VCS Module

VMD0054

MODULE FOR ESTIMATING LEAKAGE FROM ARR ACTIVITIES

Version 1.0

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Sectoral Scope 14

Version 1.0 of this module was developed by **Terra Carbon** (Scott Settelmyer, David Shoch, John Furniss, Rebecca Dickson and Devon Ericksen) and **Silvestrum Climate Associates** (Igino Emmer), with contributions from Kyle Hemes and the ABACUS working group.

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1 SOURCES

This module is used in conjunction with the following VCS methodology:

- *VM0047 Afforestation, Reforestation and Revegetation*

The following CDM tool has informed the development of this module:

- *CDM AR-TOOL15: Estimation of the increase in GHG emissions attributable to displacement of pre-project agricultural activities in A/R CDM project activity, v2.0*

2 SUMMARY DESCRIPTION OF THE ARR LEAKAGE MODULE

Project activities applying the methodology *VM0047 Afforestation, Reforestation and Revegetation* must use this module to estimate leakage. This module accounts for leakage related to the displacement of pre-project agricultural activities (including grazing) and fuelwood collection activities. It includes leakage caused by the baseline agent (activity-shifting leakage) and other actors (market leakage).

The module estimates leakage based on two factors:

1) Reduction in agricultural commodities or fuelwood produced in the project area; and
2) Impact of leakage mitigation activities to enhance production outside the project area.

The module estimates the net production in the project area replaced in the market, the amount of new forest lands brought into production outside the project area, and the associated carbon stock emissions.

3 DEFINITIONS

In addition to the definitions set out in the latest version of the *VCS Program Definitions*, the following definitions apply to this module.

Agricultural activity

Production of an agricultural commodity on agricultural land

Agricultural commodity
Any (part of) plant, animal or animal product, produced on agricultural land

Fuelwood
Includes firewood or charcoal produced from woody biomass

Subsistence commodity
Agricultural commodity that is not destined for commercial markets

4 APPLICABILITY CONDITIONS

This module applies to estimating leakage emissions from ARR activities.

Projects using this module must meet all applicability conditions of the methodology *VM0047 Afforestation, Reforestation and Revegetation.*

5 PROCEDURES

The following steps must be taken to calculate leakage emissions from ARR activities. Leakage emissions from ARR activities must be assessed and calculated for a period of five years after the project start date, or project instance start date in the case of grouped projects. This is when the effects of leakage from displaced agricultural production are expected to occur.

5.1 Step 1: Determine Foregone Production in Project Area

The baseline agricultural and fuelwood commodity production in the project area must be demonstrated using historical production records for each commodity during the chosen reference period. Use the following process to select historical production for each commodity.

Part 1: Set the historical reference period

The historical reference period is the greater of either:

1) The 3-year period immediately preceding the project start date (or the project instance start date in the case of grouped projects); or
2) One complete crop rotation (where applicable).

Part 2: Document commodities displaced and production

Identify all commodities that will be displaced in the project area using historical production records.

Then, use historical data to document the amount of production of each commodity being displaced. Eligible types of historical production records are listed below. Data sources must be used in the following order, if available (e.g., if two data sources are available, the data source nearest the top of the list must be used):

1) Grower records (e.g., management logs, receipts or invoices, logs or files containing machine and/or sensor data); or
2) Remote sensing methods where requisite information on production can be reliably determined with these methods; or
3) The most recent regional (sub-national) average values derived from published census data; or
4) The most recent national average values derived from published census data; or
5) The most recent relevant commodity or ownership class where estimates have been disaggregated by those attributes and substantiated with a signed attestation from the farmer or landowner
6) For fuelwood production, use average above-ground biomass growth rates published by the IPCC applicable to the region if regional or national averages are unavailable.

Historical production data must be supported by verifiable evidence of grower records or remote sensing data, provided that remote sensing procedures have been peer-reviewed and tested in a similar region and for the agricultural activity displaced by the project activity.

$$BP_{j,t} = \frac{\sum_{h=1}^{H} p_{j,h}}{H} \times (1 + r_j)^t \tag{1}$$

Where:

$BP_{j,t}$	=	Baseline production in the project area for commodity *j* in year *t* (units of production)
$p_{j,h}$	=	Production in the project area for commodity *j* in year *h* of the historical reference period (units of production)
H	=	Duration of historical reference period (years)
r_j	=	Annual growth rate of yield for commodity *j* (percent) or the default value (2.5 percent)
t	=	1, 2, 3, …, *t* years elapsed since the project start date

Foregone production must be calculated for commodities that were produced in the project area during the historical reference period. The amount of foregone production in the project area is the difference between baseline production for each commodity produced in the project area and the monitored production of that same commodity in the project area:

$$FP_{j,t} = BP_{j,t} - MP_{j,t} \tag{2}$$

Where:

$FP_{j,t}$	=	Foregone production in the project area for commodity *j* in year *t* (units of production)
$BP_{j,t}$	=	Baseline production in the project area for commodity *j* in year *t* (units of production)
$MP_{j,t}$	=	Monitored production in the project area for up to five years after the project start date for commodity *j* in year *t* (units of production)
t	=	1, 2, 3, ..., *t* years elapsed since the project start date

5.2 Step 2: Determine the Impact of Leakage Mitigation Activities

The project proponent may implement activities outside the project area that reduce the amount leakage. The areas in which such activities take place are called leakage mitigation areas. Leakage mitigation is optional. Leakage mitigation must meet all of the following requirements:

1) Leakage mitigation must take place in geographically delineated areas within the same region of the project. The project proponent must justify the region for leakage mitigation by referencing the production region of the agricultural commodity that is displaced by the project;
2) Leakage mitigation areas must not overlap with:
    a) the project area;
    b) areas of other carbon projects; and
    c) leakage mitigation areas of other carbon projects.
3) The project proponent must sign an agreement with the landowner that explicitly allows the project proponent to uniquely claim the increase in productivity in this area as leakage mitigation from foregone production in the project area. The term of the agreement must be no less than five years from the project start date (or last project instance start date if a grouped project); and
4) Fuelwood production must only be mitigated through the establishment of new tree plantations.

Leakage mitigation ($LM_{j,t}$) is equal to the difference in production between the project and baseline scenarios of the leakage mitigation area. Baseline production in the leakage mitigation area is derived from production over the historical reference period as defined in Section 5.1.1 Baseline production of agricultural commodities in the leakage mitigation area is calculated as follows:

$$OBP_{j,t} = \frac{\sum_{h=1}^{H} op_{j,h}}{H} \times (1 + r_j)^t \quad (3)$$

Where:

$OBP_{j,t}$ = Baseline production in the leakage mitigation area for commodity *j* in year *t* (units of production)

$op_{j,h}$ = Baseline production in the leakage mitigation area for commodity *j* in year *h* of the historical reference period (units of production)

H = Duration of historical reference period (years)

r_j = Annual growth rate of commodity yields for commodity *j* (percent) or the default value of 0.025 (2.5 percent)

t = 1, 2, 3, …, *t* years elapsed since the project start date

Baseline production of fuelwood in the leakage mitigation area (*OBP*) is zero (i.e., only newly established tree plantations are eligible). Leakage mitigation is the monitored increase in production in the leakage mitigation area that is above the baseline levels of production and is calculated as follows:

$$LM_{j,t} = OMP_{j,t} - OBP_{j,t} \tag{4}$$

Where:

$LM_{j,t}$ = Leakage mitigation of commodity *j* in year *t* (units of production)

$OMP_{j,t}$ = Monitored production in the leakage mitigation area for commodity *j* in year *t* (units of production)

$OBP_{j,t}$ = Baseline production in the leakage mitigation area for commodity *j* in year *t* (units of production)

t = 1, 2, 3, …, *t* years elapsed since the project start date

The amount of foregone production that may result in leakage is calculated as follows:

$$l_{j,t} = MAX\ (FP_{j,t} - LM_{j,t}, 0) \tag{5}$$

Where:

$l_{j,t}$ = Amount of foregone production subject to leakage for commodity *j* in year *t* (units of production); minimum value is zero

$FP_{j,t}$ = Foregone production in the project area of commodity *j* in year *t* (units of production)

$LM_{j,t}$ = Leakage mitigation of commodity *j* in year *t* (units of production)

t = 1, 2, 3, …, *t* years elapsed since the project start date

Leakage mitigation activities involving agricultural intensification in the leakage mitigation area can potentially increase GHG emissions (e.g., due to increased fertilization or stocking rates). Project proponents must account for leakage unless they demonstrate it is de minimis. Appendix 2 of *VM0047 Afforestation, Reforestation and Revegetation* must be used to determine whether decreases in carbon pools and increases in GHG emissions are de minimis.

In the case of livestock intensification, project proponents must demonstrate that stocking rates in leakage mitigation areas are not expected to exceed maximum carrying capacity and will not deplete vegetation and soil resources. Leakage from increased production of supplemental feedstocks must also be accounted for where supplemental feeding is used. Evidence of maximum carrying capacity must be sourced from reports prepared by or signed attestations from qualified independent local experts (e.g., agricultural extension agent, professional agronomist).

Assessment of nitrous oxide emissions or demonstration of stocking rates compared to carrying capacity is not required if the leakage mitigation area is included in a registered carbon project and changes in greenhouse gas emissions and soil carbon stocks are assessed.

5.3 Step 3: Determine Amount of New Land Brought into Production

Where the amount of displaced production that may result in leakage (*l*) for commodity *j* in year *t* (as calculated above) is greater than zero, the amount of new land that is brought into production outside the project area in year *t* is calculated as follows:

$$INL_{j,t} = \frac{l_{j,t} \times IS \times NL_j}{y_{j,t}} \quad (6)$$

Where:

$INL_{j,t}$	=	Area of new land brought into production in year *t* (ha)
$l_{j,t}$	=	Amount of foregone production subject to leakage for commodity *j* in year *t* (units of production)
IS	=	Share of leakage resulting in increased supply outside the project area, or default value of 0.75 (75 percent) for agricultural commodities or 1.00 (100 percent) for fuelwood
NL_j	=	Share of increased supply from new land brought into production for commodity *j*, or default value of 0.40 (40 percent) for agricultural commodities or 1.00 (100 percent) for fuelwood
$y_{j,t}$	=	Yield on new land brought into production for commodity *j* in year *t* (units of production/ha)
t	=	1, 2, 3, …, *t* years elapsed since the project start date

A fundamental premise of leakage is that where production is decreased by one unit, production in other locations will replace some, but not all, of the forgone production. This module uses a conservative default value of 75 percent for *IS* which assumes that 75 percent of the agricultural production lost in the project area is made up through increases in supply outside the project area (see Appendix 2 for background on default values). It is conservatively assumed that 100 percent of fuelwood production lost in the project area is made up through increases outside the project area.

The increases in supply outside the project area may or may not result in bringing new lands into production. Supply increases from agricultural intensification and increases in yields on nonforest lands will not lead to new lands being brought into agricultural production. This module uses a conservative default value of 40 percent for *NL*. This assumes that 40 percent of the increase in supply of agricultural commodities outside the project is made up through bringing new land into production (see Appendix 2 for background on default values). It is conservatively assumed that 100 percent of the increase in supply of fuelwood outside the project is made up through bringing new land into production.

Where the default value for *IS* or *NL* is not applied, the project proponent must provide evidence justifying the use of a different value where it is less conservative than the default value. Such evidence may include peer-reviewed studies relevant to the agricultural commodity and the region of the project. Project proponents may use more conservative values for *IS* or *NL* without providing such evidence.

For subsistence commodities, the yield of *NL* brought into production must reference the yield in the project area during the historical reference period.

For fuelwood production, yields based on the average above-ground biomass growth rates published by the IPCC applicable to the region of the project may be used if regional or national data are not available.

For non-subsistence commodities, the yield on new land brought into production must reference the following data sources as available in the order listed (e.g., if two data sources are available, the data source nearest the top of the list must be used):

1) The yield in the project area during the historical reference period; or
2) Regional data on the yields for the relevant agricultural commodities subject to foregone production; or
3) National data on the yields for the relevant agricultural commodities subject to foregone production.

The area of new land brought into production ($INL_{j,t}$) must be summed across all commodities produced in the project area during the historical reference period, as identified in above in Section 5.1.1, Step 2, to determine the total area generating leakage emissions. The area generating leakage emissions is calculated as follows:

$$AL_t = \sum_{j=1}^{T} INL_{j,t} \tag{7}$$

Where:

AL_t	=	Area generating leakage emissions in year *t* (ha)
$INL_{j,t}$	=	Area of new land brought into production for commodity *j* in year *t* (ha)
T	=	Total number of commodities produced in historical reference period
t	=	1, 2, 3, …, *t* years elapsed since the project start date

5.4 Step 4: Determine Change in Carbon Stocks in New Lands Brought into Production

This module assumes that new land brought into production is forested land. The change in carbon stocks in the new land that is brought into production is calculated as follows:

$$CS = \Delta C_{biomass} + \Delta SOC \tag{8}$$

Where:

CS	=	Change in carbon stocks on new lands brought into production (t C/ha)
$\Delta C_{biomass}$	=	Change in forest biomass carbon stocks equal to the in the regional average stock in which the project is located (t C/ha)
ΔSOC	=	Change in soil organic carbon (SOC) stocks in the region in which the project is located (t C/ha)

The change in forest biomass carbon stocks in the area generating leakage emissions assumes the complete loss of above- and belowground biomass, deadwood and litter.

The change in SOC stock is calculated as the difference between initial reference stocks and estimated future, steady-state stocks at the end of 20 years.

$$\Delta SOC = SOC_{REF} \times (1.00 - f_{LU} \times f_{MG} \times f_{IN}) \tag{9}$$

Where:

ΔSOC	=	Change in SOC stock in the area generating leakage emissions (t C/ha)
SOC_{REF}	=	SOC stock corresponding to the reference condition in native ecosystems by climate region and soil type applicable to the land receiving the displaced activity (t C/ha)
f_{LU}, f_{MG}, f_{IN}	=	Relative SOC stock change factors over 20 years for land use, management practices and inputs respectively, applicable to the displaced production (dimensionless)

5.5 Step 5: Determine Leakage Emissions

The leakage emissions from new land that is brought into production and where *t* does not exceed 5 years beyond the last project instance start date are calculated as follows:

$$LK_t = AL_t \times CS \times 44/12 \tag{10}$$

Where:

LK_t	=	Cumulative leakage up to year *t* (t CO_2e)
AL_t	=	Area generating leakage emissions in year *t* (ha)
CS	=	Change in carbon stocks on new lands brought into production (t C/ha)

t	=	1, 2, 3, …, t years elapsed since the project start date, t must not exceed five years beyond the last project instance start date
44/12	=	Conversion factor from C to CO_2e

6 DATA AND PARAMETERS

6.1 Data and Parameters Available at Validation

Data/Parameter	$p_{j,h}$
Data unit	Unit of production, varies by commodity
Description	Production in the project area for commodity *j* in year *h* of the historical reference period
Equations	(1)
Source of data	Where available, grower records (e.g., management logs, receipts or invoices, logs or files containing machine and/or sensor data), or remote sensing methods (e.g., satellite imagery, manned aerial vehicle footage, drone imagery) where it is possible to reliably determine requisite information on production with these remote sensing methods. Where historical production records for the project area do not exist, regional (sub-national) average values derived from published census data should be used. Where historical production records for the project area and regional (sub-national) average values do not exist, national average values derived from census data must be used. In the case of fuelwood production, average aboveground biomass growth rates published by the IPCC (Tables 4.9–4.11 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*) may be used where regional or national averages are not available. When using regional or national average values, official government sources must be used where available. In the absence of official government sources, published studies may be used to justify such values. In addition, when using regional or national average values, such values must be derived from all datapoints within the historical reference period where such data are available, or from the most recent datapoint to the end of the historical reference period otherwise. Historical production records must reference the relevant commodity, or ownership class where estimates have been disaggregated by those

	attributes and substantiated with a signed attestation from the farmer or landowner.
Value applied	Conditional based on source of data
Justification of choice of data or description of measurement methods and procedures applied	Should be collected for a period that includes all years within the three-year period immediately preceding the project start date or all years of one complete crop rotation where applicable, whichever is longer.
Purpose of data	Calculation of foregone production
Comments	Units of production for livestock commodities may be expressed in terms of stocks and may include number of animals, animal units or forage intake units.

Data/Parameter	H
Data unit	Years
Description	Number of years within historical reference period used to determine baseline production within the project area
Equations	(1), (3)
Source of data	N/A
Value applied	A value between 3 and the number of years for one complete crop rotation where applicable, whichever is greater
Justification of choice of data or description of measurement methods and procedures applied	Selected by the project proponent
Purpose of data	Calculation of foregone production
Comments	None

Data/Parameter	$op_{j,h}$
Data unit	Unit of production, varies by commodity

Description	Production units of commodity *j* in the leakage mitigation area in year *h* of the historical reference period
Equations	(3)
Source of data	Grower records, or remotely sensed data (e.g., satellite imagery, manned aerial vehicle footage, drone imagery) where it is possible to reliably determine the requisite information on production using these methods
Value applied	Conditional based on source of data
Justification of choice of data or description of measurement methods and procedures applied	Must be collected for each commodity produced in the project area over the historical reference period
Purpose of data	Calculation of leakage mitigation for foregone production
Comments	Units of production for livestock commodities may be expressed in terms of stocks and may include number of animals, animal units and forage intake units.

6.2 Data and Parameters Monitored

Data/Parameter	$MP_{j,t}$
Data unit	Units of production
Description	Monitored production in the project area for commodity *j* in year *t*
Equations	(2)
Source of data	Grower records (e.g., management logs, receipts or invoices, logs or files containing machine and/or sensor data), or data derived from remote sensing methods (e.g., satellite imagery, manned aerial vehicle footage, drone imagery) where it is possible to reliably determine requisite information on production with these remote sensing methods
Description of measurement methods and procedures to be applied	N/A

Frequency of monitoring/recording	At each monitoring event
QA/QC procedures to be applied	
Purpose of data	Calculation of foregone production
Calculation method	N/A
Comments	None

Data/Parameter	r_j
Data unit	Percent
Description	Annual growth rate of yield for commodity *j*
Equations	(1), (3)
Source of data	Regional (where available) yield data must be obtained or calculated using published studies or official government statistics referencing the smallest territorial administrative division (e.g., district or municipality) that encompasses all areas of land included in the ARR project activity. Yield data must be disaggregated by the ownership classes for which production data are available. In the case of crop commodities, data from FAOSTAT may be used where published studies or official government statistics are not available. Alternatively, a default value of 0.025 (2.5 percent) may be used.
Description of measurement methods and procedures to be applied	When using data from FAOSTAT (for crop commodities only), the following procedures must be applied to calculate the annual growth rate of yield for commodity *j*: 1) For year *t* (years elapsed since the project start date), find the yield for commodity *j* by selecting Group: Production; Domains: Crops and livestock products; Area: Country where ARR project activity is located; Element: Yield; and Item: Commodity *j*. 2) Calculate annual growth rate in yield for commodity *j* as: $r_j = \left(\frac{yield_{j,t}}{yield_{j,t-1}}\right) - 1$

Frequency of monitoring/recording	At each monitoring event
QA/QC procedures to be applied	
Purpose of data	Calculation of baseline commodity production in the project area and the leakage mitigation area
Calculation method	
Comments	Where default value is not applied, the yield data from the year closest to year *t* must be used unless otherwise justified. Yield data for livestock commodities is expressed in terms of stocking rate and may include number of animals, animal units and forage intake units per hectare.

Data/Parameter	$OMP_{j,t}$
Data unit	Units of production
Description	Monitored production in the leakage mitigation area for commodity *j* in year *t*
Equations	(4)
Source of data	Grower records (e.g., management logs, receipts or invoices, logs or files containing machine and/or sensor data), or data derived from remote sensing methods (e.g., satellite imagery, manned aerial vehicle footage, drone imagery) where it is possible to reliably determine requisite information on production with these remote sensing methods
Description of measurement methods and procedures to be applied	N/A
Frequency of monitoring/recording	At each monitoring event
QA/QC procedures to be applied	
Purpose of data	Calculation of leakage mitigation

Calculation method	N/A
Comments	None

Data/Parameter	*IS*
Data unit	Percent
Description	Share of leakage resulting in increased supply outside the project area
Equations	(6)
Source of data	
Description of measurement methods and procedures to be applied	Default value of 0.75 (75 percent) for agricultural commodities or 1.00 (100 percent) for fuelwood. Where the default value is not applied, evidence justifying the use of a different value must be provided. Such evidence may include government-approved or peer-reviewed studies relevant to the agricultural commodity and region in which the project is located.
Frequency of monitoring/recording	At each monitoring event
QA/QC procedures to be applied	
Purpose of data	Estimation of area of new land brought into production
Calculation method	
Comments	See Appendix 2 for background on default values

Data/Parameter	NL_j
Data unit	Percent
Description	Share of increased supply from new land brought into production for commodity *j*
Equations	(6)

Source of data	Default value of 0.40 (40 percent) for agricultural commodities or 1.00 (100 percent) for fuelwood. Where the default value is not applied, evidence justifying the use of a different value must be provided. Such evidence may include government-approved or peer-reviewed studies relevant to the commodity produced and region in which the project is located.
Description of measurement methods and procedures to be applied	N/A
Frequency of monitoring/recording	At each monitoring event
QA/QC procedures to be applied	
Purpose of data	Estimation of area of new land brought into production
Calculation method	N/A
Comments	See Appendix 2 for background on default values

Data/Parameter	$y_{j,t}$
Data unit	Production units per hectare per year
Description	Yield on new lands brought into production for commodity *j* in year *t*
Equations	(6)
Source of data	Government data or published studies Productivity data must be obtained or calculated using official government statistics or published studies where available. For crop commodities, data from FAOSTAT may be used where official government statistics or published studies are not available. Where none of the above sources of data are available, or for subsistence commodities, yield in the project area during the historical reference period may be used.
Description of measurement methods and procedures to be applied	Data from the year closest to that for which leakage emissions are being calculated must be used. For non-subsistence commodities, the yield on new land brought into production must reference regional yields for the relevant agricultural

	commodities subject to foregone production. Where regional data are not available, national data must be used. In the absence of regional and national data for the commodity, the yield in the project area during the historical reference period must be used. In the case of fuelwood production, yields based on the average aboveground biomass growth rates published by the IPCC applicable to the region of the project may be used where regional or national data are not available. For subsistence commodities, the yield of new land brought into production must reference the yield in the project area during the historical reference period. When using data from FAOSTAT (for crop commodities only), the following procedure must be applied. For the year *t* (number of years elapsed since the project start date), find the yield for commodity *j* by selecting Group: Production; Domains: Crops and livestock products; Area: Country where ARR project activity is located; Element: Yield; Item: Commodity *j*.
Frequency of monitoring/recording	At each monitoring event
QA/QC procedures to be applied	
Purpose of data	Calculation of area of new land brought into production
Calculation method	N/A
Comments	Where yield data are not available for year *t*, yield data from the year closest to the year *t* must be used unless otherwise justified. Yield on new lands brought into production for livestock commodities may be expressed in terms of stocking rate and may include number of animals, animal units and forage intake units per hectare per year.

Data/Parameter	$\Delta C_{biomass}$
Data unit	t C/ha
Description	The change in forest biomass carbon stocks equal to the regional average stock where the project is located.
Equations	(8)

Source of data	Published studies with data from country in which the project is located where such data are available, or derived from Table 3A.1.4 of the *IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2003) where such data are not available.
Description of measurement methods and procedures to be applied	$\Delta C_{Biomass}$ must reference the following data sources as available in the order listed, (e.g., if two data sources are available the data source nearest the top of the list must be used): • mean carbon stocks in forest biomass in the region; or • mean carbon stocks in forest biomass in the country where the project is located and must be obtained from published studies or official government statistics; or • mean carbon stocks in forest biomass derived from above-ground biomass estimates in Table 3A.1.4 of the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2003) if such information is not available. Determined based on data available at the time of the assessment and reflecting area-weighted mean stocks in above- and belowground biomass, dead wood and litter pools at the nearest date to the assessment date. If biomass is presented in tonnes of dry biomass per hectare, then carbon stocks should be determined using a carbon fraction default value of 0.47. If only aboveground biomass stocks are reported, then belowground biomass stocks should be estimated using allometric equations contained in Table 4.A.4 of IPCC (2003), unless verifiable information is provided to justify a different value. Similarly, if data presented include tree biomass only, then the carbon stocks in deadwood and litter must be estimated by multiplying the sum of aboveground and belowground biomass stocks by a factor of 1.1.[1]
Frequency of monitoring/recording	At the time of each monitoring event
QA/QC procedures to be applied	
Purpose of data	Calculation of leakage emissions
Calculation method	N/A

[1] Source: *CDM AR-TOOL15, v2.0*

Comments	None

Data/Parameter	SOC_{REF}
Data unit	t C/ha
Description	Soil organic carbon (SOC) stock corresponding to the reference condition in native ecosystems by climate region and soil type applicable to the land receiving the displaced activity
Equations	(9)
Source of data	Table 2.3 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Description of measurement methods and procedures to be applied	Where soils vary across the region of production, a weighted average (based on relative commodity production) or the highest, most conservative value may be used.
Frequency of monitoring/recording	At each monitoring event
QA/QC procedures to be applied	
Purpose of data	To calculate change in carbon stocks on new lands brought into production
Calculation method	N/A
Comments	None

Data/Parameter	f_{LU}, f_{MG}, f_{IN}
Data unit	Dimensionless
Description	Relative SOC stock change factors applicable to the displaced production over 20 years for land use, management practices and inputs respectively
Equations	(9)

Source of data	Table 5.5 (displaced crops, referencing tree crops in the case of fuelwood) and Table 6.2 (displaced grazing) of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*
Description of measurement methods and procedures to be applied	N/A
Frequency of monitoring/recording	At each monitoring event
QA/QC procedures to be applied	
Purpose of data	Calculation of leakage emissions
Calculation method	N/A
Comments	None

7 REFERENCES

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APPENDIX 1: LEAKAGE EXAMPLE

The following example demonstrates the application of the leakage module in hypothetical scenario. All of the values presented have been rounded to make the example simpler to read.

In year 1, a project area of 1,000 hectares is planted to trees. All cattle that were grazed in the project area are sold prior to tree planting. In the three years prior to the planting date, 300, 330 and 360 cattle were grazed in the project area respectively.

The project proponent undertakes leakage mitigation activities in a designated area outside the project area (leakage mitigation area) to increase production of cattle. In the three years prior to the planting date, 400, 420 and 440 cattle were grazed in the leakage mitigation area.

In year 5, the production of cattle in the leakage mitigation area has increased to 536 cattle (+5.0 percent per year). The yield for cattle in the region of the project area is 1.70 cattle/ha.

The total forest biomass carbon stock is 130.6 tonnes, calculated as the product of aboveground tree biomass (209 tonnes biomass), carbon fraction of tree biomass (0.50) and biomass expansion factor (1.25). Initial reference SOC stocks in native forest in the region of production are 60 tonnes, corresponding to tropical wet climate, high activity clay soils per Table 2.3 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Relative stock change factors for grassland management used are 1.0 (land use), 0.7 (management) and 1.0 (inputs) per Table 6.2 of the *2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories*.

Step 1: Determine foregone production in the project area

A historical reference period (*H*) of 3 years is selected by the project proponent. With Equation (1), baseline production of cattle in the project area, using the default production growth rate of 2.5 percent, is calculated in year 5 as follows:

$$BP_{j,t} = \frac{\sum_{h=1}^{H} p_{j,h}}{H} \times (1 + r_j)^t \tag{1}$$

$$BP_{cattle,t=5} = \frac{(300 + 330 + 360)}{3} \times (1 + 0.025)^5 = 373\ cattle$$

In year 5, the project area is monitored to quantify the number of cattle grazed in the area after the project start date. Because the cattle previously in the project area were completely removed, and no cattle are grazed after the start date, the foregone production (*FP*) in the project area in year 5 of the project is calculated using Equation (2):

$$FP_{j,t} = BP_{j,t} - MP_{j,t} \tag{2}$$

$$FP_{cattle,t=5} = 373\ cattle - 0\ cattle = 373\ cattle$$

Step 2: Determine the impact of leakage mitigation activities

Using Equation (3), the baseline production in the leakage mitigation area in year 5 is calculated as follows:

$$OBP_{j,t} = \frac{\sum_{h=1}^{H} op_{j,h}}{OH} \times (1 + r_j)^t \quad (3)$$

$$OBP_{cattle,t=5} = \frac{(400 + 420 + 440)}{3} \times (1 + 0.025)^5 = 475 \; cattle$$

Using Equation (4), and per the assumption above that the number of cattle grazed in the leakage mitigation area in year 5 is 536, the amount of leakage mitigation (*LM*) in year 5 is calculated as follows:

$$LM_{j,t} = OMP_{j,t} - OBP_{j,t} \quad (4)$$

$$LM_{cattle,t=5} = 536 \; cattle - 475 \; cattle = 61 \; cattle$$

Using Equation (5), the amount of foregone production subject to leakage in year 5 is calculated as follows:

$$l_{j,t} = FP_{j,t} - LM_{j,t} \quad (5)$$

$$l_{cattle,t=5} = 373 \; cattle - 61 \; cattle = 313 \; cattle$$

Step 3: Determine amount of new land brought into production

Using Equation (6) and the default values for *IS* (75 percent) and *NL* (40 percent), the amount of new land brought into production (*INL*) is calculated as follows:

$$INL_{j,t} = \frac{l_{j,t} \times IS \times NL_j}{y_{j,t}} \quad (6)$$

$$INL_{cattle,t=5} = \frac{313 \times 0.75 \times 0.40}{1.70} = 55 \; ha$$

Using Equation (7), considering that cattle were the only agricultural commodity produced in the historical reference period in the project area, then the area of new land brought into production and generating leakage is calculated as follows:

$$AL_t = \sum_{j=1}^{T} INL_{j,t} \quad (7)$$

$$AL_{t=5} = 55 \; ha$$

Step 4: Determine change in carbon stocks in new land brought into production

Using Equation (8), the change in carbon stocks on new land that is brought into production in year 5 is calculated as follows:

$$CS = \Delta C_{Biomass} + \Delta SOC \quad (8)$$

$$CS = (130\ t\ C/ha\ +\ 18\ t\ C/ha) = 148t\ C/ha$$

Where:

$$\Delta SOC = SOC_{REF} - (SOC_{REF} \times\ (f_{LU} \times\ f_{MG} \times f_{IN})) \quad (9)$$

$$\Delta SOC = 60\ t\ C/ha - (60\ t\ C/ha\ \times (1.00 \times 0.70 \times 1.00)) =\ 18\ t\ C/ha$$

Step 5: Determine leakage emissions

Using Equation (10), leakage emissions from new land that is brought into production in year 5 is calculated as follows:

$$LK_t = AL_t \times CS \times 44/12 \quad (10)$$

$$LK_{t=5} = 55\ ha\ \times\ (149\ t\ C/ha) \times 44/12 = 30{,}048\ t\ CO_2e$$

APPENDIX 2: BACKGROUND ON DEFAULT VALUES

Growth rate of production

The default value for growth rates of production has been developed based on reports from the International Food Policy Research Institute (IFPRI) and Food and Agriculture Organization (FAO). This default value based on the growth rates of production has been applied within this module to serve as a proxy for growth rates in yields. Analysis from the IFPRI indicates that global average agricultural growth rates over the past 40 years have remained less than 2.5 percent per decade, with values ranging from 2.08 percent to 2.42 percent (Fuglie & Nin-Pratt, 2012). Reports from FAO confirm that this is a conservative default value for growth rates. FAO predicts that agricultural growth rates within developing countries will decrease in the coming decades with an average value of 1.6 percent from 2007 to 2030 and 0.9 percent from 2030 to 2050 (Alexandratos & Bruinsma, 2012). Therefore, 2.5 percent has been selected as a conservative default value for commodity production. Projects may justify using regional or country-specific values instead where such data are relevant and available.

Share of leakage resulting in increased supply

The default value for the share of leakage resulting in increased supply of agricultural commodities outside the project area was developed considering elasticities of supply and demand as well as observed prices and quantities to develop constant elasticity of substitution (CES) demand, supply and reduced supply curves. The analysis for developing the conservative default value used elasticities of supply and demand across commodities and countries from peer-reviewed economic studies. Data on exogenous prices and quantities of commodities in specific geographic regions were gathered from several sources including USDA Economic Research Service (ERS), the Food and Agricultural Organization of the United Nations (FAO), Federal Reserve Economic Data (FRED) and Trading Economics. The elasticity data on agricultural commodities and forest products indicated that no commodities experienced perfectly inelastic supply or demand. Averaging across global commodities, production losses occurring within the project would result in a 13 to 72 percent increase in supply elsewhere. Therefore, 75 percent was selected as a conservative default value.

Share of increased supply coming from new land brought into production

The default value for the increased supply coming from new land brought into production was developed based on data and reports from the FAO. Such studies indicate that globally only 10 percent of the increases in agricultural production will come from new land being brought into production (Alexandratos & Bruinsma, 2012). Some sub-regions such as Latin America and the Caribbean may experience 40 percent of future supply coming from new land being brought into production. While these studies provide predictions regarding long-term trends in production, other studies on short-term trends result in other conclusions. Roberts and Schlenker (2013) provide evidence that shorter-term price shocks do not follow these longer-term trends and the increase in production is primarily made up by bringing new land into production.

The default value has been developed based on the assumption that projects will have longer-term impacts on commodity markets. Based on the FAO data, 40 percent was selected as a conservative threshold for the default value for agricultural commodities. This default value may be updated in the future where ARR projects are shown to have shorter-term impacts on commodity markets.

Conservative assumptions used

The use of the above default values is further supported by the following conservative assumptions that have been employed elsewhere in this module:

1) New lands brought into production are assumed to be forested lands;
2) Positive leakage effects from ARR activities that provide timber to the market and reduce harvesting on existing forested lands are not included. Similarly, increases in production in leakage mitigation areas that occur after leakage emissions are calculated are not included;
3) Leakage calculations conservatively ignore that new lands brought into production outside the host country would reduce the amount of new land brought into production within the host country and would reduce leakage emissions (limited to domestic emissions under the *VCS Standard*); and
4) Leakage estimated in this module do not decrease with time, however, the actual leakage effects may be expected to decrease as the share of carbon projects and the impact on market supply and prices from foregone production increase over time.

DOCUMENT HISTORY

Version	Date	Changes
v1.0	28 Sep 2023	Initial version released