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 (IFM)**
Assessment based on carbon crediting program documents valid as of:	**16 May 2023**
Quantification methodology:	**American Carbon Registry (ACR) IFM in non-Federal U.S. Forestlands Version 2.0**
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 American Carbon Registry (2023): Improved Forest Management in Non-Federal U.S. Forestlands, Version 2.0. https://acrcarbon.org/wp-content/uploads/2023/10/ACR-IFM-Non-Federal-v2.0.pdf

2 American Carbon Registry (2022): ERT Calculator IFM on Non-Federal U.S. Forestlands v2.0. https://acrcarbon.org/wp-content/uploads/2023/03/ACR_IFM_ERTcalculator_Methodology_v2.0_2022.07.06.xlsx

3 American Carbon Registry (2022): Description of NPV discount rates IFM on Non-Federal U.S. Forestlands v2. https://acrcarbon.org/wp-content/uploads/2023/03/ACR_IFM_FMPaddendum_Template_2022.07.07.docx

4 American Carbon Registry(2023): FMP Addendum Template IFM on Non-Federal U.S. Forestlands v2.0. https://acrcarbon.org/wp-content/uploads/2023/03/IFMv2.0-References.zip

5 ACR Improved Forest Management: A Primer. https://acrcarbon.org/wp-content/uploads/2023/03/Improved-Forest-Management-Primer.pdf

6 ACR Standard, Version 7.0, December 2020. https://acrcarbon.org/wp-content/uploads/2023/07/ACR-Standard-v7.0-Dec-2020.pdf

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 the American Carbon Registry (ACR) Improved Forest Management (IFM) in non-Federal U.S. Forestlands Version 2.0, which was released in July 2022. IFM is defined by the ACR IFM V2.0 as "projects that reduce emissions by exceeding baseline forest management practices. Removals are quantified for increased sequestration through retention of forest growth when project activities exceed the baseline." The protocol provides an overview of IFM project types in the ACR Improved Forest Management: A Primer; however, it does not specify a set list of activities eligible for this project type. Protocol reference documentation was reviewed as part of the assessment, in particular the ACR IFM in non-Federal U.S. Forestlands v2.0 and the ACR Standard, v7.0.

Under this protocol, all projects must meet a set of sustainable management requirements over the crediting period if commercial harvesting occurs. The crediting period is 20 years, and the minimum project term is 40 years.

The ACR IFM methodology accepts a broad array of activities within the IFM project type. All five types of activities, as defined above, appear to be eligible under the ACR IFM methodology).

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 ACR IFM methodology includes the following carbon pools and emission sources in the project boundary: CP1, CP3, CP9, ES2, thus covering the biggest expected pools and sources. For any decreases in carbon pools and/or increases in emission sources, the methodology also sets a de minimis threshold of 3% of the final calculation of emission reductions and removals. Any decreases in these carbon pools and/or increases in GHG emission sources must be included if they exceed the de minimis threshold. Any exclusion using the de minimis principle shall be justified using fully documented ex ante calculations. Our interpretation of the methodology is that optional pools listed below (CP4, CP5) shall be included if they exceed the de minimis threshold. The methodology also appears to assume that litter and SOC pools are always below de minimis threshold and that non-CO_2 emissions from burning biomass are negligible.

Other carbon pools or emission sources, as identified in Table 1 above, are excluded. This may lead to over- or underestimation of emission reductions or removals (OE or UE) or introduce uncertainty (Un) in their quantification. The effects are summarized in Table 2.

Table 2 Effects of the exclusion of carbon pools and emission sources

Carbon pool (CP) or emission source (ES) excluded by Methodology	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
CP2: Non-tree AGB	UE1	Un1	Un1	UE1	Un1
Optional CP4: Standing DW, including roots	Un2	UE2	Un2	UE2	Un2
Optional: CP5: Lying DW	UE3	UE3	Un3	UE3	Un3
CP6: Slash DW	OE2	OE2	Un4	OE2	Un4
CP7: Litter	-	-	-	-	-
CP8: SOC	UE4	UE4	Un5	Un5	Un5
ES1: Burning of biomass (e.g., prescribed burns)	-	OE3	OE3	-	OE3
ES3: Methane HWP decay emissions	UE5 (short term) OE4 (medium term)	UE5	Un6	UE5	Un6
ES4: Nutrient application	-	-	OE5	-	Un7
ES5: Mobile combustion from site preparation	-	-	-	-	-
ES6: Mobile combustion from project operation	-	UE6	-	Un8	-
ES7: Stationary combustion from project operation	-	-	-	-	-
ES8: Combustion emissions from production, transportation, and disposal of forest products	UE7 (short term) OE6 (medium term)	UE7 (short and medium term)	Un9 (short term) OE6 (medium term)	UE7 (short and medium term)	UE7 (short term) Un9 (medium term)
ES9: Combustion emissions from production, transportation, and disposal of	OE7 (short term)	OE7 (short and medium term)	Un10 (short term)	OE7 (short and medium term)	OE7 (short term)

Carbon pool (CP) or emission source (ES) excluded by Methodology	Extended rotation (ER)	Production to conservation (PC)	Increasing productivity (IP)	Reduced impact logging (RIL)	Avoiding degradation (AD)
alternative materials to forest products	UE8 (medium term)		UE8 (medium term)		Un10 (medium term)

Note: (-) indicates changes that are not material, therefore, not considered further in our assessment

The exclusion of several carbon pools or emission sources may lead to overestimation of emission reductions or removals:

OE1: The **non-tree aboveground biomass** (CP2) carbon pool is expected to decrease relative to the baseline in a material way under projects implementing IP activities, due to thinning of the forest. The exclusion of this carbon pool therefore leads to an **overestimation risk**. This is likely to occur in **a medium to high** fraction of projects implementing IP activities since thinning of non-tree biomass is a common way to allow trees to grow faster. For those projects where this issue materializes, the impact on total credited emission reductions or removals is estimated to be **low** (less than 10%). We estimate that there is **unknown** variability among projects in the degree of overestimation, depending on the forest type and activities undertaken.

OE2: The **slash deadwood** (CP6) pool is expected to decrease relative to baseline in a potentially material way under projects implementing ER, PC, and RIL activities as trees are harvested less frequently and/or more selectively. The exclusion of this carbon pool therefore leads to an **overestimation risk**. This is likely to occur in a **high** fraction of projects implementing ER, PC, and RIL activities. For those projects where this issue materializes, the impact on total credited emission reductions or removals is estimated to be **low** (less than 10%). The variability among projects is **unknown**, as this depends on the forest type and specific activities related to reducing the impact of harvesting.

OE3: Emissions associated with **biomass burning** (ES1) are likely to increase relative to the baseline in projects implementing PC, IP, and AD activities as prescribed burns may be used to reduce fire risk and improve forest health/productivity. The exclusion of this emission source therefore leads to an **overestimation risk.** The number of projects affected is **unknown**. For those projects where this issue materializes, the impact on total credited emission reductions or removals is assumed to be **low** (less than 10%). The variability among projects is **unknown**.

OE4: In the medium-term harvest levels might increase as a result of ER project activities. In that case methane emissions from decomposition of **HWP** (ES3) may increase relative to the baseline in a material way. Exclusion of the emissions from wood decay leads to **overestimation** in the medium-term. This is likely to occur in **a medium number of** projects implementing ER activities. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%) for ER. There is **unknown** variability in the degree of overestimation among projects, depending on the activities undertaken.

OE5: Increased **fertilization** (ES4) may occur as part of IP activities resulting in a material change in emissions. If excluded, this can lead to overestimation. This is likely to apply to a **low** fraction of projects implementing IP activities, the impact on total credited emission reductions or removals is expected to be **low** (less than 10%). The variability among projects is **unknown**.

OE6: Emissions from **mobile combustion** from production, transport, and disposal of wood products (ES8) in projects with ER and IP activities are expected to increase relative to the baseline in a potentially material way due to anticipated higher harvesting levels in the medium term. The exclusion of this emission source therefore leads to an **overestimation risk.** This is likely to be the case for a **high** fraction of projects implementing ER and IP activities. The impact on total credited emission reductions or removals is **unknown**. Furthermore, the variability among projects is also **unknown**.

OE7: Emissions from **combustion** from production, transport, and disposal of alternative materials (ES9) (i.e., leakage) in projects implementing ER and AD activities (short term) and PC and RIL activities (short and medium term) are expected to increase relative to the baseline due to anticipated lower harvesting levels. Excluding this emission source therefore leads to an **overestimation risk.** This is likely to be the case for a **high** fraction of projects implementing ER, AD, PC, and RIL activities. The impact on total credited emission reductions or removals is **unknown**. Furthermore, variability is also **unknown**.

The exclusion of several carbon pools or emission sources may lead to **underestimation** of emission reductions or removals:

UE1: The **non-tree aboveground biomass** (CP2) carbon pool is expected to increase relative to baseline in a potentially material way under ER and in a material way under RIL activities due to less disturbance. The exclusion of this carbon pool may therefore lead to **underestimation**. This is likely to occur in **a high** fraction of projects implementing ER and RIL activities. For the projects where this issue materializes, the impact on total credited emission reductions or removals is estimated to be **low** (less than 10%). The variability among projects is **unknown**, as this depends on forest type and activities undertaken.

UE2: The **standing deadwood** pool (CP4) is expected to increase relative to baseline in a material way under PC and RIL activities due to decreased harvesting and disturbance. Exclusion leads to **underestimation.**[1] This is likely to occur in **all** projects with PC and RIL activities. There can be a **medium** (10-30%) impact on total credited emission reductions or removals depending on forest type and specific activities that are undertaken. There is **unknown** variability among projects.

UE3: The natural **lying deadwood** pool (CP5) is expected to increase relative to the baseline in a potentially material way under ER, PC, and RIL activities with exclusion leading to **underestimation**. In an extended rotation, the longer time between harvests allows trees to lose more branches and create more lying DW. When implementing RIL, more trees are left after harvesting to naturally drop DW and less is removed during harvesting making this effect more significant and material. This is likely to affect **all** projects implementing ER, PC, and RIL activities. There is expected to be a **low** (less than 10%) impact on total credited emission reductions or removals to projects that implement ER, PC, and RIL activities. **High** variability (over 30%) is assessed for projects implementing ER, PC, and RIL activities as the level of changes varies depending on forest type and specific activities that are undertaken.

UE4: The **SOC** pool (CP8) may increase in a potentially material way in projects implementing ER and PC activities due to decreased disturbance relative to baseline. **The exclusion of this pool leads to underestimation.** This is likely to occur in a **high** fraction of projects implementing ER and PC activities since increasing intervals between harvesting or stopping

[1] Inclusion is optional.

commercial 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 the length of the extended rotation (for ER activities).

UE5: When harvest levels decrease as a result of project activities, methane emissions from decomposition of **HWP** (ES3) are reduced relative to baseline in a material way. Exclusion of the emissions from wood decay leads to **underestimation**. This is likely to occur in **all** projects with ER (short term) and PC activities and a **high** number of projects with RIL activities. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%) for ER, PC, and RIL. There is **unknown** variability in the degree of underestimation among projects, depending on the activities undertaken.

UE6: Emissions from **mobile combustion** from project operation (ES6) can change in a potentially material way in projects implementing PC activities. This source is expected to have a potentially material decrease due to the termination of wood harvest for timber production. Exclusion of this emission sources may therefore lead to **underestimation.** This is likely to occur in a **high** fraction of projects implementing PC activities. For those projects where this issue materializes, the impact on total credited emission reductions or removals is likely to be **low** (less than 10%). We assume that there is **high** variability (over 30%) in the degree of underestimation among projects, as this depends on the forest type and the management activities related to conservation.

UE7: Emissions from **mobile combustion** from production, transport, and disposal of wood products (ES8) in projects implementing ER and AD (short term), and PC and RIL (short and medium term) 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 implementing ER, AD, PC, and RIL activities. The impact on total credited emission reductions or removals is **unknown**. Furthermore, the variability among projects is also **unknown**.

UE8: Emissions from **mobile combustion** from production, transport, and disposal of alternative materials (ES9) in projects implementing ER and IP activities in the medium term is expected to decrease relative to the baseline in a potentially material decrease due to anticipated higher 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 implementing ER and IP activities. The impact on total credited emission reductions or removals is **unknown**. Furthermore, the variability among projects is also **unknown**.

For some carbon pools or emission sources, it is not clear whether their exclusion would lead to over- or underestimation. In this case, the exclusion introduces uncertainty in the estimation of emission reductions or removals:

Un1: There are potentially material impacts to the **non-tree AGB** (CP2) for IP, PC, and AD activities. 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 implementing PC and AD activities and a **medium** number of projects implementing IP activities. 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.

Un2: The **standing deadwood** pool (CP4) may change in magnitude in either direction relative to baseline in a potentially material way under ER, IP, and AD activities depending on project context. When implementing ER activities, standing DW may be harvested, used as firewood, or allowed to accumulate between rotations. Exclusion leads to **uncertainty**.[2] This is likely to occur in **all** projects with ER, IP, and AD activities. The uncertainty introduced by this issue adds a **medium** (10-30%) degree of uncertainty to the estimation of total credited emission reductions or removals and depends on forest type and specific activities that are undertaken. There is **unknown** variability in this uncertainty among projects.

Un3: The natural **lying deadwood** pool (CP5) may change in magnitude in either direction relative to baseline in a potentially material way under projects implementing IP and AD activities depending on project context. The exclusion of this carbon pool therefore **leads to uncertainty**.[3] This is likely to affect **all** projects implementing IP and AD activities since these projects affect natural lying deadwood. This issue introduces a **low** degree of uncertainty (less than 10%) to the estimation of total credited emission reductions or removals. There is **high** variability (over 30%) in this uncertainty among projects, as this depends on forest type and the activities undertaken.

Un4: The **slash deadwood** pool (CP6) may change in magnitude in either direction relative to the baseline in a potentially material way for projects implementing IP or AD activities depending on the project context. The exclusion of this carbon pool therefore leads to **uncertainty**. This is likely to affect **all** projects implementing IP or AD activities since slash deadwood may change with changing harvesting levels. This introduces a **low** degree of uncertainty (less than 10%) to the estimation of total credited emission reductions or removals. There is **unknown** variability in this uncertainty among projects, as this depends on forest type and the activities undertaken.

Un5: The **SOC** pool (CP8) may change in magnitude in either direction relative to the baseline in a potentially material way for projects implementing IP, RIL, and AD activities depending on project context with exclusion leading to **uncertainty**. This is likely to occur in a **high** faction of projects since disturbance of the forest floor and turnover in carbon pools that serve as soil nutrient inputs is likely to occur in projects with harvesting. The impact on total credited emission reductions or removals is assumed to be **low** (less than 10%). There is **unknown** variability in this uncertainty among projects, depending on soil type and activities undertaken.

Un6: The methane emissions from decaying **HWP** (ES3) may change in either direction relative to baseline in a potentially material way under IP and AD activities depending on project context. **The** exclusion **of this source leads** to **uncertainty**. This is likely to occur in an **unknown** number of projects as IP and AD activities may or may not change the residence time of carbon in HWP produced by the forest. This issue adds a **low** (less than 10%) degree of uncertainty to the estimation of total credited emission reductions or removals. There is **unknown** variability in this uncertainty among projects, depending on forest type and activities undertaken.

Un7: Although broadcast **fertilization** (ES4) is not allowed under the methodology, other applications of nutrients may occur or be changed through the implementation of AD activities resulting in a potentially material change in emissions from this source. The

2 Inclusion is optional.
3 Inclusion is optional.

exclusion of this emission source therefore leads to **uncertainty**. This is likely to affect a **low** fraction of projects implementing AD activities. This introduces a **low** degree of uncertainty (less than 10%) to the estimation of total credited emission reductions or removals. There is **unknown** variability in this uncertainty among projects.

Un8: Emissions from **mobile combustion** (ES6) from project operations can change relative to the baseline in a potentially material way in projects implementing RIL activities. The direction of the change in emissions and the magnitude of change depend on the project context. The exclusion of this emission source therefore leads to **uncertainty.** This is likely to affect a **high** fraction of projects implementing RIL activities since these emissions are linked to harvesting activities. This issue adds an **unknown** degree of uncertainty to the estimation of total credited emission reductions or removals. There is **unknown** variability in this uncertainty among projects because it depends on the forest type and the specific RIL activities undertaken by the project.

Un9: **Combustion** emissions from production, transport, and disposal of wood products (ES8) may change in magnitude in either direction relative to baseline in a potentially material way under IP (short term) and AD (medium term) activities depending on project context. The exclusion of this emission source therefore leads to **uncertainty**. This is likely to affect **all** projects implementing IP and AD activities since these emissions are linked to harvesting activities. This issue adds an **unknown** degree of uncertainty to the estimation of total credited emission reductions or removals. There is **unknown** variability in this uncertainty among projects as this depends on the forest type and the activities undertaken.

Un10: **Combustion** emissions from production, transport, and disposal of alternative materials (ES9) may change in magnitude in either direction relative to the baseline in a potentially material way under IP (short term) and AD (medium) activities depending on project context. The exclusion of this emission source therefore leads to **uncertainty**. This is likely to affect **all** projects implementing IP and AD projects. This issue adds an **unknown** degree of uncertainty to the estimation of total credited emission reductions or removals. There is **unknown** variability in this uncertainty among projects because the uncertainty factor depends on market conditions.

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.

The ACR IFM methodology requires that carbon stocks be estimated by modeling forest management across the baseline period. Modeling must be conducted with a peer reviewed forestry model that has been calibrated for use in the project region and approved by ACR, such as the Forest Vegetation Simulator (FVS).

The mean carbon stock in aboveground biomass per unit area is estimated based on field measurements in sample plots. ACR recommends using existing inventory procedures such as the USDA Forest Inventory Analysis (FIA) program (U.S. Forest Service 2024) or from the 2003 IPCC Good Practice Guidance for LULUCF (IPCC 2003), but also allows project developers to develop their own inventory procedure. For baseline estimates of carbon stocks, plot data used for biomass calculations may not be older than 10 years. For project estimates of carbon stocks, plot data also cannot be older than 10 years throughout the duration of the project requiring periodical remeasurements. Plots may be permanent or temporary and they may have a defined boundary or use variable radius sampling methods. Stratification may be used to improve the modeling of management scenarios and precision of carbon stock estimates.

To determine biomass of live trees, one of the following three approaches can be used:

- Generalized allometric regression equations for estimating biomass from 10 species groups
- Biomass algorithms based on the regional volume equations from the USDA Forest Service National Volume Estimator Library, as employed by default in the FVS Fire and Fuels Extension
- Species specific volume and biomass estimators according to geographic region

A default value of 0.5 is used to determine the fraction of carbon in biomass.

Inclusion of the deadwood pool is optional. Where this pool is included[4], standing deadwood in the baseline scenario must be estimated using an approved growth model that predicts deadwood dynamics, if available. If a growth model approved for use by ACR does not predict deadwood

[4] Inclusion appears to be based on whether the pool meets the de minimis 3% threshold.

dynamics, the baseline harvesting scenario may not decrease deadwood by more than 50% through the crediting period. For standing deadwood, the same biomass estimation technique must be used as live trees, with adjustments for density and structural loss. To estimate carbon in lying deadwood, project developers must use the line intersect method to sample, then categorize material by decay level and wood type and adjust density accordingly. The protocol does not include slash deadwood as a distinct carbon pool.

The ACR IFM methodology estimates carbon in HWP by determining how much carbon in trees harvested is delivered to mills, associated mill efficiencies and estimating how much carbon remains in in-use wood products and in landfills for a period of 100 years after harvest. In the project scenario, carbon stored in the HWP pools is determined every year based on the amount of harvesting that has taken place. The baseline value is the twenty-year average of annual carbon remaining stored in wood products 100 years after harvest.

Uncertainty is defined as the weighted average error of each of the included/measurement pools. For measured or modeled carbon stock estimates and wood products, the confidence interval of the input inventory data is used. For wood products with measured and documented harvest volumes, a value of zero is to be used as the confidence interval. Model uncertainty is not considered.

Total uncertainty is a function of changes in baseline and project carbon stock estimates, including harvested wood products, and their associated uncertainties (ERT Calculator IFM on Non-Federal U.S. Forestlands v2.0). The ACR IFM methodology sets a statistical precision target of ±10% of the mean with 90% confidence. When total uncertainty is beyond this threshold, an uncertainty deduction of the total uncertainty minus 10% is applied. If total uncertainty is less than or equal to 10%, no uncertainty deduction is applied.

OE8: **Flexibility in approaches for quantifying carbon pools.** The methodology offers project developers numerous choices in quantifying carbon pools, including with regard to the sampling design, the models used, and the possibility of excluding deadwood carbon pools. While the methodology offers recommendations to utilize certain tools or guidelines, project developers have the possibility to deviate from these recommendations. Moreover, many parameters within these approaches depend on project developers' choices. This poses the risk that project developers select approaches or parameters that result in higher estimates. For how many projects this will lead to overestimation and the degree of overestimation are **unknown**, though it may be significant source of overestimation. The variability among projects in the degree of overestimation is also **unknown**.

OE9: The methodology prescribes using a default value of 0.5 for the fraction of carbon in the biomass. 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 **all** projects. 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 (±30%) in the overestimated amount.

UE9: If uncertainty exceeds 10%, an uncertainty deduction is applied to the emission reductions or removals, **resulting in an underestimation of calculated emission reductions or removals.** We assume that a **medium** number of projects have an error larger than 10% and are thus subject to a deduction. The impact on total credited emission reductions or removals is estimated to be **low to medium**. We estimate that there is **medium** variability (±30%) in the degree of the underestimation among projects.

Un11: The acceptance of 10% uncertainty may in some instances lead to underestimation of emission reductions or removals and may in some instances lead to overestimation. Overall, across many projects, we assume that there is no bias and that this would lead to some uncertainty in quantifying emission reductions or removals. We assume that an **unknown** number of projects exhibit uncertainty within the 10% range. However, project developers may be motivated to reduce uncertainty in estimating baseline and/or project carbon stocks to avoid uncertainty deductions. The degree of uncertainty is **low**. The variability in uncertainty among projects is **unknown**.

Un12: **No requirement to use stratification.** The methodology allows but does not require project developers to apply stratification in their sampling approaches. A lack of stratification may lead to some uncertainty (Grimault, Bellassen, Shishlov, 2018). It is **unknown** which proportion of projects utilize stratification and which do not. The degree of uncertainty and variability of uncertainty among projects are also **unknown**.

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 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).

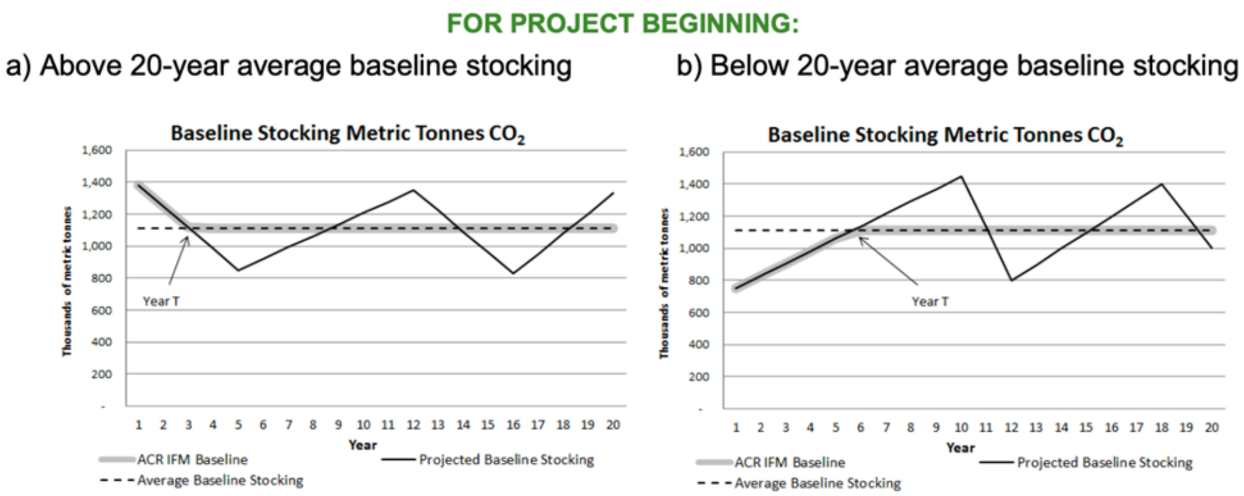
We estimate that the uncertainty in the future baseline *scenario* for IFM activities is on the order of magnitude of ±30%, given the long timespan of crediting in this sector and the various factors that could influence the level of future carbon stocks. This can have significant implications on the 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).

The ACR IFM methodology requires determining the baseline as the harvesting scenario that maximizes the Net Present Value (NPV) of the harvested wood products over a 100-year period. The discount rate (3-6%) is selected based on different classes of ownership for the forest land (Description of NPV discount rates IFM on Non-Federal U.S. Forestlands v2.0). The scenario with the highest NPV is used as baseline stocking over the 20-year crediting period. In principle, the *average* stocking level over the 20 years is set as the baseline for the 20-year crediting period. However, in the initial years of the 20-year period, the methodology sets the baseline at the modelled values for the stocking level, until the year in which modelled stocking levels reach the 20-year average level. An example of this is shown in Figure 1 below. The minimum project term is 40 years. Crediting periods may be renewed without any time limitation if all ACR requirements are met at the time of renewal. At each renewal, the baseline scenario must be reevaluated.

Figure 1 Baseline stocking levels diagram



If new legal constraints are enacted during a crediting period that legally prohibit the silvicultural practices or harvest levels identified as the baseline scenario, the baseline must be reassessed and re-modeled to reflect the changes and adjust the baseline for the remainder of the crediting period.

Required inputs for the establishment of the baseline scenario include the results of a recent forest inventory of the project lands, prices for wood products of grades that the project would produce, costs of logging, reforestation, and related costs, silvicultural treatment costs, and relevant carrying costs. The protocol stipulates that the ISO 14064-2 principle of conservativeness must be applied for the determination of the baseline scenario, however, it does not specify how this should be done.

OE10: **Project developers have leeway in modelling the baseline.** Modelling baseline carbon stocks is complex and relies on many assumptions and parameters that are associated with considerable uncertainty. There is a risk that project developers select parameters and use assumptions that tend to result in lower baseline carbon stocks. Information asymmetry makes verification of any complex modelling results challenging. This may lead to overestimation of emission reductions or removals. We estimate that the fraction of projects affected by this is likely to be **high** (more than two thirds of the projects). The impact on total credited emission reductions or removals is **unknown.** The variability among projects in the degree of overestimation is estimated to be **high** (over 30%).

Un13: **Use of a static baseline.** Once established, the baseline is not updated (see Figure 1), except if new legal constraints are enacted.[5] Nonetheless, it is likely that changes in economic conditions occur that would affect the baseline stocking levels over decadal time scales. The static baseline is therefore subject to an uncertainty risk. We assume that this could affect a **high** number of projects. We estimate that this leads to potentially **high** impacts in relation to the overall emission reductions or removals. The degree of variability among projects is likely to be **high** (over 30%), given that this depends strongly on local circumstances as well as global economic drivers. This is one the main sources of uncertainty in the protocol.

Determining project emissions and removals

Key quantification issues in the ACR IFM methodology, applicable to both baseline and project scenarios, are discussed above. In addition, the following issue is identified with regard to project emissions or removals:

OE11: **Flexibility in quantifying deadwood**. When deadwood is included in the accounting boundaries, the methodology provides two options to project developers estimate the deadwood stocks in the project scenario: they may assume that deadwood pools remain static between measurement events or they may use an approved growth model that predicts deadwood dynamics. This leads to a risk of overestimation because it allows project developers to select the option that may result in a higher calculated emission reductions or removals. The number of projects for which this leads to overestimation, the degree of overestimation for projects where this issue materializes, and the degree of variability among projects in the overestimation are **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

5 All legally binding constraints to forest management (with the exception of easements enacted less than 1 year before or less than 3 years after the project start date) must be considered in baseline modelling. These include all existing laws, regulations, legal rulings, deed restrictions, and other relevant regulatory frameworks (such as legally binding terms and conditions associated with the land acquisition, or donor funding restrictions regulating the amount or type(s) of timber harvest that can occur on the property). Best management practices to protect water, soil stability, forest productivity, and wildlife, as published or prescribed by applicable federal, state, or local government agencies are also considered legally binding constraints to forest management (ACR IFM Methodology).

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)[6], activity shifting leakage (Broekhoff et al. 2019)[7], 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 and 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

[6] 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.

[7] 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.

activities. Finally, estimating leakage requires development of data intensive models. These models are highly sensitive to changes in the researchers' selected parameters (Filewod and 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 and McCarl 2007), 84% (Wear and 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 and Solberg 2018). A study of Bolivian forest harvest reduction projects estimated leakage rates at 2-38% (Sohngen and 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 and 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 3 below.

Table 3 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 ACR IFM methodology addresses leakage due to activity shifting and market leakage.

Leakage due to activity shifting must only be considered if harvest levels decrease by more than 5% relative to the baseline. In this case, the methodology requires the landowners to demonstrate that any leakage due to activity shifting is not beyond de minimis threshold (3%).

The methodology uses leakage deductions to account for market leakage. The deduction is applied to the carbon stock change between the baseline and project during the reporting period. A tiered approach is used to determine the leakage deductions, as follows:

- Where the decrease in total wood products produced by the project relative to the baseline is less than 5% over the crediting period, no leakage deduction is applied.
- Where the decrease in total wood products produced by the project relative to the baseline is more than 5% but less than 25% over the crediting period, a leakage deduction of 10% is applied.
- Where the project is aggregated or employing a Programmatic Development Approach (PDA)[8] consisting of small private landowners (each owning less than 5,000 forested acres) and the project decreases total wood products produced by the project relative to the baseline by 25% or more over the crediting period, a leakage deduction of 20% is applied.
- Where the decrease in total wood products produced by the project relative to the baseline is 25% or more over the crediting period, a leakage deduction of 30% is applied.

The methodology stipulates that market leakage shall be accounted for at the regional scale, applied to the same general forest type as the project (i.e., forests containing the same or substitutable commercial species as the forest in the project area), and must be based on verifiable methods for quantifying leakage. The methodology does not allow crediting “negative leakage”. There is no mentioning of leakage due to substitution effects in the methodology.

OE12: **Leakage deductions are likely to be lower than overall scientific literature.** Our review of literature on leakage rates suggests that leakage rates are typically significantly higher, in particular in the United States. Therefore, a leakage deduction of 10-30% **likely results in overestimation of calculated emission reductions or removals**.

The materiality of this issue depends on the type of IFM activity. Leakage is likely to occur in projects implementing PC, AD, and RIL activities as the majority of these projects reduce

8 Combination of forest properties with multiple landowners into a single project to reduce per-acre transaction costs of monitoring, reporting, and verification (ACR Guidance for IFM Aggregation and PDA).

harvest levels. Furthermore, for ER activities, we assume that leakage occurs in the short term as harvest levels decrease and that negative leakage might occur in the medium term as harvest levels might increase. Therefore, for projects implementing PC, AD, RIL or ER (short term) activities we assume that overestimation is likely to occur in a **high** number of projects that the degree of overestimation of total credited emission reductions or removals is likely to be **high** (over 30%).[9]

For projects that only pursue IP activities, this risk is not deemed material, as harvest levels are likely to increase over the project term. For all IFM activities, there is likely to be **high** variability (over 30%) among projects with respect to the degree of overestimation because leakage is subject to market forces and local conditions.

OE13: **Unaccounted leakage.** Leakage is not accounted for if decreases in wood products produced are stated to be below certain thresholds. **This leads to overestimation of emission reductions or removals** in projects implementing ER (short term), PC, RIL, and AD activities**.** This is likely to affect a **low** number of projects because for many projects harvest levels may decrease by more than 5%. The impact on total credited emission reductions or removals is estimated to be **low** (less than 10%). We estimate that there is **medium** variability (±30%) in the degree of the overestimation among projects, depending on the forest type and activities. For projects that only pursue IP activities, this risk is not deemed material, as harvest levels are likely to increase over the project term.

OE14: **No appropriate consideration of any leakage due to activity shifting**. The methodology requires that project developers demonstrate that there is no activity shifting leakage beyond *de minimis* if harvest decreases by more than 5%. The methodology accepts management plans, historical records, adherence to sustainable management requirements, or other unspecified verifiable evidence to demonstrate that no activity shifting occurred (FMP Addendum Template IFM on Non-Federal U.S. Forestlands v2.0). Utilizing information about planned or historic harvesting levels may not necessarily be representative. If monitoring indeed demonstrates activity shifting leakage beyond *de minimis*, the methodology does not specify how the exceedance should be remedied and the number of credits generated adjusted. This poses the risk that activity shifting leakage effects are not appropriately captured. This may lead to overestimation of emission reductions or removals, especially for projects where harvest levels are expected to decrease. The number of projects affected is **unknown** as it depends on the project implementing agents and whether landowners enroll all the land they own and/or manage. The impact on total credited emission reductions or removals is estimated to be **low to medium** in projects implementing ER (short term), PC, RIL, and AD activities (0% - 30%). The variability in the degree of overestimation among projects is **unknown**. For projects that only pursue IP activities, this risk is not deemed material, as harvest levels are likely to increase over the project term.

[9] 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 the level of leakage in the US, as reported by published literature. 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. We further assume here that the production of wood products decreases by 20% relative to the baseline. In this case, the methodology requires to apply a leakage deduction of 10%. Under these assumptions, the overestimation of total credited emission reductions or removals would be 150%: the methodology would credit 90% (100% - 10%) of the increase of carbon stocks within the project forest area levels, while actually only 36% (100% - 80% * 80%) should be credited.

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. This is likely to be relevant for ER (short term), PC, RIL and AD activities because harvest is likely to decrease. The number of projects affected is **unknown**. Where this issue materializes, the impact on total credited emission reductions or removals is estimated to be **low**. The variability among projects in the degree of overestimation is **unknown**. For projects that only pursue IP activities, this risk is not deemed material, as harvest levels are likely to increase over the project term.

Un14: **Undifferentiated leakage rate**. Leakage can affect forests outside the project area differently, depending on the stocking level, species, or timber quality (e.g., if the project area would have produced high quality wood products, a larger leakage-responsive forest area may be harvested to match the quantity of high quality wood products). Leakage that leads to harvesting in non-project forest areas will lead to different amounts of emissions due to the difference in wood product quality. Therefore, the application of a flat leakage deduction, which does not incorporate the quality of wood products, is a source of uncertainty. This will affect all projects that implement ER (short term), PC, RIL, and AD activities (i.e., reduce harvest. For projects that only pursue IP activities, this risk is not deemed material, as harvest levels are likely to increase over the project term. The degree of uncertainty is estimated to be low (less than 10%). The variability among projects is likely to be **high** (over 30%) because it is subject to the forest type and management activities.

Summary and conclusion

Table 4 summarizes this assessment of the ACR Improved Forest Management Protocol. 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	Applicable activity type	Fraction of projects affected by this element[10]	Average degree of under- or overestimation where element materializes[11]	Variability among projects where element materializes[12]
Elements potentially overestimating emission reductions or removals				
OE1: Exclusion of non-tree AGB (CP2)	IP	Medium – High	Low	Unknown
OE2: Exclusion of slash DW (CP6)	ER, PC, RIL	High	Low	Unknown
OE3: Exclusion of biomass burning emissions (ES1)	PC, IP, AD	Unknown	Low	Unknown
OE4: Exclusion of methane emissions from HWP (ES3)	ER (medium term)	Medium	Low	Unknown
OE5: Exclusion of nutrient application emissions (ES4)	IP	Low	Low	Unknown
OE6: Exclusion of combustion emissions from production of wood products (ES8)	ER, IP	High	Unknown	Unknown
OE7: Exclusion of mobile combustion from production of alternative materials (ES9)	ER, AD (short term) PC, RIL (short and medium term)	High	Unknown	Unknown

10 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.

11 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.

12 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	Applicable activity type	Fraction of projects affected by this element[10]	Average degree of under- or overestimation where element materializes[11]	Variability among projects where element materializes[12]
OE8: Flexibility in choosing methods to quantify carbon pools	All	Unknown	Unknown	Unknown
OE9: Default value of 0.5 for the fraction of carbon	All	All	Low	Medium
OE10: Flexibility in baseline modelling methods	All	High	Unknown	High
OE11: Flexibility in estimating DW	All	Unknown	Unknown	Unknown
OE12: Leakage deduction lower than overall scientific literature	ER (short term) PC, RIL, AD	High	High	High
OE13: Unaccounted leakage	ER (short term) PC, RIL, AD	Low	Low	Medium
OE14: No appropriate consideration of any leakage due to activity shifting	ER (short term) PC, RIL, AD	Unknown	Low - Medium	Unknown
OE15: No consideration of leakage due to substitution of other materials	ER (short term) PC, RIL, AD	Unknown	Low	Unknown
Elements potentially underestimating emission reductions or removals				
UE1: Exclusion of non-tree AGB biomass (CP2)	ER, RIL	High	Low	Unknown
UE2: Exclusion of standing DW (CP4)	PC, RIL	All	Medium - High	Medium
UE3: Exclusion of lying DW (CP5)	ER, PC, RIL	All	Low	High
UE4: Exclusion of SOC (CP8)	ER, PC	All	Low	High
UE5: Exclusion of methane emissions from HWP (ES3)	ER (short term) PC (short and medium term)	All	Low	Medium
	RIL (short and medium term)	High	Low	Medium
UE6: Exclusion of mobile combustion emissions from project operation (ES6)	PC	High	Low	High
UE7: Exclusion of combustion emissions	ER, AD (short term)	High	Unknown	Unknown

Element	Applicable activity type	Fraction of projects affected by this element[10]	Average degree of under- or overestimation where element materializes[11]	Variability among projects where element materializes[12]
from production of wood products (ES8)	PC, RIL (short and medium term)			
UE8: Exclusion of combustion emissions from production of alternative materials (ES9)	ER IP (medium term)	High	Unknown	Unknown
UE9: Uncertainty deduction	All	Medium	Low - Medium	Medium
Elements with unknown impact				
Un1: Exclusion of aboveground biomass (CP2)	PC, AD	High	Low	Unknown
	IP	Medium	Low	Unknown
Un2: Exclusion of standing DW (CP4)	ER, IP, AD	All	Unknown	Unknown
Un3: Exclusion of lying DW (CP5)	PC, IP, AD	All	Low	High
Un4: Exclusion of slash DW (CP6)	IP, AD	All	Low	Unknown
Un5: Exclusion of SOC (CP8)	IP, RIL, AD	High	Low	Unknown
Un6: Exclusion of methane emissions from HWP (ES3)	IP, AD	High	Unknown	High
Un7: Exclusion of nutrient application emissions (ES4)	AD	Low	Low	Unknown
Un8: Exclusion of mobile combustion emissions from project operation (ES6)	RIL	High	Unknown	Unknown
Un9: Exclusion of combustion emissions from production of wood products (ES8)	IP (short term) AD (medium term)	All	Unknown	Unknown
Un10: Exclusion of combustion emissions from production of alternative materials (ES9)	IP (short term) AD (medium term)	All	Unknown	Unknown
Un11: Uncertainty within 10% of sampling error	All	Unknown	Low	Unknown
Un12: Lack of stratification	All	Unknown	Unknown	Unknown
Un13: Static baseline	All	High	High	High

Element	Applicable activity type	Fraction of projects affected by this element[10]	Average degree of under- or overestimation where element materializes[11]	Variability among projects where element materializes[12]
Un14: Undifferentiated leakage rate	ER (short term) PC, RIL, AD	All	Medium - High	High

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., over 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 and leakage quantification. The baseline modeling approach provides project developers considerable leeway in modelling the baseline which could potentially result in considerable underestimation of baseline carbon stocks (OE10). Furthermore, the relatively low leakage deductions compared to information from the literature (OE12) and the approach to account for leakage due to activity shifting (OE14) are other important sources of potential overestimation, especially for activities that mainly increase carbon stocks by reducing harvesting.

Other important sources of potential overestimation include the universal application of a default value of 0.5 for the fraction of carbon in the biomass (OE9) and flexibility in the selection of methods and/or parameters to quantify carbon stocks (OE8), next to several omissions of carbon pools or emission sources that may contribute to overestimation. In our assessment, the potential sources of underestimation do not compensate for the potential sources of overestimation. Although there is some variability in the risk of overestimation among the five types of IFM activities, we consider it likely that emission reductions or removals are overestimated by more than 30%, irrespective of the activities that are being implemented.

Next to the risk of overestimation, a key feature of all IFM activities is that there are many sources of uncertainty. In the ACR methodology, the most important sources of uncertainty relate to baseline estimates and leakage quantification. Despite the updating of the baseline every 20 years and in case of new legally binding requirements, the use of a static baseline is an important source of uncertainty in the quantification (Un13). Other uncertainties, mainly due to the exclusion of carbon pools or emissions sources and the quantification of carbon stocks, further increase the 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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