Application of the CCQI methodology for assessing the quality of carbon credits

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

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Sub-criterion:	**1.3.2: Robustness of the quantification methodologies applied to determine emission reductions or removals**
Project type:	**Improved Forest Management (Production to conservation, avoided degradation)**
Quantification methodology:	**VM0010**
Assessment based on carbon crediting program documents valid as of:	**16 May 2023**
Date of final assessment:	**21 February 2024**
Score:	**1**

Assessment

Relevant scoring methodology provisions

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

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

Carbon crediting program documents considered

1 Verra (2016): VCS Methodology VM0010 Methodology for Improved Forest Management: Conversion from Logged to Protected Forest. Version 1.3 of April 2016

2 Verra (2023) VCS Methodology Requirements. Version 4.4. https://verra.org/wp-content/uploads/2023/08/VCS-Methodology-Requirements-v4.4.pdf

3 CDM Tool for testing significance of GHG emissions in A/R CDM project activities.

Assessment outcome

The quantification methodology is assigned a score of 1.

Justification of assessment

Project type

This assessment refers to the following project type:

“Implementing forest management practices that aim to increase and/or avoid the loss of carbon stocks. Projects may involve one or several of the following activities:

- **Extended rotation (ER):** Extending the rotation (e.g., age or target diameter) at which trees are harvested in a forest or patch of forest.
- **Production to conservation (PC):** Shifting from forest management for timber production to management for conservation. Harvesting of trees for conservation purposes may continue.
- **Increasing productivity (IP):** Implementing silvicultural techniques that result in increased forest growth, e.g., by cutting climbers and vines, performing liberation thinning, or implementing enrichment planting.
- **Reduced impact logging (RIL**): Improving logging practices to reduce negative impacts on forest stands and soils during timber harvesting in a forest or patch of forest, such as by using directional felling or minimizing the number of skid trails.
- **Avoiding degradation (AD):** Avoiding the start of, or an increase in, harvesting that is assumed to occur in the baseline scenario and/or targeting harvesting towards higher quality timber, thereby avoiding the reduction of carbon stocks below current and recent levels."

Based on our evaluation of a sample of individual projects, these five activities are the most common activities implemented in IFM projects. Many projects implement a combination of these activities.

The CCQI differentiates between these activities because the robustness of quantification methodologies, the likelihood of additionality and the social and environmental impacts may depend on the type of activities that are being implemented. In some instances, the CCQI therefore derives differentiated scores for these types of activities. Where a combination of activities is implemented, as a conservative approach, the lowest applicable score among the activities is assigned.

It is important to note that caution is warranted when assessing what type of activities are implemented under a specific IFM project. First, project design documents (PDDs) sometimes do not clearly describe what exact activities are planned to be implemented. Second, the actual implementation of projects may deviate from the description in PDDs. For example, a project that is declared to be an extended rotation project may in practice be combined with measures to increase forest productivity. Third, what activities are being implemented may change over time. For example, a project that is initially planned to extend the rotation age may later be converted to a conservation project. Moreover, identifying changes may be difficult because most carbon crediting programs do not require an ex-post verification of what activities have been implemented. Where the CCQI scores differentiate between the types of activities listed above, it is therefore important to conduct due diligence to understand what type of activities have actually been implemented or to assume that the lowest score among all five types of activities, given that any type of activities could be implemented by a project in the future.

This assessment evaluates VCS Methodology VM0010, Version 1.3. “Methodology for Improved Forest Management: Conversion from Logged to Protected Forest” (Source 1). The methodology states that Projects must fall within the VCS AFOLU project category “IFM: Logged to Protected Forest” as defined in the most recent version of the VCS AFOLU Requirements document (Source 2). According to the methodology requirements, this project type includes two activities:

“a) Protecting currently logged or degraded forests from further logging.

b) Protecting unlogged forests that would otherwise be logged.”

VM0010 defines the project type as "practices that reduce net GHG emissions by converting logged forests to protected forests. By eliminating harvesting for timber, biomass carbon stocks are protected and can increase as the forest re-grows and/or continues to grow” (Source 1). The methodology further specifies that “under the project scenario, forest use must be limited to activities that do not result in commercial timber harvest or forest degradation” and the Verra methodology requirements state that under this project type “harvesting of trees to advance conservation purposes (e.g., the removal of diseased trees) may continue in the project scenario”. The methodology does not apply to wetlands and peatlands are excluded from this project type.

Based on this information, we assume that the methodology applies to the following CCQI IFM activities: production to conservation (PC) and avoiding degradation (AD).

Selection of carbon pools and emission sources for calculating emission reductions or removals

IFM projects can affect multiple carbon pools and emission sources.

First, IFM projects mainly aim to enhance carbon pools in the project forest area. Growing trees remove carbon dioxide (CO_2) from the atmosphere and store carbon in aboveground and belowground biomass pools. Harvesting removes carbon from the aboveground biomass pool. Increases in aboveground and belowground carbon pools compared to the baseline scenario constitute the main emission reductions or removals claimed by projects. However, IFM projects may also affect other carbon pools within the project forest area. Through natural processes and disturbance events, trees also produce litter and deadwood (DW). Carbon in these two pools may be released back into the atmosphere through decomposition or transferred to the soil organic carbon pool. Some of the slash from harvesting may also enter the litter and deadwood pool. Moreover, changes in silvicultural practices implemented as part of IFM projects, such as prescribed burning or other biomass extraction, could affect all carbon pools.

Second, IFM projects may indirectly affect carbon pools outside the project forest area as well as several other emission sources. This can occur in the following ways:

- **Leakage due to changes in forest carbon pools elsewhere:** A decrease in harvesting levels in the project forest area can lead to an increase in harvesting levels elsewhere. The associated emissions increase depends on the degree to which such leakage occurs and what type of forest areas are impacted (see further discussion below). Likewise, an increase in harvesting levels in the project forest area could lead to less harvesting elsewhere, which may lead to an increase in carbon stocks on other land areas and thus further emission reductions or removals beyond the project forest area. This potential increase in carbon stocks on other land areas could, however, be reversed through natural disturbances or anthropogenic interventions. As the change in carbon stocks on other land areas, and any reversals, cannot be practically monitored, this potential increase in carbon stocks should not be credited.

- **Leakage due to substitution of timber by other materials:** A decrease in harvesting levels due to the implementation of the project could lead to an increased use of alternative materials (e.g., plastic, cement), which may increase emissions elsewhere. Likewise, an increase in harvesting levels could to a decrease in alternative materials, which may lead to further emission reductions beyond the project forest area. The extent to which this occurs depends, inter alia, on the extent to which leakage occurs.
- **Changes in harvested wood product pools:** Timber that is extracted from the project forest area may be processed and stored in harvested wood products. This delays the associated CO_2 emissions. Over time, harvested wood products may be burned, leading to an immediate release of the carbon; decompose, leading to gradual release; or stored for longer periods (e.g., as products in use or in landfills). An increase in harvesting levels may – to the extent that this does not lead to leakage due to a decrease of harvesting levels elsewhere – result in an increase in carbon stored in harvested wood products, delaying the release of the carbon to the atmosphere. Likewise, a decrease in harvesting levels may – to the extent that this does not lead to an increase in harvesting elsewhere – results in a decrease in carbon stored in harvested wood products. In the long term, however, we assume the HWP pool to be transient with all the carbon stored eventually being released to the atmosphere as wood products decay.

These three effects are interrelated and depend on the elasticity of the demand for timber. If the demand for timber is relatively inelastic (a reduction in supply of timber has relatively small effect on demand), the leakage effects are relatively larger, while the impact on the harvested wood product pool is relatively smaller. By contrast, if the demand for timber is relatively elastic (a reduction in supply of timber has a significant effect on demand), leakage effects are relatively smaller, while the impact on the harvested wood product pool is relatively larger. How leakage effects and impacts on the HWP pool play out, also depends on the relative elasticity for different uses of timber (e.g., whether the demand for timber as fuel is more elastic than the demand as feedstock or for certain harvested wood products). Overall, all three effects are associated with considerable uncertainty, as discussed further below.

These three effects may change over time. Some IFM activities reduce harvest levels while others may not significantly affect or even increase harvest levels. The intensity of these effects but also whether harvest levels are reduced or increased may change over time. In assessing whether the inclusion or exclusion of leakage effects and impacts on HWP pools is likely to lead to overestimation or underestimation, we therefore consider the expected impact of the different types of activities over time (see below).

Lastly, IFM projects also affect other emission sources. Activities such as planting, tending, thinning, and wood harvest require energy that may cause CO_2 emissions from fossil fuel combustion. The application of N-fertilizers would cause nitrous oxide (N_2O) emissions. Furthermore, methane (CH_4) may be released when wood decomposes in landfills.

The relevance and materiality of these effects depends on the specific conditions of each IFM project. Some effects, however, can be commonly observed for certain types of IFM activities. Therefore, for assessing whether the inclusion or exclusion of carbon pools and emission sources for calculating emission reductions or removals of IFM projects leads to underestimation or overestimation, we make assumptions on how each of our five types of IFM activities may typically be implemented, noting that *what* activities are implemented may also change over time:

- **Extended rotation (ER):** This type of activity delays wood harvest by applying a longer rotation time or target diameter to forest stands in the project area. After the extension of rotation, trees are harvested. The delay of harvest leads to an increase in aboveground and belowground biomass in the project forest area compared to the baseline scenario, both at the point of harvest and on average over the crediting period. Individual trees get larger which can have implications for stocks of deadwood, litter, and soil organic carbon as well as on harvest methods and associated emissions.

- **Production to conservation (PC):** This type of activity terminates wood harvest for timber production in forest stands in the project area. The termination of wood harvest leads to an increase in aboveground and belowground biomass compared to the baseline scenario. Individual trees get larger which can have implications for stocks of deadwood, litter, and soil organic matter. Implementation of the activity may, in the long-term, lead to more natural dynamics in the forest, including natural disturbances, increased mortality, and natural regeneration. Emissions associated with harvest decrease.

- **Increasing productivity (IP):** This type of activity involves silvicultural techniques that result in increased forest growth. This may involve enrichment planting, which increases aboveground and belowground biomass, but also activities that may reduce aboveground biomass, such as from cutting climbers and vines or performing liberation thinning. This results in a potential increase in the amount of wood harvest. Increasing productivity may affect aboveground and belowground tree and non-tree biomass carbon stocks positively or negatively, depending on the concrete practices. Depending on the practices implemented it can have implications also for stocks of deadwood, litter, and soil organic carbon.

- **Reduced impact logging (RIL):** This type of activity reduces the impacts of wood harvest by applying improved logging practices in the project area. This can result also in a reduction in the amount of wood harvest. The implementation usually leads to an increase of aboveground and belowground biomass. Also, stocks of natural (standing and lying) deadwood, litter, and soil organic carbon might increase. Due to changes in harvest methods, the emissions associated with harvesting might also change.

- **Avoiding degradation (AD):** This type of activity avoids the start of, or an increase in, harvesting that is assumed to occur in the baseline scenario and/or targets harvesting towards higher quality timber, with the view to avoiding a reduction in forest carbon stocks in the project area. Refraining from harvesting or changing the harvest practices leads, relative to the baseline scenario, to higher stocks of aboveground and belowground biomass. It may also affect carbon stocks of deadwood, litter, and soil organic carbon. Due to the changes in harvest practices relative to the baseline, the emissions associated with harvesting might also change.

Based on the above considerations, Table 1 below identifies the carbon pools and emission sources that may be impacted by an IFM project. The table further identifies for each of the five types of IFM activities whether the identified carbon pool and/or emission source has (a) a material effect on overall emission reductions or removals, (b) potentially a material effect (i.e., it may be material only in certain contexts), or (c) no material effect (i.e., it is negligible in size). The table assesses the materiality of the changes in pools and sources that can be expected from the implementation of different types of IFM activities relative to the baseline. The table also indicates whether the exclusion of a pool or source in the quantification emission reductions or removals may lead to **overestimation** or **underestimation** of the overall emission reductions or removals, or whether it contributes to **uncertainty** in the quantification of overall emission reductions or removals (i.e., it could lead to either over- or underestimation, depending on the circumstances).

Note that IFM methodologies typically account for a subset of the carbon pools and emission sources from Table 1. Quantification methodologies typically include all main carbon pools affected by IFM projects in project boundaries, i.e., carbon in living and dead tree biomass and harvested wood products. Other pools or emission sources are often excluded due to their relatively small size, assumptions that they remain unchanged compared baseline levels or that their exclusion is conservative, or lacking data to estimate them accurately. Based on our analysis, the following carbon pools can, for most type of activities, have a material impact on overall emission reductions or removals and their exclusion would not necessarily be conservative:

- Deadwood (DW);
- Soil organic carbon (SOC);
- Harvested wood products (HWP).

These are discussed in more detail in the following.

Deadwood

Deadwood (DW) can be standing or lying and occur either naturally or as a result of harvest or management activities (e.g., pruning), known as slash. Different types of deadwood are affected differently by different activities, leading to material or potentially material changes in the deadwood carbon pools. Lying deadwood is often not very durable and rather quickly decomposes compared to standing deadwood, therefore impacts for lying deadwood are likely to be lower in magnitude. While quantification methodologies might not differentiate between different types of deadwood, the exclusion of this pool should always be considered closely because it may lead to different quantification outcomes (overestimating, underestimation, or uncertainty) depending on the type of activity and whether harvest levels increase or decrease due to the implementation of the project.

In some instances, excluding deadwood can lead to an underestimation of emissions from the deadwood pool and thus overestimation of total emission reductions or removals. For example, a reduction of harvest levels typically leads to a reduction of slash material and thus a reduction in the amount of carbon in the slash deadwood pool compared to the baseline. By contrast, if harvesting levels increase due to the implementation of the project, excluding the slash deadwood pool would be conservative. Moreover, activities that reduce harvest levels of living trees might result in an increased use of standing deadwood (i.e., decreasing the deadwood carbon pool). Excluding deadwood can also lead to uncertainty in quantification, without any known bias towards over- or underestimation, because the amount of deadwood may change in either direction under some forest management activities.

Soil organic carbon

The soil organic carbon (SOC) pool is likely to be affected by all IFM project activities to some degree, leading to either material or potentially material changes. It is labour-intensive to quantify, especially small changes, and the detection of changes in soil carbon is difficult due to high spatial variability. Therefore, quantification methodologies typically exclude this pool. As the pool is not directly targeted through IFM activities, impacts are rather complex. Decreased harvest levels can lead to more living biomass with increased litter production and thus larger carbon inputs to SOC. Harvest activities disturb the soil with potentially negative impacts on SOC that may be reduced when IFM projects are implemented. However, a reduction in harvest levels also lowers the amount of slash material as a carbon inflow to SOC. Overall, we assume that the exclusion of this pool can lead to underestimation or uncertainty, depending on type of IFM activity, but is unlikely to lead to an overestimation of emission reductions or removals.

Harvested wood products

The pool of harvested wood products (HWP) may increase or decrease due to the implementation of an IFM project activity. The HWP pool delays emissions from harvested wood. The impact of excluding HWP in the calculation of emission reductions or removals depends on the timeframe and whether harvest levels are increasing or decreasing.

In projects that implement activities leading to a decrease of harvest levels relative to the baseline, the amount of wood being transferred to the HWP pool is reduced. This applies to IFM projects shifting from production to conservation (PC), applying reduced impact logging (RIL), or avoiding degradation (AD). In this case, an exclusion of the HWP pool leads to overestimation. By contrast, the inclusion neither leads to underestimation nor to overestimation (as long as quantification is robust).

In projects that implement activities leading to an increase of harvest levels relative to the baseline, the amount of wood being transferred to the HWP pool is increased. This applies to IFM projects improving productivity (IP). In this case, in principle, an exclusion of the HWP pool would lead to underestimation, whereas the inclusion instead would neither lead to overestimation nor to underestimation (as long as quantification is robust). The incremental increase in carbon stocks in the HWP may, however, be reversed over time if the management practices of the project are not continued. For this reason, this assessment does not consider any potential underestimation due to the exclusion of the HWP pool in the overall assessment of the degree of conservativeness of the quantification methodologies.

It has to be noted that the harvest levels might change over the course of the project duration. For example, projects that extend forest rotation (ER) delay the harvest, thus reduce the amount of harvest temporarily but can result in higher harvest levels at the end of the extended rotation time due to the fact that wood volume has increased over time. In this case, an exclusion of the HWP pool leads to overestimation in the short run but potential underestimation in the longer run.

Table 1 Impact of different types of IFM activities on carbon pools (referred to as pools) and emission sources (referred to as sources) relative to the baseline

Carbon pool (CP) or emission source (ES)	Gases	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
CP1: Aboveground biomass (AGB) in trees	CO_2	*Material pool.* This is the main carbon pool affected by this activity.	*Material pool.* This is the main carbon pool affected by this activity.	*Material pool.* This is the main carbon pool affected by this activity.	*Material pool.* This is the main carbon pool affected by this activity.	*Material pool.* This is the main carbon pool affected by this activity.
CP2: Non-tree AGB (e.g., shrubs)	CO_2	*Potentially material pool.* Expected to increase due to accumulation of biomass between extended harvest events. The magnitude of the change depends on the project context. Exclusion leads to underestimation.	*Potentially material pool.* There may be material changes. The pool could decrease or increase. Exclusion leads to uncertainty.	*Potentially material pool.* Might increase or decrease depending on concrete practices. Exclusion leads to uncertainty.	*Material pool.* Expected to increase due to less destructive harvesting practices and less disturbance of forest floor. Exclusion leads to underestimation.	*Potentially material pool.* There may be material changes. The pool could decrease or increase. Exclusion leads to uncertainty.
CP3: Belowground biomass (BGB)	CO_2	*Material pool.* Expected to increase, proportional to AGB. Exclusion leads to underestimation.	*Material pool.* Expected to increase, proportional to AGB. Exclusion leads to underestimation.	*Material pool.* Expected to increase, proportional to AGB. Exclusion leads to underestimation.	*Material pool.* Expected to increase, proportional to AGB. Exclusion leads to underestimation.	*Material pool.* Expected to increase, proportional to AGB. Exclusion leads to underestimation.
CP4: Deadwood (DW) Standing, including roots	CO_2	Material pool. Carbon pool can potentially increase or decrease. Standing DW may be harvested, used as firewood, or allowed to accumulate between rotations.	Material pool. Might increase due to less harvesting overall. Exclusion leads to underestimation.	Material pool. Might increase or decrease depending on project context. Exclusion leads to uncertainty.	Material pool. Might increase due to decreased disturbance. Exclusion leads to underestimation.	Material pool. Might increase or decrease depending on the project context. Exclusion leads to uncertainty.

Carbon pool (CP) or emission source (ES)	Gases	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
		Exclusion leads to uncertainty.				
CP5: DW Lying (naturally occurring)	CO_2	*Potentially material pool.* The longer trees stand, the more they may lose branches and create more lying DW, however the magnitude of the change depends on the project context. Exclusion leads to underestimation.	*Potentially material pool.* The longer trees stand, the more they may lose branches and create more lying DW, however the magnitude of the change depends on the project context. Exclusion leads to underestimation.	*Potentially material pool.* The magnitude and direction of the change depends on the forest type and management practices. Exclusion can lead to uncertainty.	*Potentially material pool.* Expected to increase because there are more trees left after harvesting that can contribute to lying DW and there is less need to remove the lying DW when harvesting. Exclusion leads to underestimation.	*Potentially material pool.* Changes in lying DW may occur in either direction and to a variable degree of magnitude, depending on management practices. Exclusion leads to uncertainty.
CP6: DW Slash	CO_2	*Potentially material pool.* The amount of slash stays the same, but the intervals between producing slash are longer resulting potentially in a reduction of the carbon stock in DW. Exclusion leads to overestimation.	*Material pool.* Expected to decrease due to reduction of harvesting levels. Switch to conservation management results in little to no harvesting and leads to a reduction of slash DW. Exclusion leads to overestimation.	*Potentially material pool.* The direction and magnitude of change depends on the project context. To increase productivity, less slash may be left in the forest, reducing the pool. Improved tree growth can also lead to more slash being produced when harvest occurs. Exclusion leads to uncertainty.	*Material pool.* Expected to decrease due to less human-induced disturbances of the forest. Exclusion may lead to overestimation.	*Potentially material pool.* The direction and magnitude of change depends on the project context. To increase productivity, less slash may be left in the forest, reducing the pool. Improved tree growth can also lead to more slash being produced when harvest occurs. Exclusion leads to uncertainty.
CP7: Litter	CO_2	*Not material.* Only negligible effects expected.	*Not material.* Only negligible effects expected.	*Not material.* Only negligible effects expected.	*Not material.* Only negligible effects expected.	*Not material.* Only negligible effects expected.

Carbon pool (CP) or emission source (ES)	Gases	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
CP8: Soil organic carbon (SOC)	CO_2	*Potentially material pool.* May increase due to decreased disturbance. Exclusion leads to underestimation.	*Material pool.* Expected to increase due to decreased disturbance and more inputs from increased biomass stock. Exclusion can lead to underestimation.	*Potentially material pool.* The direction and magnitude of change depends on the project context. Thinning may decrease SOC stocks due to disturbance and less inputs from woody debris. Fertilizer leads to transformation and decomposition of organic carbon by microbes. Exclusion leads to uncertainty.	*Material pool.* The direction and magnitude of change depends on the project context. SOC stocks may increase due to decreased disturbance. SOC stocks may decrease due to a decrease in inputs from slash material. Exclusion leads to uncertainty.	*Material pool.* The direction and magnitude of change depends on the project context. Thinning may decrease SOC stocks due to disturbance and less inputs from slash material. Decreased harvesting may increase SOC stocks due to decreased disturbance. Exclusion leads to uncertainty.
CP9: Harvested wood products (HWP), includes carbon stocks in both, in-use and landfilled products	CO_2	*Material pool – time dependent.* In the short term, the activity leads to lower harvest levels and reduces the amount of wood being transferred to the HWP pool that may therefore decrease. Exclusion leads to overestimation. In the medium term, harvest levels may potentially increase,	*Material pool – time dependent.* In the short and medium term, the activity likely leads to lower harvest levels and reduces the amount of wood being transferred to the HWP pool that therefore decreases. Exclusion leads to overestimation.	*Material pool – time dependent.* In the short term, the direction and magnitude of change depends on the project context. Exclusion leads to uncertainty. In the medium term, harvest levels may potentially increase, leading to an increase in the HWP pool.	*Material pool – time dependent.* In the short and medium term, the activity likely leads to lower harvest levels and reduces the amount of wood being transferred to the HWP pool that therefore decreases. Exclusion leads to overestimation.	*Material pool – time dependent.* In the short term, the activity leads to lower harvest levels and reduces the amount of wood being transferred to the HWP pool that therefore decreases. Exclusion leads to overestimation. In the medium term, harvest levels may increase or decrease.

Carbon pool (CP) or emission source (ES)	Gases	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
		leading to an increase in the HWP pool. Exclusion leads to underestimation.		Exclusion leads to underestimation.		Exclusion leads to uncertainty.
ES1: Burning of biomass (e.g., prescribed burns)	N_2O, CH_4	*Not material.* Likely to remain at a similar level.	*Material source.* Prescribed burns may be used to reduce fire risk, improve habitat, and control for pests. Exclusion leads to overestimation.	*Material source.* Prescribed burns may be used to reduce fire risk and improve forest health/productivity. Exclusion leads to overestimation.	*Not material.* Likely to remain at a similar level.	*Material source.* Prescribed burns may be used to reduce fire risk and improve forest health/productivity. Exclusion leads to overestimation.
ES2: Emissions from changes in timber harvest levels on forestland outside the activity area (i.e., leakage)	CO_2	*Material source – time dependent.* In the short term, the activity is likely to lower harvest levels. This can result in increased harvest levels outside the project boundary and associated emissions. Exclusion leads to overestimation. In the medium term, harvest levels may potentially increase, leading to decreased harvest levels outside the product boundary.	*Material source – time dependent.* In the short term and medium term, the activity is likely to lower harvest levels. This can result in increased harvest levels outside the project boundary and associated emissions. Exclusion leads to overestimation.	*Material source – time dependent.* In the short term, the direction and magnitude of change depends on the project context. Exclusion leads to uncertainty. In the medium term, harvest levels may potentially increase, leading to a decrease in harvest levels outside the project boundary. Exclusion leads to underestimation.	*Material source – time dependent.* In the short and medium term, the activity likely leads to lower harvest levels. This can result in increased harvest levels outside the project boundary and associated emissions. Exclusion leads to overestimation.	*Material source – time dependent.* In the short term, the activity leads to lower harvest levels. This can result in increased harvest levels outside project boundary and associated emissions. Exclusion leads to overestimation. In the medium term, harvest levels may increase or decrease. Exclusion leads to uncertainty.

Carbon pool (CP) or emission source (ES)	Gases	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
		Exclusion leads to underestimation.				
ES3: Emissions from decomposition of wood products	CH_4	*Potentially material source.* In the short term, emissions are likely to decrease because of anticipated lower harvest levels. Exclusion leads to underestimation. In the medium term, emissions are likely to increase because of anticipated higher harvest levels. Exclusion leads to overestimation.	*Potentially material source.* Source will likely decrease because of anticipated lower harvest levels. Exclusion leads to underestimation.	*Potentially material source.* May change in either direction depending on harvest levels and market conditions. Exclusion leads to uncertainty.	*Potentially material source.* Source will likely decrease because of anticipated lower harvest levels. Exclusion leads to underestimation.	*Potentially material source.* May change in either direction depending on harvest levels and market conditions. Exclusion leads to uncertainty.
ES4: Nutrient application	N_2O	*Not material.* Fertilization, if occurring, likely to remain at a similar level.	*Not material.* Fertilization unlikely to occur.	*Material source.* The activity may lead to higher fertilization applied to increase productivity. Exclusion leads to overestimation.	*Not material.* Fertilization unlikely to occur.	*Potentially material source.* The direction and magnitude of change depends on the project context. Exclusion leads to uncertainty.
ES5: Mobile combustion emissions from site preparation	CO_2, N_2O, CH_4	*Not material.* Likely to remain at a similar level.	*Not material.* Not occurring.	*Not material.* Likely to remain at a similar level.	*Not material.* Not occurring.	*Not material.* Not occurring.
ES6: Mobile combustion	CO_2, N_2O, CH_4	*Not material.*	*Potentially material source.*	*Not material.*	*Potentially material source.*	*Not material.*

Carbon pool (CP) or emission source (ES)	Gases	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
emissions from ongoing project operation and maintenance		Likely to remain at a similar level.	Emission reductions may occur as less machinery is utilized. Exclusion leads to underestimation.	Likely to remain at a similar level.	The direction and magnitude of change depends on the project context. Exclusion leads to uncertainty.	Likely to remain at a similar level.
ES7: Stationary combustion emissions from ongoing project operation and maintenance	CO_2, N_2O, CH_4	*Not material*. Likely to remain at a similar level.	*Not material*. Likely to remain at a similar level.	*Not material*. Likely to remain at a similar level.	*Not material*. Likely to remain at a similar level.	*Not material*. Likely to remain at a similar level.
ES8: Combustion emissions from production, transportation, and disposal of forest products	CO_2, N_2O, CH_4	*Potentially material source – time dependent.* In the short term, emissions are likely to decrease because of anticipated lower harvest levels. Exclusion leads to underestimation. In the medium term, emissions are likely to increase because of anticipated higher harvest levels. Exclusion leads to overestimation.	*Potentially material source – time dependent.* In the short and medium term, emissions are likely to decrease because of anticipated lower harvest levels. Exclusion leads to underestimation.	*Potentially material source – time dependent.* In the short term, the direction and magnitude of change depends on the context. Exclusion leads to uncertainty. In the medium term, emissions are likely to increase because of anticipated higher harvest levels. Exclusion leads to overestimation.	*Potentially material source – time dependent.* In the short and medium term, emissions are likely to decrease because of anticipated lower harvest levels. Exclusion leads to underestimation.	*Potentially material source – time dependent.* In the short term, emissions are likely to decrease because of anticipated lower harvesting levels. Exclusion leads to underestimation. In the medium term, harvest levels may increase or decrease. Exclusion leads to uncertainty.
ES9: Combustion emissions from production,	CO_2, N_2O, CH_4	*Potentially material source – time dependent.*	*Potentially material source – time dependent.*	*Potentially material source – time dependent.*	*Potentially material source – time dependent.*	*Potentially material source – time dependent.*

Carbon pool (CP) or emission source (ES)	Gases	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
transportation, and disposal of alternative materials to forest products (i.e., leakage due to substitution effects)		In the short term, emissions are likely to increase because of anticipated lower harvest levels. Exclusion leads to overestimation. In the medium term, emissions are likely to decrease because of anticipated higher harvest levels. Exclusion leads to underestimation.	In the short and medium term, emissions may increase because of anticipated lower harvesting levels. Exclusion leads to overestimation.	In the short term, the direction and magnitude of change depends on the context. Exclusion leads to uncertainty. In the medium term, emissions are likely to decrease because of anticipated higher harvest levels. Exclusion leads to underestimation.	In the short and medium term, emissions may increase because of anticipated lower harvesting levels. Exclusion leads to overestimation.	In the short term, emissions are likely to increase because of anticipated lower harvesting levels. Exclusion leads to overestimation. In the medium term, harvest levels may increase or decrease. Exclusion leads to uncertainty.

The methodology requires that projects "clearly define the spatial boundaries", these project boundaries are fixed for the whole crediting period. More than one discrete area of land can be included in the project activity. Specific information must be provided for each discrete area. This includes maps and geographic coordinates, which can be provided in non-digital form, although the digital option is "preferred".

VM0010 identifies the following carbon pools relevant for quantifying emission reductions or removals associated with the project activity:

- CP1: Aboveground biomass (AGB) in trees,
- CP6: Deadwood (DW) from slash,
- CP9: Harvested wood products,
- ES1: Burning of biomass (CO_2 and CH_4, N_2O considered negligible),
- ES2: Emissions from changes in timber harvest levels on forestland outside the activity area (i.e., leakage),
- ES6: Mobile combustion emissions from ongoing project operation and maintenance (only included in the baseline if significant, excluded from the project emissions as considered to be insignificant),
- ES7: Stationary combustion emissions from ongoing project operation and maintenance (only included in the baseline if significant, excluded from the project emissions as considered to be insignificant).

The following carbon pools and emissions sources are explicitly excluded by the methodology. The exclusion may lead to over- or underestimation of emission reductions or removals (OE or UE) or introduce uncertainty (Un) in their quantification:

Un1: There are potentially material impacts to the **non-tree aboveground biomass** (CP2). The pool could decrease or increase based on the project's forest management changes with exclusion leading to **uncertainty**. This is likely to occur in **all** projects. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%). There is **unknown** variability in this uncertainty among projects, on forest type and activities undertaken.

UE1: **Belowground biomass** (CP3): This pool is expected to increase compared to the baseline, proportional to the increase in AGB. Therefore, the exclusion leads to **underestimation**. This issue applies to **all** projects. The impact on the total credited emission reductions or removals is expected to be **medium** (10-30%), depending on the root to shoot ratio. We estimate that there is a **medium** variability in the degree of underestimation among projects, depending on the forest type and the root to shoot ratios that would be used as well as their associated uncertainty.

UE2: **Standing deadwood** pool (CP4): the methodology refers to the IPCC methodologies' Tier 1 assumption that this pool is the same if forest land remains forest land. However, a shift from logging to conservation could also lead to an increase in the pool due to decreased harvesting and disturbance. Therefore, exclusion leads to **underestimation**. This issue applies to **all** projects. The impact on total credited emission reductions or removals is expected to be a **medium** (10-30%) impact on total credited emission reductions or removals as standing deadwood can form significant shares of AGB. There is **unknown** variability among projects, depending on the forest type, environmental conditions and activities taking place during the project, e.g., if standing DW is extracted for conservation purposes.

UE3: The natural **lying DW** (CP5) pool is excluded by the methodology because no change is expected compared to the baseline. However, we conclude that this pool is likely to increase under the project as the forest stand is allowed to grow older. The exclusion of this carbon pool may therefore lead to **underestimation**. This is likely to affect **all** projects. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%), as this carbon pool is smaller than that of CP4. **High** (over 30%) variability is assessed for projects, as the level of changes varies depending on forest type, environmental condition, and specific activities that are undertaken.

UE4: **Soil organic carbon** (CP8): The methodology refers to the IPCC methodologies' Tier 1 assumption that SOC does not change when forest land remains forest land. However, SOC may increase in a potentially material way relative to the baseline due to decreased disturbance and inputs from an increased biomass stock if the project activity is carried out in a degraded forest. The exclusion of this pool leads to **underestimation**. This is likely to occur in **all** projects since reducing intensity of harvesting or stopping harvesting altogether decreases the disturbance of the soil. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%). There is **unknown** variability in this uncertainty among projects depending on the soil type and management activity.

The methodology states that emissions from the combustion of fossil fuels are only included if tested to be significant. Emission sources specifically mentioned are harvesting (felling and snigging), log hauling, log transport, (all three ES6) and log processing (ES7). Emissions from timber processing can only be included if the processing plant is situated in the project area. Due to the project type, which implies halting forest operations, one could assume that fossil fuel emissions will be zero. But there may also be continued emissions from forest maintenance activities, which are permitted for conservation purposes.

OE1: **Emissions from fossil fuel combustion only included the baseline calculation:** The methodology states that "as commercial timber harvest and activities that result in forest degradation are not eligible under the methodology in the project scenario, emissions sources from combustion of fossil fuels from vehicles, machinery and equipment are de minimis and not accounted by the methodology in the project scenario." An inclusion only in the baseline and exclusion in the project leads to **overestimation**, in the event that there are any ongoing forest operations. We assume this applies to **all** projects as it is likely that project proponents include this emission source in their baselines. The impact on total credited emission reductions or removals is **unknown** but likely to be small, it depends on the forest operations for conservation purposes. The variability in the degree of overestimation among projects is **unknown**.

Un1: **Non-tree aboveground biomass** (CP2): This pool is expected to increase compared to the baseline, if the project is carried out in a currently logged or degraded forest. An exclusion may lead to **uncertainty**. This issue applies to **all** projects. If the project is carried out in a forest that is not yet logged, it is expected to change according to natural forest dynamics similar to those in the baseline. In case of a logged forest as a starting point, we estimate the impact on credited emission reductions or removals to be **low** (less than 10%). The variability in the magnitude of the uncertainty among projects is **unknown**, depending on the forest type and the state of the pool at the beginning of the project.

The following emission sources are not mentioned in the methodology:

UE5: **Combustion emissions from production, transportation, and disposal of wood products** (ES8): Activities are expected to decrease relative to the baseline in a potentially material way due to anticipated lower harvesting levels. The exclusion of this emission source may therefore lead to **underestimation**. This is likely to be the case for a **high** fraction of projects. The impact on total credited emission reductions or removals is **unknown**. Furthermore, the variability among projects is also **unknown**.

OE2: **Emissions from production, transportation, and disposal of alternative materials** (ES9): Emissions are likely to increase because of lower harvest levels. An exclusion leads to **overestimation** and affects a **high** fraction of projects. The impact on total credited emission reductions or removals is **unknown**. Furthermore, the variability among projects is also unknown.

UE6: **Methane emissions from decomposition of the HWP** pool (ES3): When harvest levels decrease as a result of project activities, methane emissions from decomposition of HWP are reduced relative to the baseline in a material way. Exclusion of methane emissions from wood decay leads to **underestimation**. This is likely to occur in **all** projects. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%). The degree of underestimation among projects is **unknown**.

Quantification of carbon stocks in the project and the baseline scenario

The carbon stored in a forest ecosystem is challenging to measure due to various factors. First, determining the amount of carbon stored in a single tree (Vorster et al. 2020), e.g., through measurements at plot level in forest inventories, is associated with uncertainties. Second, at a larger scale, the diversity of tree species, forest composition, and age structure, ecological dynamics and natural disturbances add uncertainty when scaling up plot level estimates. Moreover, there are multiple non-tree carbon pools and emission sources (e.g., shrubs, soil, different types of deadwood) that exist within forests. Plot level measurements are also affected by factors like terrain, skill level of inventory staff or distance from roads that can make certain measurement practices impractical. Overall, this can lead to significant uncertainty in determining carbon stocks. This applies to carbon stocks estimated under both the project scenario and the baseline scenario.

Forest carbon stocks may be determined through direct measurements, remote sensing measurements, and/or modelling approaches. Direct measurements, i.e., forest inventories, rely on sampling methods to address the challenges described above: applying allometric equations to estimate an individual tree's total biomass, factors to account for wood density and wood carbon content, identifying shares of species, diversity of forest vertical structure, and age-class distribution of entire forest landscapes. Belowground biomass is a carbon pool that is particularly challenging to estimate accurately, given that it can only be accurately assessed by digging and extracting the extent of tree roots. Due to a direct relationship between above- and belowground biomass of a plant, changes in belowground biomass pool are typically evaluated by applying root-to-shoot ratios developed from the limited number of studies that have been conducted for individual tree species. Aerial or satellite imagery collected remotely can be used for forest measurement to stratify the forest and thus reduce costs of measurements or increase accuracy of estimates. Stratification can help identify forest areas with similar properties and develop an adequate sampling design for ground measurements. Remote sensing methods, however, also involve significant uncertainties (Vorster et al. 2020).

The accuracy and uncertainty of quantification of biomass carbon pools mainly depends on four dimensions (Haya et al. 2023):

- Accuracy of measurements in the field;
- Choice of allometric models (including selection of wood density values and root-to-shoot ratios);
- Sampling uncertainty related to plot size;
- Sampling uncertainty related to statistical representativeness of the plots within the whole landscape (e.g., stratification).

Soil organic carbon quantification relies on similar sampling principles with sampling design appropriate to capture variability in soil types, climate zones, and management systems. Soil carbon dynamics can also be represented by biogeochemical models that require extensive data for robust calibration and prediction.

Quantification of carbon pools in harvested wood products (HWP) requires data on wood production, allocation to product categories (e.g., sawn wood, pulp wood) as well as mean residence time for carbon in these wood product categories. Products like timber, plywood, or paper are produced from harvested trees that are processed at lumber mills. The logs are transformed into sellable wood products with some losses in woody biomass occurring that are identified as the efficiencies of lumber mills and used to quantify the amount of carbon stored in HWP. The different HWP types generated from a shipment of harvested logs can be tracked by lumber mills through their production records or estimated based upon regional, national, or global values. Lumber mill records may not always be available to project developers, may not be associated with specified shipments of harvested logs, or record databases may be poorly managed. Some countries like the United States may have published average regional data estimating the proportion of wood product types from harvested trees across regions that can incorporate and provide distinguished results based upon characteristics like region, forest type, previous land use, and potentially also include productivity class and management intensity (Smith et al. 2006). Uncertainties relating to regional average data are significant due to the variability that can exist within regions regarding the harvested wood produced, annual changes in types of wood products demanded, and the practices of individual lumber mills compared to the region’s average lumber practice (Smith et al. 2006). These uncertainties are greater when estimating carbon stored in HWP at national or global levels.

Resident times of the carbon stored in wood products in use differ for different product categories. There is typically a lack of data at regional or even national level for residence times of products. The IPCC offers default values for average half-lives of wood products for different categories, e.g., 30 years for solid wood products and 2 years for paper products (IPCC 2006). These factors also include recycling cycles that might occur after the end of life of wood products. Disposal of wood products as they reach the end of their lifecycle at solid waste disposal sites such as landfills also constitutes long term storage of carbon. Quantification of carbon stocks in disposed wood products is a function of wood product type, disposal facility type, availability of bioenergy capture, capacity for reuse and recycling, etc. Such data may not be available to project developers, resulting in estimates that are highly uncertain. Moreover, residence times and recycling rates change over time and vary regionally. Wood disposal in some regions, e.g., European Union, is banned and wood waste is burned, partly for energy generation. Thus, it can be assumed that HWP in that region release all CO_2 at the end of their life.

Harvested wood products also act as an emission source due to decay of carbon while in use or in disposal. Decay rates depend on product type and disposal pathways. As discussed above, data may be extremely limited leading to high uncertainty in estimating changes in emissions.

Quantification methodologies typically account for uncertainty in quantifying carbon pools by applying deductions proportional to the level sampling error. This generally contributes to conservativeness. Some quantification methodologies also provide flexibility by giving discretion to project developers when selecting methodological approaches or data sources for quantifying carbon stocks. This can lead to overestimation because project developers may systematically "pick and choose" those approaches that provide them with more carbon credits.

OE3: **Flexibility in choosing the value for the fraction of carbon in biomass**: The methodology offers using either a default value of 0.5 for the fraction of carbon in the biomass or species-specific values from literature. The project proponent is free to choose between the two options. Studies suggest that using a ratio of 0.5 overestimates carbon stocks in a variety of tree species in different climate zones (Martin et al. 2018). The study reports that carbon fractions depend on forest types and indicates errors in the existing forest carbon estimates of 4.8%, on average, and most extreme errors of 8.9% in tropical forests. The use of the default 0.5 value would therefore be a potential source of **overestimation** of carbon stocks. This overestimation occurs in an **unknown** number of projects that apply a default value. The prescribed use of 0.5 is likely to result in a **low** degree of overestimation of total credited emission reductions or removals (less than 10%). There is **medium** variability in the overestimated amount.

Determination of baseline emissions or removals

Estimating baseline emissions of IFM projects is associated with considerable uncertainty. This is because many exogenous factors – beyond the control of forest landowners – can affect forest management practices and carbon stocks in the baseline scenario:

- Forest management is influenced by policies and regulations. Such policies and regulations could either enhance the pressure on forests (e.g., policies promoting the use of biomass as energy source) or provide incentives for enhancing carbon stocks (e.g., incentive schemes to promote certain forest management practice or the introduction of carbon pricing instruments giving stored carbon a higher value). As the role of forests and removals will need to be enhanced considerably to meet the goals of the Paris Agreement, it is reasonable to assume that jurisdictions will increasingly adopt policies and regulations that support the enhancement of carbon stocks on forest land.
- Forest management is partially driven by prices for timber and other forest-related products. These prices may change considerably over time, including for different tree species. Similarly, the opportunity costs of using the land for other purposes may change. This could lead to a change in forest management practices over time, or even the conversion of the forest to other uses.
- Forest management practices may depend on ownership (which could change during the course of a project or in the baseline scenario), knowledge, established practices, and data availability in the region. These could, however, change and evolve over time, as new (information) technologies and data becomes available, enabling the implementation of improved management practices in the baseline scenario.
- There is inherent uncertainty in forest growth and harvesting in the baseline scenario. Existing forest stocks will continue to grow and might even seed more trees over the crediting period. On the other hand, harvesting may occur and ongoing degradation of a forest may continue.

- Finally, the impacts of climate change on forests may also be significant (United States Environmental Protection Agency (EPA) 2023) and our ability to predict the impacts of climate change on forests and their management is limited. Natural disturbances already form a major threat to certain forest types and climate change is likely to accelerate their dynamics and severity.

It is difficult to make predictions or assumptions of how these factors will evolve over time, and it is challenging to determine their impact on a forestry project's baseline scenario. A further challenge is that the crediting periods for improved forest management projects are often very long, varying from 20 to 100 years. Estimating baselines over such long time periods further enhances the uncertainty.

Furthermore, an important consideration is how the uncertainty of the baseline compares to the level of emission reductions or removals achieved due to the implemented measures. If the uncertainty of the baseline is large but the improved forest management activities applied in the project scenario have only relatively small effects on carbon pools, the estimated emission reductions may be difficult to clearly attribute to the improved forest management measures being implemented. The observed changes could also occur due to one of the exogenous factors referred to above. This issue has been referred to as signal-to-noise issue in the literature (Chagas et al. 2020).

We estimate that the uncertainty in the future baseline *scenario* for IFM activities is on the order of magnitude of ±30%, given the long timespan of crediting in this sector and the various factors that could influence the level of future carbon stocks. This can have significant implications on the overall uncertainty of emission reductions or removals. For example, if an IFM project monitors an enhancement of carbon stocks by 10% compared to the assumed baseline (e.g., continuation of historical carbon stocks), a ±30% uncertainty with regard to the baseline scenario would imply that the actual impact of the project could be between an *increase* of emissions by 20% and removals by 40%. This means that the project either only receives a quarter of the actual removals or that the project could actually have led to an absolute increase of emissions to the atmosphere. This example only covers the uncertainty in the baseline scenario but not yet a range of other factors that further add uncertainty to the overall emission reductions, such as uncertainty in the quantification of carbon stocks or leakage effects. This illustrates that a signal-to-noise issue is a key challenge and risk for this project type.

Quantification methodologies use a variety of approaches to establish baselines. The assessed methodologies allow for different methods to establish baselines. Usually, they require a number of alternative forest management scenarios to be compared to the proposed project activity. The establishment of a baseline needs to reflect a management system that involves IFM-related activities covered by the methodology. The most common method are historical baselines that assume the continuation of pre-project forest management. Methodologies have different requirements for how far back in time historical baselines need to reach. This also depends on data availability which might be limited, e.g., in the case of changes in ownership. Alternative approaches are therefore baselines that are based on legal requirements for forest management in the region where the project is implemented. The information basis for such baselines are laws and management plans as well as silvicultural management rules. In many cases, the specific management practices implemented by the project may not be explicitly referred to in regulations. Therefore, methodologies often require that the legality and plausibility of these practices is confirmed by independent parties. Another approach is to establish a baseline built on common practice identified as being representative for the region.

The available literature suggests that deflated baselines may lead to considerable overestimation. The most prominent literature is available for projects enrolled under the California Air Resources

Board (CARB). Two studies used remote sensing data to compare IFM projects registered under the CARB with a control group of lands not registered under carbon crediting programs (Coffield et al. 2022; Stapp et al. 2023). Both studies do not find a statically significant difference in key parameters for land management between the two groups (e.g., harvesting levels, disturbances, carbon accumulation). Under the CARB, the baseline is established based on average regional values. Both studies found that this led to adverse selection: lands registered under the CARB had higher carbon stocks than the regional averages, thus earning carbon credits for having existing carbon stocks, rather than changes in forest management practices. These findings are similar to the analysis by Badgley et al. (2022) who compared initial carbon stocks of projects enrolled under the CARB with regional averages and concluded that the use of regional carbon averages as baselines has led to over-crediting of 29.4% of the credits analyzed. While these studies are limited to the CARB methodology, the findings could also apply to the CAR US methodology which also uses regional averages as the baseline. Further literature also points to significant overestimation in one project registered under the VCS (van Kooten et al. 2015) and various other challenges in establishing baselines for IFM activities, such as information asymmetry and perverse incentives (see Haya et al. 2023 for an overview).

According to the VM0010 methodology, forest management in the baseline scenario must be planned timber harvest; otherwise the methodology is not applicable. A "legal right to harvest" must predate project implementation and legal proof of it must be provided. Harvesting in the baseline scenario may occur multiple times and in any year of the crediting periods. The project must demonstrate that timber harvest is planned. This should be demonstrated through a forest management plan that specifies the harvesting practices and the volume of timber resources to be extracted. In addition to the legal right to harvest, proof of "intent to harvest" is required. Evidence for this is either a "verifiable government approved timber management plan" or documents showing that planned harvest is representative of harvesting practices in the country in the past two years and proof of commercial viability through access to transport and processing infrastructure. A conversion to managed plantation is not allowed as the baseline scenario.

The methodology allows for two options to model a baseline scenario:

1. <u>Historical baseline scenario:</u> This approach must be used if records on forest management for at least 5 years prior to the project start date exist and if the project proponent can demonstrate that past management practices comply with relevant forest legislation and that they provided above average financial returns. The historical baseline scenario must be based on a "timber harvest plan" and specifying a "timber harvesting schedule" (See Box 1 in methodology).

2. <u>Common practice baseline scenario:</u> Common practice is defined as the timber harvest plan developed when complying with legal forest management requirements and applying the timber harvesting practice of a reference area. The methodology specifies requirements for the selection of the reference area. It must be in the same region as the project area and have the same mix of forest types (+/-20%) and annual precipitation (+/-20%). The proportion of elevation classes in 500m steps must be the same (±20%). Up to 5% of the project area can be excluded for assessment if no suitable reference area is found.

This methodology limits the quantified carbon stocks to those in commercial merchantable timber (see section 8.1.1). It starts the quantification of baseline emissions by determining the potentially available timber for harvest (mean merchantable volume per unit area of species and stratum). This is done either through sample plots or by using pre-existing forest inventory data. In the latter case, this data must represent forest strata and be not older than 10 years old. In case the data is older, limited sampling is required. The merchantable tree volume can be estimated using "locally derived allometric equations or yield tables" for each species. If these are not available, default values and other regional or national equations or yield tables can be used. The values of mean merchantable volume are then used as a reference to determine mean **extracted volumes** of timber according to the timber harvest plan in the baseline scenario.

The timber harvest plan provides the following information for the baseline scenario:

- Clear identification of areas that can be harvested and those that will not, non-harvest areas include "legally required exclusions for environmental reasons".
- Clearly designated land parcels or "annual operating areas" to subdivide the forest that is to be harvested.
- Planned forestry infrastructure (roads, skid trails, log landings)
- A timber harvesting schedule for each identified land parcel that indicates:
    - the "mean extracted volume of extracted merchantable timber per unit area by species in each stratum in each year"
    - the mean volume of merchantable timber per unit area by species in each stratum in each year that is harvested for the establishment of forestry infrastructure and further processed
    - the mean volume of merchantable timber per unit area by species in each stratum in each year that is harvested for the establishment of forestry infrastructure and remains in the forest.

Carbon stocks are calculated by multiplying timber volumes with biomass conversion and expansion factors and factors for the carbon fraction of biomass for each species. The methodology requires ex-ante stratification if the project area covers multiple forest types or forests with different carbon density. The criteria for establishing strata are robust, namely forest type, vegetation type and/or the target timber species. The basis for stratification is either existing and legally documented vegetation maps and stratifications or standard assessment protocols.

Baseline emissions are calculated ex-ante and are not adjusted throughout the crediting period. The total emissions are averaged across the project crediting period to give annual emissions and are multiplied by the time elapsed since the start of the project activity.

OE4: **Flexibility in setting the baseline scenario:** The methodology states that the historical baseline must be used if information for a minimum of five years preceding the project start date is available. Otherwise, the common practice baseline scenario must be used. The choice between these baseline scenarios is relevant when the project is carried out in logged forest. In forest that has not been logged, a historical baseline would not deliver any information relevant for a harvest plan, leaving only the common practice baseline as an option. In case of already logged forest, there are no requirements to prove that historical information is not available. The project developers could thus disregard historical information that indicates low harvest levels, in favour of a common practice baseline scenario. Although the common practice scenario is not supposed to contradict "management by the baseline agent" (section 6.2.2.), except where it would indicate a lower harvest intensity, there are no information requirements related to "management by the baseline agent", if not historical. It is unclear how a situation could be prevented, where the baseline agent withholds information about lower planned harvest levels, compared to a common practice baseline with higher harvest levels. In case historic harvest data is used, the methodology does not specify a maximum number of years it may lay back. Project proponents could thus choose from information that is at least five years old, as required by the methodology or much older information that may indicate higher harvest levels. Flexibility in selecting baseline scenarios can lead to **overestimation**. A **high** number of projects are potentially affected by this. The impact on total credited emission reductions or removals is **unknown** but has the potential to be very significant. The variability in the degree of overestimation among projects is also **unknown**.

OE5 **Risk of adverse selection when projects are implemented in unlogged forest:** If the project is implemented in unlogged forest that would otherwise be logged, expected harvesting levels would be derived from common practice. In this case the project type can also be classified as avoiding degradation. As described by Haya et al. (2023), only the project proponent knows with certainty if the forest would have been logged without carbon credit revenue. The forest may also have been left intact or be only minimally logged, in which case a common practice baseline would lead to **overestimation**. The proportion of projects affected by this risk is **unknown**. The degree of overestimation and the variability among projects are also **unknown**.

OE6 **Choice of reference area in common practice baseline:** These criteria are generally appropriate to identify similar forest areas; however, they do not exclude a discretionary selection towards a reference area that would have higher harvest rates (e.g., areas with lower elevation and higher precipitation) leading to potential **overestimation**. The fraction of projects affected by this is **unknown**. The impact on total credited emission reductions or removals is **unknown**. We estimate that there is **medium** (±30%) variability in the degree of overestimation among projects.

Un2: **Static baseline based on historical situation as default:** The methodology uses a static baseline that is based on historical data. This ignores any potential changes in government policies, incentives, or common practice. The failure to account for any changing policy, economic, or common practice conditions could lead to overestimation of a project's emission reductions or removals in case that new policies lead to greater carbon stocks than the historical situation (e.g., subsidies for sustainable forest management). However, new policies could lead to underestimation of emission reductions or removals where these lead to lower forest carbon stocks than in the historical situation (e.g., policies promoting the use of biomass as a fuel or feedstock). The baseline is not being updated if new policies emerge. The leads to **uncertainty**. This is likely to affect a **high** number of projects that apply the methodology. The impact on total credited emission reductions or removals is estimated to be **high** (more than 30%). The variability in the uncertainty among projects is estimated to be **high**.

Un3: **Uncertainty with regards to timber harvest plans**: Initial volumes of merchantable timber per unit area and a detailed plan on when and what timber is going to be harvested, are at the center of how this methodology calculates baseline and project emissions. Detailed information is required in advance, based on common practice or historical information. However, it cannot be assured that timber harvesting plans actually would have been carried out. This may result in higher or lower levels of harvest than initially planned leading either to an over- or underestimation of emission reductions or removals, leading to **uncertainty**. This issue is expected to be affecting **all** projects. It contributes a **medium** uncertainty to the estimation of total credited emission reductions or removals. The variability among those projects for which the issue materializes is **unknown**.

OE7: **Flexibility in choosing the forest regrowth rate post timber harvest**: Carbon stock change due to forest regrowth is included in the baseline calculation. The methodology states that "carbon sequestration resulting from forest regrowth after timber harvest up to year t is equal to the forest regrowth rate of each stratum". Three options to determine regrowth rates are provided:

- data generated in a reference area using measurements of timber volume in a chronosequence of replicated sample plots;
- published data on forest growth after timber harvest of the same forest type within the same region as the project;
- the IPCC default values for aboveground net biomass growth in natural forests.

This provides flexibility for project proponents to potentially choose the option that delivers the smallest regrowth rates, which would lead to an **overestimation** of emissions in the baseline. The number of projects affected by this issue is **unknown**. The issue contributes to **medium** uncertainty of the estimation of total credited emission reductions or removals. The variability among those projects for which the issue materializes is **unknown**.

OE8: **Flexibility in the estimation of harvested wood product classes:** Project proponents must indicate the share of wood products they will harvest as part of the baseline calculation. The methodology distinguishes between three wood product classes: 1) Wood products that decay within 3 years after harvest (wood waste and short-lived wood products), these are assumed to cause emissions at the time of harvest; 2) Wood products retired between 3 and 100 years, for which emissions are assumed to occur according to a linear decay function; and 3) wood products that are permanently stored. The share of harvest that goes into the different wood products is estimated by expert knowledge. No further guidance is provided. This leaves considerable leeway to project developers for choosing options with higher shares harvested for classes 2 and 3. This would lead to an **overestimation** of emission reductions or removals. The fraction of projects affected by this is **unknown**. The impact on total credited emission reductions or removals is **unknown**. The variability in the degree of overestimation among projects is **unknown**.

Un4: **Decay rate for HWP**. The methodology applies decay rates for different types of wood products. Carbon in short-lived wood products with a lifetime of up to 3 years is assumed to be released instantaneously. Medium-lived wood products are products that will be disposed of between 3 and 100 years from the date of harvest. Long-lived wood products are products that are considered permanent (stored for 100 years or more). For medium-lived wood products, a 20-year linear decay is assumed. Annually 1/20th of the carbon allocated to these products after harvest is deducted from the harvested wood product pools. 20 years after harvesting, the stock of products of that kind is zero. Assuming a linear decay rate results in higher calculated HWP carbon pool levels than the approach provided by the IPCC that applies a first order decay function which, in the short term, leads to a faster decomposition of HWP. Assuming that production to conservation activities reduce harvest levels relative to the baseline scenario, using a linear decay rate, in the short-term, thus underestimates emissions from products and thus overestimates emission reductions or removals. By contrast, in the mid-term using a linear decay rate underestimates overall emission reductions or removals. Overall, this leads to **uncertainty**. This is likely to affect a **high** number of projects that apply the methodology. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%). The variability in the uncertainty among projects is estimated to be **medium**, depending on the type of wood product.

Determination of project emissions or removals

In this methodology the baseline calculation serves to identify the trees that would be harvested. Project emissions and removals are then calculated solely on the basis of changes related to these trees. The calculation of project emissions includes the “change in carbon stocks of ongoing forest growth, forest disturbances and illegal logging” (section 8.2).

The calculation of carbon stocks in AGB includes the following steps:

- Selection or development of allometric equations for species or forest type found in the inventory.
- Measurement of trees in sample plots. These are only required for “individual trees, species and strata” that would be harvested in the baseline scenario (section 8.2.1.2).
- Calculation of AGB in each sample plot by species, by using measurement data and allometric equations.
- Calculation of carbon stocks in each sample plot, by multiplying AGB by the carbon fraction of biomass.
- Calculation of mean carbon stock values per stratum and hectare.

The annual carbon stock change is calculated from the differences in the mean carbon stock of the latest “sampling event” (section 8.2.1.26) and the previous sampling event, divided by the number of years between sampling events. A minimum of 1 year and a maximum of 10 years is accepted between sampling events referred to as monitoring period in section 5.2.

Project proponents are not required to estimate “carbon stock changes from forest growth from undisturbed forest”, but they may choose to do so in the project scenario and must then carry out “detailed sampling”. As a final step the methodology requires that the total calculated emissions and removals be adjusted for uncertainty and a deduction to account for non-permanence risk be applied.

Emissions from natural disturbances (fire, wind, pests) are subtracted from removals occurring due to tree growth. The methodology assumes that all disturbance events that occur in the project scenario would also have occurred in the baseline scenario (section 8.2.2.1). The difference being that the trees would have been harvested and removed in the baseline scenario but are present in the project and hence affected by disturbances.

The methodology does not provide full clarity on how monitoring of biomass should be carried out. Section 8.2.1.2 on measurements states “only the individual trees, species and strata which were to be harvested in the baseline scenario are to be measured.” Section 8.2.1.4 on determining stratum carbon stocks states "The total carbon stock in the aboveground biomass of **all trees** present in sample plot sp in stratum i at time t, must be calculated” (emphasis added). Section 9.2. describes the monitoring plan. It states that DBH and merchantable biomass as a proportion of total aboveground tree biomass for stratum i must be monitored. Total aboveground tree biomass needs to be measured and the proportion of merchantable biomass estimated. Indications in section 8.2.1.4 and 9.2 seem to contradict the statement in section 8.2.1.2. that only trees to be harvested should be included. For this analysis we assume that the complete biomass in a sample plot is measured in each monitoring event.

Lack of clarity also arises regarding the statement that "it is not a requirement (...) for the project proponent to estimate carbon stock change from forest growth in the project scenario of undisturbed forest. However, where the project proponent chooses to determine stock change from forest growth in the project scenario, a detailed sampling plan must be provided in the project documents" (see section 8.2). It is not clear to which part of the project this sentence refers to. Project areas where harvesting would have occurred and that are not affected by natural disturbances always need to be monitored. Any other area should not be part of the project.

UE7: **Emissions from fire disturbance exclude emissions from extracted timber for forest infrastructure:** Emissions from fire disturbance are calculated according to the Tier 1 methodology indicated in the 2006 IPCC GPG (Chapter 2, equation 2.27). In the IPCC methodology the "mass of fuel for combustion" in tonnes per ha is multiplied by the burnt area and a combustion and an emission factor. In this methodology the mass of fuel is estimated as the "average above ground biomass stock present in the project scenario but absent in the baseline scenario before burning" ($B_{i,t|PRJ}$). Thus, for estimating fire emissions, only trees that are not being harvested due to the project, are considered. This is in line with the assumption that the fire events occurring in the project would also have occurred in the baseline. However, $B_{i,t|PRJ}$ is calculated only based on the mean volume of extracted timber, while in the timber harvest plan and baseline calculations also cover emissions from "mean volume of extracted timber for forestry infrastructure" (see equation 3). The methodology treats trees harvested for forestry infrastructure explicitly as extracted (see section 8.1.1 chapeau of equation 3), so they would also be left standing. In the project scenario these trees would cause emissions when being affected by fires. Their exclusion leads to **underestimation**. The number of projects impacted by this is **unknown**. For those projects where this issue materializes, the impact on total credited emission reductions or removals is expected to be **low**, as the share of timber extracted for forestry infrastructure is likely small compared to merchantable timber. The variability among those projects for which the issue materializes is **unknown**.

Un5: **Emissions from fires do not consider biomass increment:** The calculation of baseline emissions considers changes in carbon stocks due to forest growth after harvest. The estimation of project emissions is based on the carbon stock change between monitoring events. However, emissions from fire disturbance are calculated based solely on the mean volume of extracted timber per ha indicated in the baseline. Assuming trees were supposed to be harvested in years 1, 10 and 20 of the baseline, and monitoring events took place every five years and a fire occurred in year 15. Emissions from trees not harvested in years 1 and 10 would then be underestimated, since their biomass increase is not considered. Emissions from trees harvested in year 20 would be overestimated. Overall, this leads to **uncertainty**. The number of projects impacted by this is **unknown**. For those projects where this issue materializes, the impact on total credited emission reductions or removals is **unknown**. The variability among those projects for which the issue materializes is **unknown**.

Un6: **Emissions from fires only consider harvested biomass:** All other biomass that would be burnt in case of a fire is not included in the estimation of fire emissions. These emissions occur in the baseline and the project scenario. However, their exclusion leads to **uncertainty**. The number of projects impacted by this is **unknown**. For those projects where this issue materializes, the impact on total credited emission reductions or removals is **unknown**, as it depends on the proportion of harvested biomass to not harvested biomass in the project. The variability among those projects for which the issue materializes is **unknown**.

OE9: **Estimation of emissions from illegal logging:** Expected illegal logging in the project scenario must be assessed ex-ante and ex-post. The methodology prescribes two ground-based methods to monitor illegal logging. Participatory rural appraisals (PRA) conducted every two years, and limited field sampling. If the PRA delivers no indication for illegal logging, emissions must not be monitored. If there is an indication of illegal logging, the area potentially impacted must be delineated and at least 1% of the area must be sampled. After application of the CDM tool for significance, only if a significant number of tree stumps is found, emissions must be estimated. From the methodology it is not clear whether the monitoring of illegal logging only applies to trees that would be harvested or to all trees. It is also not clear, whether this monitoring applies to undisturbed forest or not, which can be excluded from the calculation of carbon stock changes. This approach likely leads to **overestimation** of emission reductions or removals. Methods to assess illegal logging are not state of the art and even if illegal logging occurs, if it is not significant, it is excluded from quantification. If trees without commercial value, e.g., for fuelwood, are logged and the loss is not monitored this would also lead to an overestimation. The fraction of projects affected by this is **unknown**. The impact on total credited emission reductions or removals is estimated to be **low to medium**, assuming only low to medium levels of illegal logging would go undetected. We estimate there is a **low to medium** variability among the projects where the issue materialises, depending on the forest type and conditions that drive illegal logging.

OE10: **Flexibility in choosing the quantification approach for fossil fuel consumption from forestry and wood processing machinery:** Multiple options are provided to determine fuel consumption (common practice, peer reviewed literature, ranges with justification). This flexibility may lead project proponents to select non-conservative consumption levels when they include these emissions in their baseline. Even if the methodology states, that a conservative approach must be chosen, the flexibility may lead to **overestimation** The fraction of projects affected by this is likely to be **low** because it can be assumed that proponents may prefer to exclude this source for sake of simplicity. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%), as this is only a small fraction of total emissions. We estimate that there is **high** variability in the degree of overestimation among projects, because of the nature of forest operations.

Un7: **Lack of clarity regarding monitoring intervals**: The methodology does not give a clear indication when monitoring of carbon stock changes need to occur. Section 5.2 indicates "The minimum duration of a monitoring period is one year, and the maximum duration is 10 years.". Section 8.2.2. indicates that the area burnt must be monitored at least every five years and sampling for illegal logging must also occur every five years. While section 9.3.5 states: "carbon stock changes over time must be estimated by taking measurements in plots at each monitoring event. Monitoring events must take place at intervals of 5, or preferably 3 years." This leads to **uncertainty**. This issue applies to **all** projects. The impact on total credited emission reductions or removals is **unknown**. The variability among those projects for which the issue materializes is **unknown**.

Determination of leakage emissions

The main leakage risk arises from reduced harvesting levels. In the context of IFM projects, the main risk of leakage emissions is that harvesting outside the project area increases to make up for reduced harvesting within the boundaries of the IFM project. A decrease in harvest levels due to the project can cause three types of negative leakage effects: market leakage (World Bank 2021)[1], activity shifting leakage (Broekhoff et al. 2019)[2], and substitution effects. Market leakage occurs when changes of harvest levels inside the project cause a change of harvest levels outside the project, e.g., through timber prices. Activity shifting leakage occurs when wood production is directly relocated from the project forest area to other areas. Substitution effects occur when changes in harvest levels increase or decrease the use of alternative materials, such as plastics or cement, resulting in changes in emissions associated with the production, use and disposal of these substitutes. A reduction in harvesting can also induce an increase in afforestation activities. Depending on how the afforestation land has been previously used (e.g., agriculture), such afforestation could however also lead to greater deforestation elsewhere (e.g., if agricultural production is shifted elsewhere).

Increased harvesting can lead to temporary negative leakage effects. If harvest levels increase within the project area, e.g., due to increased productivity of the forest, this can result in "negative leakage" through less harvesting and less associated emissions outside the project area. However, these potential decreases of emissions outside the project area may be non-permanent, i.e., subject to reversal risk. Any reversals outside the project forest area would be difficult to identify, quantify and attribute to the project. It is, therefore, good practice not to credit such negative leakage, though some methodologies allow project proponents to quantify negative leakage and recoup any positive leakage deductions that have occurred previously or may occur in future reporting periods. While not accounting for negative leakage is good practice, it should be noted that negative leakage may lead to some further (temporary) emission reductions outside the project's accounting boundaries. Not accounting for negative leakage thus leads to a (temporary) underestimation of emission reductions (see Table 1).

Leakage emissions depend on various factors and are methodologically difficult to estimate. Estimating market leakage is particularly challenging as it requires assessing market forces and the responsiveness of regional forest production rates related to such market forces, both of which are time intensive, costly, and challenging to estimate (Richards und Andersson 2001; Guizar-Coutiño et al. 2022). Leakage is also challenging to assess temporally, as leakage effects may be delayed from the occurrence of a change in harvesting practices. Furthermore, it is difficult to establish the appropriate geographical boundaries for assessing leakage. Timber is a rather universal good that is traded globally. This means that, for many projects, leakage could also occur beyond national or regional boundaries.

A further challenge is that the degree to which leakage occurs depends on the quality of the wood products and the forest productivity in the project area and the forest areas where production would be shifted to. If the project forest area would, in the baseline scenario, have produced higher quality forest products or had a higher productivity than other forest areas in its region, and market or activity-shifting leakage occurs, the forest areas that respond to these forces (and harvest more) might not be able to provide the same quantity and quality of forest products per hectar of forest area. It might be needed to increase the level of harvest to provide a comparable quantity and quality of forest products. Vice versa, production could also be shifted to areas with more intensive forest management, thereby reducing the impacts of any leakage. Leakage rates also depend on the overall size of the areas that enroll in improved forest management, avoided deforestation of afforestation activities. Finally, estimating leakage requires development of data intensive models. These models

1 Market leakage: Upstream or downstream effects involving market response occur when a project activity changes market supply and demand and alternative providers or users of an input or product react to the change.

2 Activity shifting leakage: displacement of harvesting or land-use development that results in reduced harvest in one area but can cause an increase in harvesting or land-use development elsewhere.

are highly sensitive to changes in the researchers' selected parameters (Filewod und McCarney 2023). These factors make the estimation of leakage very uncertain.

Leakage is quantified in different metrics. Quantification methodologies and the relevant literature use different metrics of leakage rates that are not comparable. Leakage rates are usually related to either (changes in) harvest volumes or to the overall carbon stock changes within the project forest area. In quantification methodologies, leakage deductions are also applied to different terms: to the emission reductions or removals (ACR, VCS VM0003 and VM0012), to the difference between baseline and project harvest levels (CARB and CAR) or to harvesting levels in the baseline (VCS, VM0010) or to the emissions from relogging in the baseline (VCS, VM0005). The leakage deduction rates used in the methodologies are therefore not directly comparable to each other: the same leakage deduction applied to emission reductions or removals (or carbon stock changes) is more conservative than the same leakage rate applied to change in harvest levels.

Quantification methodologies use simplified approaches to account for leakage. Due to the methodological challenges with estimating market leakage, most quantification methodologies use default deductions to account for market leakage. Methodologies sometimes use a single default deduction (e.g., a deduction of 20%) and sometimes differentiate the deductions according to the leakage risk. Sometimes these deductions also depend on where harvesting is expected to be shifted to, i.e., whether forests outside the project area have higher or lower carbon stocks or higher or lower shares of merchantable timber. Many methodologies also require monitoring for any activity shifting leakage within the forest region and quantifying associated emissions. Others require demonstrating that leakage due to activity shifting is likely to be small. None of the assessed methodologies addresses leakage due to the substitution of timber by other materials, such as plastics or cement.

Leakage is likely to be very large for IFM projects. For projects that produce timber in the baseline and reduce the level of harvesting, leakage is likely to be very large. While such projects enhance carbon stocks with the project area, they do not alter the demand for timber or other forest-related products. Less supply of timber could increase prices and, depending on the price elasticity of demand, reduce overall timber use. However, a reduction in timber use could then lead to leakage emissions associated with the production of substitutes (e.g., plastics, concrete, etc.).

A review of studies on leakage rates suggests that leakage levels are likely to be high but vary depending on the region, the mitigation measure and other factors. Harvest leakage rates in the United States are assessed at 42-95% (Gan und McCarl 2007), 84% (Wear und Murray 2004), and 70-85% (Nepal et al. 2013). Murray et al. (2004) conclude that domestic leakage rates (i.e., not considering international leakage) in the United States could vary from less than 10% to more than 90%, depending on the activity and region. In China, a study estimates that projects targeting reductions in harvest levels will cause leakage rates of 80-89% (Hu et al. 2014). Another study evaluated leakage from forestry projects in Norway at 60-100% (Kallio und Solberg 2018). A study of Bolivian forest harvest reduction projects estimated leakage rates at 2-38% (Sohngen und Brown 2004). These comparably low rates of leakage have been identified by the authors as being specific for small countries with rather limited access to timber and capital markets. Indeed, a key factor for leakage rates is how far the market extends beyond the region in which the activities occur, noting the global market for wood products (Filewod und McCarney 2023). The differences between countries likely relate to the countries' level of integration into the global market for wood products (Haya et al. 2023). Daigneault et al. (2023) use a dynamic global forest sector model to estimate the leakage effects of extended rotations and permanent set aside under varying implementation rates and conditions. They conclude that leakage rates vary widely across forest-type, project, and time. If all forest types can implement forest carbon projects, they estimate that for extended rotation carbon leakage will range from +19 to +54% and harvest leakage from -6% to +40%. Overall, this suggests that while leakage rates may differ strongly depending on the specific conditions, the overall level of leakage is likely to be high for measures that reduce harvesting at existing timber plantations.

In addition to the leakage rate, an important factor in assessing leakage effects is the degree to which the emission reductions or removals in the project forest area are achieved through reduced harvesting or through other measures. On-site carbon stocks may be enhanced by directly reducing timber harvest or through activities that primarily have other targets (but may indirectly also affect harvest levels), including measures to reduce natural disturbances, such as reducing forest fires; measures to reduce anthropogenic disturbances, such as implementing reduced impact logging; or measures to increase forest productivity, such as implementing enrichment planting. The degree to which less harvesting or other measures contribute to emission reductions or removals is a key consideration for determining leakage deductions that are applied to the net emission reductions or removals within the project forest area. This is because the necessary level of the leakage deduction is a product of the fraction of emission reductions or removals achieved through less harvesting and the leakage rate. The impact of these two factors on the required leakage deduction is illustrated in Table 2 below.

Table 2 Required leakage deduction to emission reductions or removals within the project forest area as a function of the leakage rate and the share of on-site emission reductions or removals that occur due to less harvesting

		Share of on-site emission reductions or removals that occur due to less harvesting				
		0%	**25%**	**50%**	**75%**	**100%**
Leakage rate (i.e. share of harvesting that shifts elsewhere)	**20%**	0%	5%	10%	15%	20%
	40%	0%	10%	20%	30%	40%
	60%	0%	15%	30%	45%	60%
	80%	0%	20%	40%	60%	80%
	100%	0%	25%	50%	75%	100%

Source: Own illustration. Note that we do not consider here the effect that the forests where timber production is shifted to may have different features.

For many projects, reducing harvest levels could make up a significant share of emission reductions or removals in the project forest area. For many IFM activities, reducing harvest levels relative to the baseline scenario is likely to be an important cause for increasing removals or avoiding emissions within the forest project area, for two reasons:

- First, in most cases, managed or logged forests, which form the baseline situation for IFM projects, do not have significant levels of natural mortality. Natural mortality, which limits the increase in carbon stocks in unmanaged forests, plays a stronger role at higher forest stand densities that are typically not reached in managed forests. This implies that a change in harvest levels directly leads to an increase or decrease in carbon stocks in the forest.
- Second, reducing harvest levels is the main measure implemented under ER and PC activities and is likely to play a significant role in AD and RIL activities. While projects with these activities may also take measures to reduce natural disturbances, such as forest fires, this is likely to contribute a minor share to overall emissions reductions or removals within the project forest area. By contrast, in the case of IP activities, any (temporary) reduction in harvest levels may play a minor

role. When projects combine different activities, the overall contribution of less harvesting to emission reductions or removals in the project forest area may be difficult to estimate. However, we estimate that in forests managed by large-scale timber operations less harvesting is likely to play the main role.

Leakage deductions applied in quantification methodologies appear overall too low. Quantification methodologies often prescribe default leakage deductions in the order of 10% or 20%. Moreover, leakage beyond national boundaries and leakage due to substitution effects are generally not considered. Given that reducing harvesting levels is one of the key means to achieve increases in carbon stocks in the project forest area, leakage effects are likely to be significantly underestimated and can lead to a significant overestimation of emission reductions or removals.

The geographic boundaries to determine market leakage are the country borders in which the project area is located. To address market leakage the net emissions from planned timber harvest in the baseline are multiplied by a leakage factor. The methodology defines the leakage factor as a "dimensionless number with values between 0 and 1 assigned ex ante on the basis of a comparison between the ratio of merchantable biomass to total biomass across all strata in the base year, and the ratio of merchantable biomass to total biomass of the country's forest estate where harvesting would likely be displaced to." Base year is understood to be the inventory year used to determine volumes of merchantable timber to establish the timber harvest plan. The term is only used twice in the methodology and not further defined (see sections 6.3. and 8.3.2).

For market leakage the methodology requires that project proponents determine the ratio merchantable biomass total biomass in each stratum (MB/TB) and compare it to the ratio of merchantable biomass to total biomass in a comparable forest type in the country MBf/TBf. The leakage factors in Table 3 are then applied.

Table 3 Leakage deduction rate estimation based on forest type

Forest type comparison (forest where leakage is directed versus forest where project occurs)	Leakage rate to be applied
Ratio of merchantable biomass to total biomass is more than 15% less	70%
Ratio of merchantable biomass to total biomass is in between 15% more and less	40%
Ratio of merchantable biomass to total biomass is more than 15% more	20%

OE11: **Option to apply a leakage factor of 0**: Project proponents can apply a leakage factor of 0 if they can demonstrate that "no-market effect leakage will occur" in the country. For this they need to demonstrate that no concessions are being assigned, extracted timber volumes cannot be increased within existing concessions and no or only de minimis illegal logging occurs in the country. It is not specified when this demonstration needs to occur and whether it must be recurrent. If such a demonstration were to be possible, it should be repeated frequently as it is likely that at least one of the criteria above would change over time. We consider this to be a highly uncertain approach, with potentially high impact on the estimation of leakage emissions that leads to potentially large **overestimation**. Especially since the project type reduces all timber output. The fraction of projects affected by this issue is assumed to be **low**, as we expect few countries where a demonstration of zero leakage is possible. The impact on total credited emission reductions or removals is estimated to be **medium to high**, depending on the baseline harvest levels. We estimate that there is a **medium to high** variability in the degree of overestimation, depending on the forest type and project activity.

OE12: **No appropriate consideration of leakage due to activity shifting.** The methodology does not consider any activity shifting that may occur to lands owned by other entities. This is likely to lead to **overestimation** of emission reductions or removals but the number of projects affected is **unknown**, as it depends on the project implementing agents. Where this issue materializes, the impact on total credited emission reductions or removals is estimated to be **low to medium** (more than 30%) because considerable leakage might occur. The variability in the degree of overestimation among projects is **unknown**.

OE13: **Confinement of leakage consideration to the national boundaries of the host country**. A rate of zero leakage may be assumed for market leakage that is expected to shift timber production outside of the project country. However, timber is a globally traded product and leakage is generally assumed in the literature to occur beyond the boundary of the host country. This provision leads to **overestimation** of emission reductions or removals and is likely to affect a **high** number of projects that apply the methodology. The impact on total credited emission reductions or removals is estimated to be **medium** (between 10 and 30%) assuming that in many cases considerable shares of leakage can be attributed to shifts to forests outside the project country. We estimate that there is **medium** variability (±30%) in the degree of overestimation among projects, depending on the forest type and activities.

OE14: **Leakage deductions are likely to be lower than overall scientific literature**: The proposed leakage discount factors appear significantly lower than the degree of likely leakage according to the relevant literature. The provision to base the leakage factor on the share of merchantable biomass aims to reflect that shift of wood production can affect forests outside the project area differently, depending on the relative share of merchantable timber. This differentiation captures emissions occurring through leakage more accurately than global leakage rates. However, the leakage deductions applied can still be considered relatively low compared to scientific studies. This leads to **overestimation** of emission reductions or removals achieved by the project. This is likely to affect a **high** number of projects that apply the methodology. The impact on total credited emission reductions or removals is estimated to be **high** (more than 30%).[3] This is because for activities shifting from logging to protecting forests the emission reductions or removals are mainly achieved by reductions in harvesting, while at the same time leakage rates are likely to be high for timber operations that are eligible under this methodology. The variability among projects is estimated to be **high** (over 30%).

OE15: **No consideration of leakage due to substitution of other materials.** The methodology does not consider the risk of leakage due to substitution of timber by other materials (e.g., plastic, cement). This may lead to overestimation of emission reductions or removals. The number of projects affected is **unknown**. Where this issue materializes, the impact on total credited

[3] To demonstrate the magnitude of the risk, we use a simplified example. We assume that the actual (unknown) leakage rate would be 80%, which is representative of a typical level of leakage reported by most published literature. In projects with forests that have similar average carbon stocks compared to the mean national forest carbon stock, a 40% leakage deduction is applied to net emissions from planned timber harvest in the baseline. We further assume that 80% of the increase in carbon stocks in the project forest area occurs due to a decrease in harvesting levels and that the effect of leakage in other forest areas is similar to that in the project forest area. Under these assumptions, the overestimation of total credited emission reductions or removals would be 89%: the methodology would credit 68% (100% - 40% * 80%) of the increase of carbon stocks within the project forest area levels, while actually only 36% (100% - 80% * 80%) should be credited.

emission reductions or removals is estimated to be **low**. The variability among projects in the degree of overestimation is **unknown**.

Summary and conclusion

Table 4 summarizes this assessment of the VCS Methodology VM0010, Methodology for Improved Forest Management: Conversion from Logged to Protected Forest. For each of the elements discussed above it summarizes the potential impact on the quantification of emission reductions or removals.

Table 4 Relevant elements of assessment and qualitative ratings

Element	Fraction of projects affected by this element[4]	Average degree of under- or overestimation where element materializes[5]	Variability among projects where element materializes[6]
Elements likely to contribute to overestimating emission reductions or removals			
OE1: Emissions from fossil fuel combustion only included in the baseline calculation	All	Unknown	Unknown
OE2: Exclusion of emission from production, transportation, and disposal of alternative materials (ES9)	High	Unknown	Unknown
OE3: Flexibility in choosing the value for the fraction of carbon in biomass	Unknown	Low	Medium
OE4: Flexibility in setting the baseline scenario	High	Unknown	Unknown

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

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

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

Element	Fraction of projects affected by this element[4]	Average degree of under- or overestimation where element materializes[5]	Variability among projects where element materializes[6]
OE5: Adverse selection due to common practice baseline	Unknown	Unknown	Unknown
OE6: Choice of reference area in common practice baselines	Unknown	Unknown	Medium
OE7: Flexibility in choosing the forest regrowth rate post timber harvest	Unknown	Medium	Unknown
OE8: Flexibility in the estimation of harvested wood product classes	Unknown	Unknown	Unknown
OE9: Estimation of emissions from illegal logging	Unknown	Low - Medium	Low - Medium
OE10: Flexibility in choosing the quantification approach for fossil fuel consumption from forestry and wood processing machinery	Low	Low	High
OE11: Option to apply leakage factor of 0	Low	Medium - High	Medium - High
OE12: No appropriate consideration for any leakage due to activity shifting	Unknown	Low - Medium	Unknown
OE13: Confinement of leakage consideration to the national boundaries of the host country	High	Medium	Medium
OE14: Leakage deductions lower than overall scientific literature	High	High	High
OE15: No consideration of leakage due to substitution of other materials	Unknown	Low	Unknown
Elements likely to contribute to underestimating emission reductions or removals			
UE1: Exclusion of BGB (CP3)	All	Medium	Medium
UE2: Exclusion of standing DW (CP4)	All	Medium	Unknown
UE3: Exclusion of lying DW (CP5)	All	Low	High
UE4: Exclusion of SOC (CP8)	All	Low	Unknown
UE5: Exclusion of combustion emissions from production, transportation,	High	Unknown	Unknown

Element	Fraction of projects affected by this element[4]	Average degree of under- or overestimation where element materializes[5]	Variability among projects where element materializes[6]
and disposal of wood products (ES8)			
UE6: Exclusion of methane emissions from decomposition of HWP (ES3)	All	Low	Unknown
UE7: Emissions from fire disturbance exclude emissions from extracted timber for forest infrastructure	Unknown	Low	Unknown
Elements with unknown impact			
Un1: Exclusion of non-tree AGB (CP2)	All	Low	Unknown
Un2: Static baseline	High	High	High
Un3: Uncertainty with regards to timber harvest plans	All	Medium	Unknown
Un4: Decay rate of HWP	High	Low	Medium
Un5: Emissions from fires do not consider biomass increment	Unknown	Unknown	Unknown
Un6: Emissions from fires only consider harvested biomass	Unknown	Unknown	Unknown
Un7: Lack of clarity regarding monitoring intervals	All	Unknown	Unknown

The table shows that there are many potential sources of overestimation, underestimation, and uncertainty. Based on our assessment of the elements in the table, we conclude that the methodology is likely to lead to overestimation of emission reductions or removals and that the degree of overestimation is likely to be large (i.e., larger than 30%). This corresponds to a score of 1 according to the CCQI methodology (see page 2).

In our assessment, the most significant issues relate to baseline establishment, carbon stock quantification and leakage quantification. The methodology provides considerable flexibility and leeway on how to establish the baseline (OE4 to OE6). Similarly, the methodology includes various provisions that could lead to an overestimation of carbon stocks or emission sources (OE7 to OE10). The leakage deductions are low compared to the scientific literature and some forms of leakage may not be appropriately considered (OE11 to OE15). Other sources of potential overestimation include the flexibility in choosing the value for the fraction carbon in the biomass (OE3) and the exclusion of some emission sources or carbon pools (OE1 and OE2). The methodology also includes provisions that may lead to underestimation, most importantly the exclusion of belowground biomass (UE1) and the exclusion of standing DW (UE2). In our assessment, the potential sources of underestimation do not compensate for the potential sources of overestimation.

Next to the risk of overestimation, a key feature of all IFM activities is that there are many sources of uncertainty. The use of a static baseline (Un2) is the most significant contributor to overall uncertainty. Overall, in our assessment the many and significant uncertainties lead to a large overall uncertainty in the quantification of emission reductions or removals. As the emissions impact of the projects could be smaller than the baseline uncertainty, there is also considerable uncertainty whether the credited emission reductions or removals are attributable to the implementation of the project (which is sometimes referred to as “signal-to-noise issue”).

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