actual emission reductions than carbon market approaches. This applies mainly where the mitigation measures affect activity data and where the underlying statistics on activity data are robust.

In some instances, however, data from carbon market approaches may be more accurate and could be used to determine national GHG inventory emissions. This holds in particular if the emissions from specific sources are directly measured, and not adjusted downwards to account for uncertainty.

A further important issue to consider is the level of aggregation. The GHG inventory estimates the emissions for the entire country, whereas carbon market approaches may only address specific facilities or only some of the sector’s emissions (e.g., if an ETS excludes smaller installations). Ensuring consistency under different levels of aggregation can be challenging in practice.

**Implications for the scope of NDCs**

In this paper, we identified that NDCs that cover only some gases or sectors of the economy could involve risks: first, countries may not achieve their NDCs if part of the emission reductions occur outside the scope of their NDC or if emissions decrease outside but increase within the scope. Second, environmental integrity could be undermined if emissions decrease within but increase outside the scope. In some instances, it could also be methodologically challenging to determine what occurred within or outside scope. To avoid such effects, we recommend that Parties strive to expand the scope of their NDC when they prepare a new or updated NDC. According to Article 4 of the Paris Agreement, each Party shall communicate an NDC every five years, but may also at any time adjust its existing NDC with a view to enhancing its level of ambition.

In order to facilitate the visibility of mitigation actions, including carbon market approaches, we recommended that all sectors that are affected by the main mitigation actions be included within the scope of NDCs. This enables countries to use these mitigation outcomes towards their NDCs and avoids the risks associated with cross-effects.

**Notes**

1. See, for example, the Clean Development Mechanism (CDM) methodologies ACM0001 and AMS-III.G
2. ACM0015, ACM0005
3. Refer to CDM methodologies AM0021 and ACM0019.
4. Solid waste disposal: ACM0001, ACM0012, ACM0022, ACM0024; Wastewater treatment: AM0080, AMS-III.H.; Manure management: AM0073, AMS-III.D.
5. IPCC (2006) uses two different terms for MCF. In the waste sector, it describes the methane correction factor (fraction of aerobic decomposition). In the agriculture sector, it describes the methane conversion factor (portion of methane produced from the manure).
6. However, the Tier 1 approach sometimes – although recommending to use country-specific data – allows for the use of aggregated data (e.g. aggregate statistics per country like the FAO database). If this aggregated data is used, the measure may not be reflected in the GHG inventory.
7. However, the Tier 1 approach – although recommending the use of country-specific data – allows for FAO activity data for mineral nitrogen fertilizer use. If this aggregated data is used, the measure may not be reflected in the GHG inventory.
8. Refer to CDM methodologies AR-AM-0014, AR-ACM-0003, AR-AMS-0003 and AR-AMS-0007
9. See also mitigation actions category D

**Disclosure statement**

No potential conflict of interest was reported by the authors.
Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. Decision 18/CMA.1. FCCC/PA/CMA/2018/3/Add.2. Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement; 2018.

2. Prag A, Hood C, Barata PM. Made to measure: options for emissions accounting under the UNFCCC (COM/ENV/EPOC/IEA/SLT(2013)1). Paris: OECD/IEA; 2013.

3. Howard A, Chagas T, Hoogzaad J, et al. Features and implications of NDCs for carbon markets. Amsterdam: Climate Focus B.V.; 2017.

4. Kollmuss A, Schneider L, Zhezherin V. Has joint implementation reduced GHG emissions? Lessons learned for the design of carbon market mechanisms. Stockholm: Stockholm Environment Institute; 2015.

5. Schneider L, Füssler J, Kohli A, et al. Robust accounting of international transfers under Article 6 of the Paris Agreement. Berlin: German Emissions Trading Authority (DEHSt); 2017.

6. IPCC. 2006 IPCC guidelines for national greenhouse gas inventories: prepared by the National Greenhouse Gas Inventories Programme. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K, eds. Hayama: IGES; 2006.

7. Schneider L, Duan M, Stavins R, et al. Double counting and the Paris Agreement rulebook. Science. 2019;366(6462):180–183. doi:10.1126/science.aay8750.

8. Decision 2/CMA.3. FCCC/PA/CMA/2021/10/Add.1. Guidance on cooperative approaches referred to in Article 6, paragraph 2, of the Paris Agreement; 2021.

9. Herold A, Böttcher H. Accounting of the land-use sector in nationally determined contributions (NDCs) under the Paris Agreement. Bonn: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; 2018.

10. Kreibich N, Hermwille L. Robust transfers of mitigation outcomes: understanding environmental integrity challenges (JIKO Policy paper; no. 20/2016). Wuppertal: Wuppertal Institute for Climate, Environment and Energy GmbH; 2016.

11. Schneider L, Kollmuss A, Lazarus M. Addressing the risk of double counting emission reductions under the UNFCCC. Clim Change. 2015;131(4):473–486. doi:10.1007/s10584-015-1398-y.

12. Schneider L, Kollmuss A. Perverse effects of carbon markets on HFC-23 and SF₆ abatement projects in Russia. Nature Clim Change. 2015;5(12):1061–1063. doi:10.1038/nclimate2772.

13. Schneider L, La Hoz Theuer S. Environmental integrity of international carbon market mechanisms under the Paris Agreement. Climate Policy. 2019;19(3):386–400. doi:10.1080/14693062.2018.1521332.

14. Kollmuss A, Füssler J. Overview of carbon offset programs – similarities and differences (Partnership for Market Readiness Technical Note; no. 6). Washington: World Bank; 2015.

15. IPCC. Refinement to the 2006 Guidelines for National Greenhouse Gas Inventories. Calvo Buendia E, Tamnabe K, Kranjc A, Baasansuren J, Fukuda M, Ngarize S, Osako A, Pyrozhenco Y, Shermanau P, Federici S, eds. Geneva: IPCC; 2019.

16. Lo Re L, Ellis J, Vaidyula M, et al. Designing the Article 6.4 mechanism: assessing selected baseline approaches and their implications (COM/ENV/EPOC/IEA/SLT(2019)5). Paris: OECD/IEA; 2019.

17. Schneider L, Day T, La Hoz Theuer S, et al. CDM supply potential up to 2020. Berlin: German Emissions Trading Authority (DEHSt); 2017.

18. Warnecke C, Schneider L, Day T, et al. Robust eligibility criteria essential for new global scheme to offset aviation emissions. Nat Clim Chang. 2019;9(3):218–221. doi:10.1038/s41558-019-0415-y.

19. Decision 3/CMA.3. FCCC/PA/CMA/2021/10/Add.1. Rules, modalities and procedures for the mechanism established by Article 6, paragraph 4, of the Paris Agreement; 2021.

20. Grassi G, Monni S, Federici S, et al. Applying the conservativeness principle to REDD to deal with the uncertainties of the estimates. Environ. Res. Lett. 2008;3(3):035005. doi:10.1088/1748-9326/3/3/035005.