

ANNEX 2

SUMMARY OF EQUATIONS

Contents

A. AFOLU General Equations	A2.3
B. Equations for Biomass	A2.4
C. Equations for Dead Organic Matter	A2.9
D. Equations for Soil Carbon	A2.11
E. Equations for Biomass Burning	A2.13
F. Equations for Rice Cultivation	A2.13
G. Equations for Wetlands	A2.14
H. Equations for Livestock	A2.17
I. Equations for N ₂ O and Other CO ₂ Emissions from Managed Soils	A2.27
J. Equations for Harvested Wood Products	A2.32

A. AFOLU GENERAL EQUATIONS

EQUATION 2.1
ANNUAL CARBON STOCK CHANGES FOR THE ENTIRE AFOLU SECTOR ESTIMATED AS THE SUM OF CHANGES IN ALL LAND-USE CATEGORIES

$$\Delta C_{AFOLU} = \Delta C_{FL} + \Delta C_{CL} + \Delta C_{GL} + \Delta C_{WL} + \Delta C_{SL} + \Delta C_{OL}$$

Where:

ΔC = carbon stock change

Indices denote the following land-use categories:

AFOLU = Agriculture, Forestry and Other Land Use

FL = Forest Land

CL = Cropland

GL = Grassland

WL = Wetlands

SL = Settlements

OL = Other Land

EQUATION 2.2
ANNUAL CARBON STOCK CHANGES FOR A LAND-USE CATEGORY AS A SUM OF CHANGES IN EACH STRATA WITHIN THE CATEGORY

$$\Delta C_{LU} = \sum_i \Delta C_{LU_i}$$

Where:

ΔC_{LU} = carbon stock changes for a land-use (LU) category as defined in Equation 2.1.

i = denotes a specific stratum or subdivision within the land-use category (by any combination of species, climatic zone, ecotype, management regime etc., see Chapter 3), $i = 1$ to n .

EQUATION 2.3
ANNUAL CARBON STOCK CHANGES FOR A STRATUM OF A LAND-USE CATEGORY AS A SUM OF CHANGES IN ALL POOLS

$$\Delta C_{LU_i} = \Delta C_{AB} + \Delta C_{BB} + \Delta C_{DW} + \Delta C_{LI} + \Delta C_{SO} + \Delta C_{HWP}$$

Where:

ΔC_{LU_i} = carbon stock changes for a stratum of a land-use category

Subscripts denote the following carbon pools:

AB = above-ground biomass

BB = below-ground biomass

DW = dead wood

LI = litter

SO = soils

HWP = harvested wood products

EQUATION 2.4
ANNUAL CARBON STOCK CHANGE IN A GIVEN POOL AS A FUNCTION OF GAINS AND LOSSES
(GAIN-LOSS METHOD)

$$\Delta C = \Delta C_G - \Delta C_L$$

Where:

ΔC = annual carbon stock change in the pool, tonnes C yr⁻¹

ΔC_G = annual gain of carbon, tonnes C yr⁻¹

ΔC_L = annual loss of carbon, tonnes C yr⁻¹

EQUATION 2.5
CARBON STOCK CHANGE IN A GIVEN POOL AS AN ANNUAL AVERAGE DIFFERENCE BETWEEN
ESTIMATES AT TWO POINTS IN TIME (STOCK-DIFFERENCE METHOD)

$$\Delta C = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)}$$

Where:

ΔC = annual carbon stock change in the pool, tonnes C yr⁻¹

C_{t_1} = carbon stock in the pool at time t_1 , tonnes C

C_{t_2} = carbon stock in the pool at time t_2 , tonnes C

EQUATION 2.6
NON-CO₂ EMISSIONS TO THE ATMOSPHERE

$$Emission = A \cdot EF$$

Where:

Emission = non- CO₂ emissions, tonnes of the non-CO₂ gas

A = activity data relating to the emission source (can be area, animal numbers or mass unit, depending on the source type)

EF = emission factor for a specific gas and source category, tonnes per unit of A

B. EQUATIONS FOR BIOMASS

EQUATION 2.7
ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS
IN LAND REMAINING IN A PARTICULAR LAND USE -CATEGORY (GAIN-LOSS METHOD)

$$\Delta C_B = \Delta C_G - \Delta C_L$$

Where:

ΔC_B = annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass terms in Equation 2.3) for each land sub-category, considering the total area, tonnes C yr⁻¹

ΔC_G = annual increase in carbon stocks due to biomass growth for each land sub-category, considering the total area, tonnes C yr⁻¹

ΔC_L = annual decrease in carbon stocks due to biomass loss for each land sub-category, considering the total area, tonnes C yr⁻¹

EQUATION 2.8
ANNUAL CHANGE IN CARBON STOCKS IN BIOMASS
IN LAND REMAINING IN THE SAME LAND-USE CATEGORY (STOCK-DIFFERENCE METHOD)

$$\Delta C_B = \frac{(C_{t_2} - C_{t_1})}{(t_2 - t_1)} \quad (a)$$

where

$$C = \sum_{i,j} \{A_{i,j} \cdot V_{i,j} \cdot BCEF_{S_{i,j}} \cdot (1 + R_{i,j}) \cdot CF_{i,j}\} \quad (b)$$

Where:

ΔC_B = annual change in carbon stocks in biomass (the sum of above-ground and below-ground biomass terms in Equation 2.3) in land remaining in the same category (e.g., *Forest Land Remaining Forest Land*), tonnes C yr⁻¹

C_{t_2} = total carbon in biomass for each land sub-category at time t_2 , tonnes C

C_{t_1} = total carbon in biomass for each land sub-category at time t_1 , tonnes C

C = total carbon in biomass for time t_1 to t_2

A = area of land remaining in the same land-use category, ha (see note below)

V = merchantable growing stock volume, m³ ha⁻¹

i = ecological zone i ($i = 1$ to n)

j = climate domain j ($j = 1$ to m)

R = ratio of below-ground biomass to above-ground biomass, in tonnes d.m. below-ground biomass (tonne d.m. above-ground biomass)⁻¹

CF = carbon fraction of dry matter, tonnes C (tonne d.m.)⁻¹

$BCEF_S$ = biomass conversion and expansion factor for expansion of merchantable growing stock volume to above-ground biomass, tonnes above-ground biomass growth (m³ growing stock volume)⁻¹, (see Table 4.5 for Forest Land). $BCEF_S$ transforms merchantable volume of growing stock directly into its above-ground biomass. $BCEF_S$ values are more convenient because they can be applied directly to volume-based forest inventory data and operational records, without the need of having to resort to basic wood densities (D). They provide best results, when they have been derived locally and based directly on merchantable volume. However, if $BCEF_S$ values are not available and if the biomass expansion factor (BEF_S) and D values are separately estimated, the following conversion can be used:

$$BCEF_S = BEF_S \cdot D$$

EQUATION 2.9
ANNUAL INCREASE IN BIOMASS CARBON STOCKS DUE TO BIOMASS INCREMENT
IN LAND REMAINING IN THE SAME LAND-USE CATEGORY

$$\Delta C_G = \sum_{i,j} (A_{i,j} \cdot G_{TOTAL_{i,j}} \cdot CF_{i,j})$$

Where:

ΔC_G = annual increase in biomass carbon stocks due to biomass growth in land remaining in the same land-use category by vegetation type and climatic zone, tonnes C yr⁻¹

A = area of land remaining in the same land-use category, ha

G_{TOTAL} = mean annual biomass growth, tonnes d. m. ha⁻¹ yr⁻¹

i = ecological zone ($i = 1$ to n)

j = climate domain ($j = 1$ to m)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹

EQUATION 2.10
AVERAGE ANNUAL INCREMENT IN BIOMASS

Tier 1

$G_{TOTAL} = \sum \{G_W \cdot (1 + R)\}$ Biomass increment data (dry matter) are used directly

Tiers 2 and 3

$G_{TOTAL} = \sum \{I_V \cdot BCEF_I \cdot (1 + R)\}$ Net annual increment data are used to estimate G_W by applying a biomass conversion and expansion factor

Where:

G_{TOTAL} = average annual biomass growth above and below-ground, tonnes d. m. $ha^{-1} yr^{-1}$

G_W = average annual above-ground biomass growth for a specific woody vegetation type, tonnes d. m. $ha^{-1} yr^{-1}$

R = ratio of below-ground biomass to above-ground biomass for a specific vegetation type, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass) $^{-1}$. R must be set to zero if assuming no changes of below-ground biomass allocation patterns (Tier 1).

I_V = average net annual increment for specific vegetation type, $m^3 ha^{-1} yr^{-1}$

$BCEF_I$ = biomass conversion and expansion factor for conversion of net annual increment in volume (including bark) to above-ground biomass growth for specific vegetation type, tonnes above-ground biomass growth (m^3 net annual increment) $^{-1}$, (see Table 4.5 for Forest land). If $BCEF_I$ values are not available and if the biomass expansion factor (BEF) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_I = BEF_I \cdot D$$

EQUATION 2.11
ANNUAL DECREASE IN CARBON STOCKS DUE TO BIOMASS LOSSES
IN LAND REMAINING IN THE SAME LAND-USE CATEGORY

$$\Delta C_L = L_{wood-removals} + L_{fuelwood} + L_{disturbance}$$

Where:

ΔC_L = annual decrease in carbon stocks due to biomass loss in land remaining in the same land-use category, tonnes C yr^{-1}

$L_{wood-removals}$ = annual carbon loss due to wood removals, tonnes C yr^{-1} (See Equation 2.12)

$L_{fuelwood}$ = annual biomass carbon loss due to fuelwood removals, tonnes C yr^{-1} (See Equation 2.13)

$L_{disturbance}$ = annual biomass carbon losses due to disturbances, tonnes C yr^{-1} (See Equation 2.14)

EQUATION 2.12
ANNUAL CARBON LOSS IN BIOMASS OF WOOD REMOVALS

$$L_{wood-removals} = \{H \cdot BCEF_R \cdot (1 + R) \cdot CF\}$$

Where:

$L_{wood-removals}$ = annual carbon loss due to biomass removals, tonnes C yr^{-1}

H = annual wood removals, roundwood, $m^3 yr^{-1}$

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass) $^{-1}$. R must be set to zero if assuming no changes of below-ground biomass allocation patterns (Tier 1).

CF = carbon fraction of dry matter, tonne C (tonne d.m.) $^{-1}$

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to total biomass removals (including bark), tonnes biomass removal (m^3 of removals) $^{-1}$, (see Table 4.5 for Forest Land). However, if $BCEF_R$ values are not available and if the biomass expansion factor for

wood removals (BEF_R) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_R = BEF_R \bullet D$$

EQUATION 2.13
ANNUAL CARBON LOSS IN BIOMASS OF FUELWOOD REMOVAL

$$L_{fuelwood} = [\{FG_{trees} \bullet BCEF_R \bullet (1 + R)\} + FG_{part} \bullet D] \bullet CF$$

Where:

$L_{fuelwood}$ = annual carbon loss due to fuelwood removals, tonnes C yr⁻¹

FG_{trees} = annual volume of fuelwood removal of whole trees, m³ yr⁻¹

FG_{part} = annual volume of fuelwood removal as tree parts, m³ yr⁻¹

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)⁻¹; R must be set to zero if assuming no changes of below-ground biomass allocation patterns. (Tier 1)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹

D = basic wood density, tonnes d.m. m⁻³

$BCEF_R$ = biomass conversion and expansion factor for conversion of removals in merchantable volume to biomass removals (including bark), tonnes biomass removal (m³ of removals)⁻¹, (see Table 4.5 for Forest Land). If $BCEF_R$ values are not available and if the biomass expansion factor for wood removals (BEF_R) and basic wood density (D) values are separately estimated, then the following conversion can be used:

$$BCEF_R = BEF_R \bullet D$$

EQUATION 2.14
ANNUAL CARBON LOSSES IN BIOMASS DUE TO DISTURBANCES

$$L_{disturbance} = \{A_{disturbance} \bullet B_W \bullet (1 + R) \bullet CF \bullet fd\}$$

Where:

$L_{disturbances}$ = annual other losses of carbon, tonnes C yr⁻¹ (Note that this is the amount of biomass that is lost from the total biomass. The partitioning of biomass that is transferred to dead organic matter and biomass that is oxidized and released to the atmosphere is explained in Equations 2.15 and 2.16).

$A_{disturbance}$ = area affected by disturbances, ha yr⁻¹

B_W = average above-ground biomass of land areas affected by disturbances, tonnes d.m. ha⁻¹

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)⁻¹. R must be set to zero if no changes of below-ground biomass are assumed (Tier 1)

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)⁻¹

fd = fraction of biomass lost in disturbance (see note below)

Note: The parameter fd defines the proportion of biomass that is lost from the biomass pool: a stand-replacing disturbance will kill all ($fd = 1$) biomass while an insect disturbance may only remove a portion (e.g. $fd = 0.3$) of the average biomass C density. Equation 2.14 does not specify the fate of the carbon removed from the biomass carbon stock. The Tier 1 assumption is that all of $L_{disturbances}$ is emitted in the year of disturbance. Higher Tier methods assume that some of this carbon is emitted immediately and some is added to the dead organic matter pools (dead wood, litter) or HWP.

EQUATION 2.15
ANNUAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO OTHER LAND-USE
CATEGORY (TIER 2)

$$\Delta C_B = \Delta C_G + \Delta C_{CONVERSION} - \Delta C_L$$

Where:

ΔC_B = annual change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr⁻¹

ΔC_G = annual increase in carbon stocks in biomass due to growth on land converted to another land-use category, in tonnes C yr⁻¹

$\Delta C_{CONVERSION}$ = initial change in carbon stocks in biomass on land converted to other land-use category, in tonnes C yr⁻¹

ΔC_L = annual decrease in biomass carbon stocks due to losses from harvesting, fuel wood gathering and disturbances on land converted to other land-use category, in tonnes C yr⁻¹

EQUATION 2.16
INITIAL CHANGE IN BIOMASS CARBON STOCKS ON LAND CONVERTED TO ANOTHER LAND
CATEGORY

$$\Delta C_{CONVERSION} = \sum_i \{ (B_{AFTER_i} - B_{BEFORE_i}) \cdot \Delta A_{TO_OTHERS_i} \} \cdot CF$$

Where:

$\Delta C_{CONVERSION}$ = initial change in biomass carbon stocks on land converted to another land category, tonnes C yr⁻¹

B_{AFTER_i} = biomass stocks on land type i immediately after the conversion, tonnes d.m. ha⁻¹

B_{BEFORE_i} = biomass stocks on land type i before the conversion, tonnes d.m. ha⁻¹

$\Delta A_{TO_OTHERS_i}$ = area of land use i converted to another land-use category in a certain year, ha yr⁻¹

CF = carbon fraction of dry matter, tonne C (tonnes d.m.)⁻¹

i = type of land use converted to another land-use category

Additional Equations for Biomass in Settlements

EQUATION 8.1
ANNUAL CARBON CHANGE IN LIVE BIOMASS POOLS IN SETTLEMENTS REMAINING SETTLEMENTS

$$\Delta C_B = \Delta C_{Trees} + \Delta C_{Shrubs} + \Delta C_{Herbs}$$

Where:

ΔC_B = annual carbon accumulation attributed to biomass increment in *Settlements Remaining Settlements*, tonnes C yr⁻¹

ΔC_{Trees} = annual carbon accumulation attributed to biomass increment in trees in *Settlements Remaining Settlements*, tonnes C yr⁻¹

ΔC_{Shrubs} = annual carbon accumulation attributed to biomass increment in shrubs in *Settlements Remaining Settlements*, tonnes C yr⁻¹

ΔC_{Herbs} = annual carbon accumulation attributed to biomass increment in herbaceous biomass in *Settlements Remaining Settlements*, tonnes C yr⁻¹

EQUATION 8.2
ANNUAL BIOMASS INCREMENT BASED ON TOTAL CROWN COVER AREA

$$\Delta C_G = \sum_{i,j} AT_{i,j} \cdot CRW_{i,j}$$

Where:

ΔC_G = annual carbon accumulation attributed to biomass increment in *Settlements Remaining Settlements*, tonnes C yr⁻¹

AT_{ij} = total crown cover area of class i in woody perennial type j , ha

CRW_{ij} = crown cover area-based growth rate of class i in woody perennial type j , tonnes C (ha crown cover)⁻¹ yr⁻¹

EQUATION 8.3
ANNUAL BIOMASS GROWTH BASED ON NUMBER OF INDIVIDUAL WOODY PLANTS IN BROAD CLASSES

$$\Delta C_G = \sum_{i,j} NT_{i,j} \cdot C_{i,j}$$

Where:

ΔC_G = annual carbon accumulation due to live biomass increment in *Settlements Remaining Settlements*, tonnes C yr⁻¹

NT_{ij} = number of individuals of class i in perennial type j

C_{ij} = annual average carbon accumulation per class i of perennial type j , tonnes C yr⁻¹ per individual

C. EQUATIONS FOR DEAD ORGANIC MATTER

EQUATION 2.17
ANNUAL CHANGE IN CARBON STOCKS IN DEAD ORGANIC MATTER

$$\Delta C_{DOM} = \Delta C_{DW} + \Delta C_{LT}$$

Where:

ΔC_{DOM} = annual change in carbon stocks in dead organic matter (includes dead wood and litter), tonnes C yr⁻¹

ΔC_{DW} = change in carbon stocks in dead wood, tonnes C yr⁻¹

ΔC_{LT} = change in carbon stocks in litter, tonnes C yr⁻¹

EQUATION 2.18
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD OR LITTER (GAIN-LOSS METHOD)

$$\Delta C_{DOM} = A \cdot \{(DOM_{in} - DOM_{out}) \cdot CF\}$$

Where:

ΔC_{DOM} = annual change in carbon stocks in the dead wood/litter pool, tonnes C yr⁻¹

A = area of managed land, ha

DOM_{in} = average annual transfer of biomass into the dead wood/litter pool due to annual processes and disturbances, tonnes d.m. ha⁻¹ yr⁻¹

DOM_{out} = average annual decay and disturbance carbon loss out of dead wood or litter pool, tonnes d.m. ha⁻¹ yr⁻¹

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹

EQUATION 2.19
ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD OR LITTER (STOCK-DIFFERENCE METHOD)

$$\Delta C_{DOM} = \left[A \cdot \frac{(DOM_{t_2} - DOM_{t_1})}{T} \right] \cdot CF$$

Where:

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter, tonnes C yr⁻¹

A = area of managed land, ha

DOM_{t1} = dead wood/litter stock at time t₁ for managed land, tonnes d.m. ha⁻¹

DOM_{t2} = dead wood/litter stock at time t₂ for managed land, tonnes d.m. ha⁻¹

T = (t₂ - t₁) = time period between time of the second stock estimate and the first stock estimate, yr

CF = carbon fraction of dry matter (default = 0.37 for litter), tonnes C (tonne d.m.)⁻¹

EQUATION 2.20
ANNUAL CARBON IN BIOMASS TRANSFERRED TO DEAD ORGANIC MATTER

$$DOM_{in} = \{L_{mortality} + L_{slash} + (L_{disturbance} \cdot f_{BLol})\}$$

Where:

DOM_{in} = total carbon in biomass transferred to dead organic matter, tonnes C yr⁻¹

L_{mortality} = annual biomass carbon transfer to DOM due to mortality, tonnes C yr⁻¹ (See Equation 2.21)

L_{slash} = annual biomass carbon transfer to DOM as slash, tonnes C yr⁻¹ (See Equations 2.22)

L_{disturbances} = annual biomass carbon loss resulting from disturbances, tonnes C yr⁻¹ (See Equation 2.14)

f_{BLol} = fraction of biomass left to decay on the ground (transferred to dead organic matter) from loss due to disturbance. As shown in Table 2.1, the disturbance losses from the biomass pool are partitioned into the fractions that are added to deadwood (cell B in Table 2.1) and to litter (cell C), are released to the atmosphere in the case of fire (cell F) and, if salvage follows the disturbance, transferred to HWP (cell E).

Note: If root biomass increments are counted in Equation 2.10, then root biomass losses must also be counted in Equations 2.20, and 2.22.

EQUATION 2.21
ANNUAL BIOMASS CARBON LOSS DUE TO MORTALITY

$$L_{mortality} = \sum (A \cdot G_w \cdot CF \cdot m)$$

Where:

L_{mortality} = annual biomass carbon loss due to mortality, tonnes C yr⁻¹

A = area of land remaining in the same land use, ha

G_w = above-ground biomass growth, tonnes d.m. ha⁻¹ yr⁻¹ (see Equation 2.10)

CF = carbon fraction of dry matter, tonnes C (tonne d.m.)⁻¹

m = mortality rate expressed as a fraction of above-ground biomass growth

EQUATION 2.22**ANNUAL CARBON TRANSFER TO SLASH**

$$L_{slash} = [\{H \cdot BCEF_R \cdot (1 + R)\} - \{H \cdot D\}] \cdot CF$$

Where:

L_{slash} = annual carbon transfer from above-ground biomass to slash, including dead roots, tonnes C yr⁻¹

H = annual wood harvest (wood or fuelwood removal), m³ yr⁻¹

BCEF_R = biomass conversion and expansion factors applicable to wood removals, which transform merchantable volume of wood removal into above-ground biomass removals, tonnes biomass removal (m³ of removals)⁻¹. If BCEF_R values are not available and if BEF and Density values are separately estimated then the following conversion can be used:

$$BCEF_R = BEF_R \cdot D$$

- D is basic wood density, tonnes d.m. m⁻³
- Biomass Expansion Factors (BEF_R) expand merchantable wood removals to total aboveground biomass volume to account for non-merchantable components of the tree, stand and forest. BEF_R is dimensionless.

R = ratio of below-ground biomass to above-ground biomass, in tonne d.m. below-ground biomass (tonne d.m. above-ground biomass)⁻¹. R must be set to zero if root biomass increment is not included in Equation 2.10 (Tier 1)

CF = carbon fraction of dry matter, tonne C (tonne d.m.)⁻¹

EQUATION 2.23**ANNUAL CHANGE IN CARBON STOCKS IN DEAD WOOD AND LITTER DUE TO LAND CONVERSION**

$$\Delta C_{DOM} = \frac{(C_n - C_o) \cdot A_{on}}{T_{on}}$$

Where:

ΔC_{DOM} = annual change in carbon stocks in dead wood or litter, tonnes C yr⁻¹

C_o = dead wood/litter stock, under the old land-use category, tonnes C ha⁻¹

C_n = dead wood/litter stock, under the new land-use category, tonnes C ha⁻¹

A_{on} = area undergoing conversion from old to new land-use category, ha

T_{on} = time period of the transition from old to new land-use category, yr. The Tier 1 default is 20 years for carbon stock increases and 1 year for carbon losses.

D. EQUATIONS FOR SOIL CARBON**EQUATION 2.24****ANNUAL CHANGE IN CARBON STOCKS IN SOILS**

$$\Delta C_{Soils} = \Delta C_{Mineral} - L_{Organic} + \Delta C_{Inorganic}$$

Where:

ΔC_{Soils} = annual change in carbon stocks in soils, tonnes C yr⁻¹

$\Delta C_{Mineral}$ = annual change in organic carbon stocks in mineral soils, tonnes C yr⁻¹

$L_{Organic}$ = annual loss of carbon from drained organic soils, tonnes C yr⁻¹

$\Delta C_{Inorganic}$ = annual change in inorganic carbon stocks from soils, tonnes C yr⁻¹ (assumed to be 0 unless using a Tier 3 approach)

EQUATION 2.25
ANNUAL CHANGE IN ORGANIC CARBON STOCKS IN MINERAL SOILS

$$\Delta C_{\text{Mineral}} = \frac{(SOC_0 - SOC_{(0-T)})}{D}$$

$$SOC = \sum_{c,s,i} (SOC_{REF_{c,s,i}} \cdot F_{LU_{c,s,i}} \cdot F_{MG_{c,s,i}} \cdot F_{I_{c,s,i}} \cdot A_{c,s,i})$$

(Note: T is used in place of D in this equation if T is ≥ 20 years, see note below)

Where:

$\Delta C_{\text{Mineral}}$ = annual change in carbon stocks in mineral soils, tonnes C yr⁻¹

SOC_0 = soil organic carbon stock in the last year of an inventory time period, tonnes C

$SOC_{(0-T)}$ = soil organic carbon stock at the beginning of the inventory time period, tonnes C

SOC_0 and $SOC_{(0-T)}$ are calculated using the SOC equation in the box where the reference carbon stocks and stock change factors are assigned according to the land-use and management activities and corresponding areas at each of the points in time (time = 0 and time = 0-T)

T = number of years over a single inventory time period, yr

D = time dependence of stock change factors which is the default time period for transition between equilibrium SOC values, yr. Commonly 20 years, but depends on assumptions made in computing the factors F_{LU} , F_{MG} and F_I . If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years).

c = represents the climate zones, s the soil types, and i the set of management systems that are present in a country.

SOC_{REF} = the reference carbon stock, tonnes C ha⁻¹ (Table 2.3)

F_{LU} = stock change factor for land-use systems or sub-system for a particular land-use, dimensionless

[Note: F_{ND} is substituted for F_{LU} in forest soil C calculation to estimate the influence of natural disturbance regimes.

F_{MG} = stock change factor for management regime, dimensionless

F_I = stock change factor for input of organic matter, dimensionless

A = land area of the stratum being estimated, ha. All land in the stratum should have common biophysical conditions (i.e., climate and soil type) and management history over the inventory time period to be treated together for analytical purposes.

EQUATION 2.26
ANNUAL CARBON LOSS FROM DRAINED ORGANIC SOILS (CO₂)

$$L_{\text{Organic}} = \sum_c (A \cdot EF)_c$$

Where:

L_{Organic} = annual carbon loss from drained organic soils, tonnes C yr⁻¹

A = land area of drained organic soils in climate type c, ha

Note: A is the same area (F_{os}) used to estimate N₂O emissions in Chapter 11, Equations 11.1 and 11.2

EF = emission factor for climate type c, tonnes C ha⁻¹ yr⁻¹

E. EQUATIONS FOR BIOMASS BURNING

EQUATION 2.27
ESTIMATION OF GREENHOUSE GAS EMISSIONS FROM FIRE

$$L_{fire} = A \cdot M_B \cdot C_f \cdot G_{ef} \cdot 10^{-3}$$

Where:

L_{fire} = amount of greenhouse gas emissions from fire, tonnes of each GHG e.g., CH₄, N₂O, etc.

A = area burnt, ha

M_B = mass of fuel available for combustion, tonnes ha⁻¹. This includes biomass, ground litter and dead wood. When Tier 1 methods are used then litter and dead wood pools are assumed zero, except where there is a land-use change (see Section 2.3.2.2).

C_f = combustion factor, dimensionless (default values in Table 2.6)

G_{ef} = emission factor, g kg⁻¹ dry matter burnt (default values in Table 2.5)

Note: Where data for M_B and C_f are not available, a default value for the amount of fuel actually burnt (the product of M_B and C_f) can be used (Table 2.4) under Tier 1 methodology.

F. EQUATIONS FOR RICE CULTIVATION

EQUATION 5.1
CH₄ EMISSIONS FROM RICE CULTIVATION

$$CH_4 \text{ Rice} = \sum_{i,j,k} (EF_{i,j,k} \cdot t_{i,j,k} \cdot A_{i,j,k} \cdot 10^{-6})$$

Where:

$CH_4 \text{ Rice}$ = annual methane emissions from rice cultivation, Gg CH₄ yr⁻¹

EF_{ijk} = a daily emission factor for i, j , and k conditions, kg CH₄ ha⁻¹ day⁻¹

t_{ijk} = cultivation period of rice for i, j , and k conditions, day

A_{ijk} = annual harvested area of rice for i, j , and k conditions, ha yr⁻¹

i, j , and k = represent different ecosystems, water regimes, type and amount of organic amendments, and other conditions under which CH₄ emissions from rice may vary

EQUATION 5.2
ADJUSTED DAILY EMISSION FACTOR

$$EF_i = EF_c \cdot SF_w \cdot SF_p \cdot SF_o \cdot SF_{s,r}$$

Where:

EF_i = adjusted daily emission factor for a particular harvested area

EF_c = baseline emission factor for continuously flooded fields without organic amendments

SF_w = scaling factor to account for the differences in water regime during the cultivation period (from Table 5.12)

SF_p = scaling factor to account for the differences in water regime in the pre-season before the cultivation period (from Table 5.13)

SF_o = scaling factor should vary for both type and amount of organic amendment applied (from Equation 5.3 and Table 5.14)

$SF_{s,r}$ = scaling factor for soil type, rice cultivar, etc., if available

EQUATION 5.3
ADJUSTED CH₄ EMISSION SCALING FACTORS FOR ORGANIC AMENDMENTS

$$SF_o = \left(1 + \sum_i ROA_i \cdot CFOA_i \right)^{0.59}$$

Where:

SF_o = scaling factor for both type and amount of organic amendment applied

ROA_i = application rate of organic amendment i , in dry weight for straw and fresh weight for others, tonne ha⁻¹

$CFOA_i$ = conversion factor for organic amendment i (in terms of its relative effect with respect to straw applied shortly before cultivation) as shown in Table 5.14.

G. EQUATIONS FOR WETLANDS

EQUATION 7.1
CO₂ EMISSIONS FROM WETLANDS

$$CO_{2_W} = CO_{2_W\text{peat}} + CO_{2_W\text{flood}}$$

Where:

CO_{2_W} = CO₂ emissions from Wetlands, Gg CO₂ yr⁻¹

$CO_{2_W\text{peat}}$ = CO₂ emissions from peatlands managed for peat production, Gg CO₂ yr⁻¹

$CO_{2_W\text{flood}}$ = CO₂ emissions from (lands converted to) Flooded Land, Gg CO₂ yr⁻¹

EQUATION 7.2
CO₂ EMISSIONS IN PEATLANDS DURING PEAT EXTRACTION

$$CO_{2_WW\text{peat}} = \left(CO_{2_C_WW\text{peat}_{\text{off-site}}} + CO_{2_C_WW\text{peat}_{\text{on-site}}} \right) \cdot \left(\frac{44}{12} \right)$$

Where:

$CO_{2_WW\text{peat}}$ = CO₂ emissions from land undergoing peat extraction, Gg CO₂ yr⁻¹

$CO_{2_C_WW\text{peat}_{\text{off-site}}}$ = off-site CO₂-C emissions from peat removed for horticultural use, Gg C yr⁻¹

$CO_{2_C_WW\text{peat}_{\text{on-site}}}$ = on-site CO₂-C emissions from drained peat deposits, Gg C yr⁻¹

EQUATION 7.3
CO₂-C EMISSIONS FROM MANAGED PEATLANDS (TIER 1)

$$CO_{2_C_WW\text{peat}} = CO_{2_C_WW\text{peat}_{\text{off-site}}} + CO_{2_C_WW\text{peat}_{\text{on-site}}}$$

Where:

$CO_{2_C_WW\text{peat}}$ = CO₂-C emissions from managed peatlands, Gg C yr⁻¹

$CO_{2_C_WW\text{peat}_{\text{on-site}}}$ = on-site emissions from peat deposits (all production phases), Gg C yr⁻¹

$CO_{2_C_WW\text{peat}_{\text{off-site}}}$ = off-site emissions from peat removed for horticultural use, Gg C yr⁻¹

EQUATION 7.4
ON-SITE SOIL CO₂-C EMISSIONS FROM MANAGED PEATLANDS (TIER 1)

$$CO_2-C_{WW_{peat_{on-site}}} = \left[\frac{(A_{peatRich} \cdot EF_{CO_2_{peatRich}}) + (A_{peatPoor} \cdot EF_{CO_2_{peatPoor}})}{1000} \right] + \Delta C_{WW_{peatB}}$$

Where:

$CO_2-C_{WW_{peat_{on-site}}}$ = on-site CO₂-C emissions from peat deposits (all production phases), Gg C yr⁻¹

$A_{peatRich}$ = area of nutrient-rich peat soils managed for peat extraction (all production phases), ha

$A_{peatPoor}$ = area of nutrient-poor peat soils managed for peat extraction (all production phases), ha

$EF_{CO_2_{peatRich}}$ = CO₂ emission factors for nutrient-rich peat soils managed for peat extraction or abandoned after peat extraction, tonnes C ha⁻¹ yr⁻¹

$EF_{CO_2_{peatPoor}}$ = CO₂ emission factors for nutrient-poor peat soils managed for peat extraction or abandoned after peat extraction, tonnes C ha⁻¹ yr⁻¹

$\Delta C_{WW_{peatB}}$ = CO₂-C emissions from change in carbon stocks in biomass due to vegetation clearing, Gg C yr⁻¹

EQUATION 7.5
OFF-SITE CO₂-C EMISSIONS FROM MANAGED PEATLANDS (TIER 1)

$$CO_2-C_{WW_{peat_{off-site}}} = \frac{(Wt_{dry_peat} \cdot Cfraction_{wt_peat})}{1000}$$

or

$$CO_2-C_{WW_{peat_{off-site}}} = \frac{(Vol_{dry_peat} \cdot Cfraction_{vol_peat})}{1000}$$

Where:

$CO_2-C_{WW_{peat_{off-site}}}$ = off-site CO₂-C emissions from peat removed for horticultural use, Gg C yr⁻¹

Wt_{dry_peat} = air-dry weight of extracted peat, tonnes yr⁻¹

Vol_{dry_peat} = volume of air-dry peat extracted, m³ yr⁻¹

$Cfraction_{wt_peat}$ = carbon fraction of air-dry peat by weight, tonnes C (tonne of air-dry peat)⁻¹

$Cfraction_{vol_peat}$ = carbon fraction of air-dry peat by volume, tonnes C (m³ of air-dry peat)⁻¹

EQUATION 7.6
ON-SITE CO₂-C EMISSIONS FROM MANAGED PEATLANDS (TIERS 2 AND 3)

$$CO_2-C_{WW_{peat_{on-site}}} = \left(\begin{array}{l} CO_2-C_{WW_{peat_{conversion}}} + CO_2-C_{WW_{peat_{extraction}}} + \\ CO_2-C_{WW_{peat_{stockpiling}}} + CO_2-C_{WW_{peat_{post}}} \end{array} \right)$$

Where:

$CO_2-C_{WW_{peat_{on-site}}}$ = on-site CO₂-C emissions from peat deposits, Gg C yr⁻¹

$CO_2-C_{WW_{peat_{conversion}}}$ = on-site CO₂-C emissions from lands conversion for peat extraction, Gg C yr⁻¹

$CO_2-C_{WW_{peat_{extraction}}}$ = CO₂-C emissions from the surface of peat extraction area, Gg C yr⁻¹

$CO_2-C_{WW\text{peat}_{stockpiling}}$ = CO_2-C emissions from peat stockpiles prior to off-site removal, Gg C yr⁻¹

$CO_2-C_{WW\text{peat}_{post}}$ = CO_2-C emissions from soils of abandoned, cut-over peatlands, Gg C yr⁻¹

EQUATION 7.7
N₂O EMISSIONS FROM PEATLANDS DURING PEAT EXTRACTION

$$N_2O_{WW\text{peat}_{Extraction}} = \left(A_{\text{peat}_{Rich}} \cdot EF_{N_2O-N_{\text{peat}_{Rich}}} \right) \cdot \frac{44}{28} \cdot 10^{-6}$$

Where:

$N_2O_{WW\text{peat}_{Extraction}}$ = direct N₂O emissions from peatlands managed for peat extraction, Gg N₂O yr⁻¹

$A_{\text{peat}_{Rich}}$ = area of nutrient-rich peat soils managed for peat extraction, including abandoned areas in which drainage is still present, ha

$EF_{N_2O-N_{\text{peat}_{Rich}}}$ = emission factor for drained nutrient-rich wetlands organic soils, kg N₂O-N ha⁻¹ yr⁻¹

EQUATION 7.8
CO₂-C EMISSIONS IN PEATLAND BEING DRAINED FOR PEAT EXTRACTION

$$CO_2-C_{LW_{\text{peat}_{on-site}}} = \left(-\Delta C_{WW_{\text{peat}_B}} \right) + \left(-\Delta C_{WW_{\text{peat}_{DOM}}} \right) + CO_2-C_{LW_{\text{peat}_{drainage}}}$$

Where:

$CO_2-C_{LW_{\text{peat}_{on-site}}}$ = CO_2-C emissions from land being converted for peat extraction, Gg C yr⁻¹

$\Delta C_{WW_{\text{peat}_B}}$ = CO_2-C emissions from change in carbon stocks in living biomass, Gg C yr⁻¹

$\Delta C_{WW_{\text{peat}_{DOM}}}$ = CO_2-C emissions from change in carbon stocks in dead organic matter pool, Gg C yr⁻¹

$CO_2-C_{LW_{\text{peat}_{drainage}}}$ = CO_2-C emissions from soils during drainage, Gg C yr⁻¹

EQUATION 7.9
CO₂-C EMISSIONS FROM SOILS IN PEATLAND BEING DRAINED FOR PEAT EXTRACTION

$$CO_2-C_{LW_{\text{peat}_{drainage}}} = \left[\frac{\left(A_{\text{drained}_{\text{peat}_{Rich}}} \cdot EF_{CO_2\text{drained}_{\text{peat}_{Rich}}} \right) + \left(A_{\text{drained}_{\text{peat}_{Poor}}} \cdot EF_{CO_2\text{drained}_{\text{peat}_{Poor}}} \right)}{1000} \right]$$

Where:

$CO_2-C_{LW_{\text{peat}_{drainage}}}$ = CO_2-C emissions from soils on lands converted for peat extraction, Gg C yr⁻¹

$A_{\text{drained}_{\text{peat}_{Rich}}}$ = area of nutrient-rich peat soils being drained, ha

$A_{\text{drained}_{\text{peat}_{Poor}}}$ = area of nutrient-poor peat soils being drained, ha

$EF_{CO_2\text{drained}_{\text{peat}_{Rich}}}$ = emission factors for CO₂-C from nutrient-rich peat soils being drained, tonnes C ha⁻¹ yr⁻¹

$EF_{CO_2\text{drained}_{\text{peat}_{Poor}}}$ = emission factors for CO₂-C from nutrient-poor peat soils being drained, tonnes C ha⁻¹ yr⁻¹

EQUATION 7.10
ANNUAL CHANGE IN CARBON STOCKS IN LIVING BIOMASS ON LAND CONVERTED TO PERMANENTLY FLOODED LAND

$$\Delta C_{LWflood_{LB}} = \left[\sum_i A_i \cdot (B_{After_i} - B_{Before_i}) \right] \cdot CF$$

$$CO_{2_LWflood} = \Delta C_{LWflood_{LB}} \cdot \frac{-44}{12}$$

Where:

$\Delta C_{LWflood_{LB}}$ = annual change in carbon stocks in biomass on *Land Converted to Flooded Land*, tonnes C yr⁻¹

A_i = area of land converted annually to Flooded Land from original land use i , ha yr⁻¹

B_{After_i} = biomass immediately following conversion to Flooded Land, tonnes d.m. ha⁻¹ (default = 0)

B_{Before_i} = biomass in land immediately before conversion to Flooded Land, tonnes d.m. ha⁻¹

CF = carbon fraction of dry matter (default = 0.5), tonnes C (tonne d.m.)⁻¹

$CO_{2_LWflood}$ = annual CO₂ emissions on *Land Converted to Flooded Land*, tonnes CO₂ yr⁻¹

H. EQUATIONS FOR LIVESTOCK

EQUATION 10.1
ANNUAL AVERAGE POPULATION

$$AAP = Days_alive \cdot \left(\frac{NAPA}{365} \right)$$

Where:

AAP = annual average population

NAPA = number of animals produced annually

EQUATION 10.2
COEFFICIENT FOR CALCULATING NET ENERGY FOR MAINTENANCE

$$Cf_i(in_cold) = Cf_i + 0.0048 \cdot (20 - ^\circ C)$$

Where:

Cf_i = a coefficient which varies for each animal category as shown in Table 10.4 (Coefficients for calculating NE_m), MJ day⁻¹ kg⁻¹

°C = mean daily temperature during winter season

EQUATION 10.3
NET ENERGY FOR MAINTENANCE

$$NE_m = Cf_i \cdot (Weight)^{0.75}$$

Where:

NE_m = net energy required by the animal for maintenance, MJ day⁻¹

Cf_i = a coefficient which varies for each animal category as shown in Table 10.4 (Coefficients for calculating NE_m), MJ day⁻¹ kg⁻¹

Weight = live-weight of animal, kg

EQUATION 10.4
NET ENERGY FOR ACTIVITY (FOR CATTLE AND BUFFALO)

$$NE_a = C_a \cdot NE_m$$

Where:

- NE_a = net energy for animal activity, MJ day⁻¹
 C_a = coefficient corresponding to animal's feeding situation (Table 10.5, Activity coefficients)
 NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day⁻¹

EQUATION 10.5
NET ENERGY FOR ACTIVITY (FOR SHEEP)

$$NE_a = C_a \cdot (\text{weight})$$

Where:

- NE_a = net energy for animal activity, MJ day⁻¹
 C_a = coefficient corresponding to animal's feeding situation (Table 10.5), MJ day⁻¹ kg⁻¹
 weight = live-weight of animal, kg

EQUATION 10.6
NET ENERGY FOR GROWTH (FOR CATTLE AND BUFFALO)

$$NE_g = 22.02 \cdot \left(\frac{BW}{C \cdot MW} \right)^{0.75} \cdot WG^{1.097}$$

Where:

- NE_g = net energy needed for growth, MJ day⁻¹
 BW = the average live body weight (BW) of the animals in the population, kg
 C = a coefficient with a value of 0.8 for females, 1.0 for castrates and 1.2 for bulls (NRC, 1996)
 MW = the mature live body weight of an adult female in moderate body condition, kg
 WG = the average daily weight gain of the animals in the population, kg day⁻¹

EQUATION 10.7
NET ENERGY FOR GROWTH (FOR SHEEP)

$$NE_g = \frac{WG_{lamb} \cdot (a + 0.5b(BW_i + BW_f))}{365}$$

Where:

- NE_g = net energy needed for growth, MJ day⁻¹
 WG_{lamb} = the weight gain ($BW_f - BW_i$), kg yr⁻¹
 BW_i = the live bodyweight at weaning, kg
 BW_f = the live bodyweight at 1-year old or at slaughter (live-weight) if slaughtered prior to 1 year of age, kg
 a, b = constants as described in Table 10.6.

EQUATION 10.8
NET ENERGY FOR LACTATION (FOR BEEF CATTLE, DAIRY CATTLE AND BUFFALO)

$$NE_1 = Milk \cdot (1.47 + 0.40 \cdot Fat)$$

Where:

- NE_1 = net energy for lactation, MJ day⁻¹
 Milk = amount of milk produced, kg of milk day⁻¹
 Fat = fat content of milk, % by weight.

EQUATION 10.9
NET ENERGY FOR LACTATION FOR SHEEP (MILK PRODUCTION KNOWN)

$$NE_1 = Milk \cdot EV_{milk}$$

Where:

- NE_1 = net energy for lactation, MJ day⁻¹
 Milk = amount of milk produced, kg of milk day⁻¹
 EV_{milk} = the net energy required to produce 1 kg of milk. A default value of 4.6 MJ/kg (AFRC, 1993) can be used which corresponds to a milk fat content of 7% by weight

EQUATION 10.10
NET ENERGY FOR LACTATION FOR SHEEP (MILK PRODUCTION UNKNOWN)

$$NE_1 = \left[\frac{(5 \cdot WG_{wean})}{365} \right] \cdot EV_{milk}$$

Where:

- NE_1 = net energy for lactation, MJ day⁻¹
 WG_{wean} = the weight gain of the lamb between birth and weaning, kg
 EV_{milk} = the energy required to produce 1 kg of milk, MJ kg⁻¹. A default value of 4.6 MJ kg⁻¹ (AFRC, 1993) can be used.

EQUATION 10.11
NET ENERGY FOR WORK (FOR CATTLE AND BUFFALO)

$$NE_{work} = 0.10 \cdot NE_m \cdot Hours$$

Where:

- NE_{work} = net energy for work, MJ day⁻¹
 NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day⁻¹
 Hours = number of hours of work per day

EQUATION 10.12
NET ENERGY TO PRODUCE WOOL (FOR SHEEP)

$$NE_{wool} = \left(\frac{EV_{wool} \cdot Production_{wool}}{365} \right)$$

Where:

- NE_{wool} = net energy required to produce wool, MJ day⁻¹

EV_{wool} = the energy value of each kg of wool produced (weighed after drying but before scouring), MJ kg^{-1} . A default value of 24 MJ kg^{-1} (AFRC, 1993) can be used for this estimate.

$\text{Production}_{\text{wool}}$ = annual wool production per sheep, kg yr^{-1}

EQUATION 10.13
NET ENERGY FOR PREGNANCY (FOR CATTLE/BUFFALO AND SHEEP)

$$NE_p = C_{\text{pregnancy}} \cdot NE_m$$

Where:

NE_p = net energy required for pregnancy, MJ day^{-1}

$C_{\text{pregnancy}}$ = pregnancy coefficient (see Table 10.7)

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

EQUATION 10.14
RATIO OF NET ENERGY AVAILABLE IN A DIET FOR MAINTENANCE TO DIGESTIBLE ENERGY CONSUMED

$$REM = \left[1.123 - (4.092 \cdot 10^{-3} \cdot DE\%) + \left[1.126 \cdot 10^{-5} \cdot (DE\%)^2 \right] - \left(\frac{25.4}{DE\%} \right) \right]$$

Where:

REM = ratio of net energy available in a diet for maintenance to digestible energy consumed

DE% = digestible energy expressed as a percentage of gross energy

EQUATION 10.15
RATIO OF NET ENERGY AVAILABLE FOR GROWTH IN A DIET TO DIGESTIBLE ENERGY CONSUMED

$$REG = \left[1.164 - (5.160 \cdot 10^{-3} \cdot DE\%) + \left[1.308 \cdot 10^{-5} \cdot (DE\%)^2 \right] - \left(\frac{37.4}{DE\%} \right) \right]$$

Where:

REG = ratio of net energy available for growth in a diet to digestible energy consumed

DE% = digestible energy expressed as a percentage of gross energy

EQUATION 10.16
GROSS ENERGY FOR CATTLE/BUFFALO AND SHEEP

$$GE = \left[\frac{\left(\frac{NE_m + NE_a + NE_l + NE_{\text{work}} + NE_p}{REM} \right) + \left(\frac{NE_g + NE_{\text{wool}}}{REG} \right)}{\frac{DE\%}{100}} \right]$$

Where:

GE = gross energy, MJ day^{-1}

NE_m = net energy required by the animal for maintenance (Equation 10.3), MJ day^{-1}

NE_a = net energy for animal activity (Equations 10.4 and 10.5), MJ day^{-1}

NE_l = net energy for lactation (Equations 10.8, 10.9, and 10.10), MJ day^{-1}

NE_{work} = net energy for work (Equation 10.11), MJ day^{-1}

- NE_p = net energy required for pregnancy (Equation 10.13), MJ day⁻¹
 REM = ratio of net energy available in a diet for maintenance to digestible energy consumed (Equation 10.14)
 NE_g = net energy needed for growth (Equations 10.6 and 10.7), MJ day⁻¹
 NE_{wool} = net energy required to produce a year of wool (Equation 10.12), MJ day⁻¹
 REG = ratio of net energy available for growth in a diet to digestible energy consumed (Equation 10.15)
 $DE\%$ = digestible energy expressed as a percentage of gross energy

EQUATION 10.17
ESTIMATION OF DRY MATTER INTAKE FOR GROWING AND FINISHING CATTLE

$$DMI = BW^{0.75} \cdot \left[\frac{(0.2444 \cdot NE_{ma} - 0.0111 \cdot NE_{ma}^2 - 0.472)}{NE_{ma}} \right]$$

Where:

- DMI = dry matter intake, kg day⁻¹
 BW = live body weight, kg
 NE_{ma} = estimated dietary net energy concentration of diet or default values in Table 10.8, MJ kg⁻¹

EQUATION 10.18a
ESTIMATION OF DRY MATTER INTAKE FOR MATURE BEEF CATTLE

$$DMI = BW^{0.75} \cdot \left[\frac{(0.0119 \cdot NE_{ma}^2 + 0.1938)}{NE_{ma}} \right]$$

Where:

- DMI = dry matter intake, kg day⁻¹
 BW = live body weight, kg
 NE_{ma} = estimated dietary net energy concentration of diet or default values given in Table 10.8, MJ kg⁻¹

EQUATION 10.18b
ESTIMATION OF DRY MATTER INTAKE FOR MATURE DAIRY COWS

$$DMI = \left[\frac{\left(\frac{(5.4 \cdot BW)}{500} \right)}{\left(\frac{(100 - DE\%)}{100} \right)} \right]$$

Where:

- DMI = dry matter intake, kg day⁻¹
 BW = live body weight, kg
 $DE\%$ = digestible energy expressed as a percentage of gross energy (typically 45-55% for low quality forages)

EQUATION 10.19
ENTERIC FERMENTATION EMISSIONS FROM A LIVESTOCK CATEGORY

$$Emissions = EF_{(T)} \cdot \left(\frac{N_{(T)}}{10^6} \right)$$

Where:

Emissions = methane emissions from Enteric Fermentation, Gg CH₄ yr⁻¹

EF_(T) = emission factor for the defined livestock population, kg CH₄ head⁻¹ yr⁻¹

N_(T) = the number of head of livestock species / category T in the country

T = species/category of livestock

EQUATION 10.20
TOTAL EMISSIONS FROM LIVESTOCK ENTERIC FERMENTATION

$$\text{Total CH}_{4\text{Enteric}} = \sum_i E_i$$

Where:

Total CH₄_{Enteric} = total methane emissions from Enteric Fermentation, Gg CH₄ yr⁻¹

E_i = is the emissions for the *i*th livestock categories and subcategories

EQUATION 10.21
CH₄ EMISSION FACTORS FOR ENTERIC FERMENTATION FROM A LIVESTOCK CATEGORY

$$EF = \left[\frac{GE \cdot \left(\frac{Y_m}{100} \right) \cdot 365}{55.65} \right]$$

Where:

EF = emission factor, kg CH₄ head⁻¹ yr⁻¹

GE = gross energy intake, MJ head⁻¹ day⁻¹

Y_m = methane conversion factor, per cent of gross energy in feed converted to methane

The factor 55.65 (MJ/kg CH₄) is the energy content of methane

EQUATION 10.22
CH₄ EMISSIONS FROM MANURE MANAGEMENT

$$CH_{4\text{Manure}} = \sum_{(T)} \frac{(EF_{(T)} \cdot N_{(T)})}{10^6}$$

Where:

CH₄_{Manure} = CH₄ emissions from Manure Management, for a defined population, Gg CH₄ yr⁻¹

EF_(T) = emission factor for the defined livestock population, kg CH₄ head⁻¹ yr⁻¹

N_(T) = the number of head of livestock species/category T in the country

T = species/category of livestock

EQUATION 10.23
CH₄ EMISSION FACTOR FROM MANURE MANAGEMENT

$$EF_{(T)} = (VS_{(T)} \cdot 365) \cdot \left[B_{o(T)} \cdot 0.67 \text{ kg} / \text{m}^3 \cdot \sum_{S,k} \frac{MCF_{S,k}}{100} \cdot MS_{(T,S,k)} \right]$$

Where:

- $EF_{(T)}$ = annual CH₄ emission factor for livestock category T , kg CH₄ animal⁻¹ yr⁻¹
 $VS_{(T)}$ = daily volatile solid excreted for livestock category T , kg dry matter animal⁻¹ day⁻¹
 365 = basis for calculating annual VS production, days yr⁻¹
 $B_{o(T)}$ = maximum methane producing capacity for manure produced by livestock category T , m³ CH₄ kg⁻¹ of VS excreted
 0.67 = conversion factor of m³ CH₄ to kilograms CH₄
 $MCF_{(S,k)}$ = methane conversion factors for each manure management system S by climate region k , %
 $MS_{(T,S,k)}$ = fraction of livestock category T 's manure handled using manure management system S in climate region k , dimensionless

EQUATION 10.24
VOLATILE SOLID EXCRETION RATES

$$VS = \left[GE \cdot \left(1 - \frac{DE\%}{100} \right) + (UE \cdot GE) \right] \cdot \left[\frac{(1 - ASH)}{18.45} \right]$$

Where:

- VS = volatile solid excretion per day on a dry-organic matter basis, kg VS day⁻¹
 GE = gross energy intake, MJ day⁻¹
 DE% = digestibility of the feed in percent (e.g. 60%)
 (UE • GE) = urinary energy expressed as fraction of GE. Typically 0.04GE can be considered urinary energy excretion by most ruminants (reduce to 0.02 for ruminants fed with 85% or more grain in the diet or for swine). Use country-specific values where available.
 ASH = the ash content of manure calculated as a fraction of the dry matter feed intake (e.g., 0.08 for cattle). Use country-specific values where available.
 18.45 = conversion factor for dietary GE per kg of dry matter (MJ kg⁻¹). This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

EQUATION 10.25
DIRECT N₂O EMISSIONS FROM MANURE MANAGEMENT

$$N_2O_{D(mm)} = \left[\sum_S \left[\sum_T (N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)}) \right] \cdot EF_{3(S)} \right] \cdot \frac{44}{28}$$

Where:

- $N_2O_{D(mm)}$ = direct N₂O emissions from Manure Management in the country, kg N₂O yr⁻¹
 $N_{(T)}$ = number of head of livestock species/category T in the country
 $Nex_{(T)}$ = annual average N excretion per head of species/category T in the country, kg N animal⁻¹ yr⁻¹
 $MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless
 $EF_{3(S)}$ = emission factor for direct N₂O emissions from manure management system S in the country, kg N₂O-N/kg N in manure management system S

- S = manure management system
 T = species/category of livestock
 44/28 = conversion of (N₂O-N)_(mm) emissions to N₂O_(mm) emissions

EQUATION 10.26
N LOSSES DUE TO VOLATILISATION FROM MANURE MANAGEMENT

$$N_{volatilization-MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)} \right) \cdot \left(\frac{Frac_{GasMS}}{100} \right)_{(T,S)} \right] \right]$$

Where:

- N_{volatilization-MMS} = amount of manure nitrogen that is lost due to volatilisation of NH₃ and NO_x, kg N yr⁻¹
 N_(T) = number of head of livestock species/category *T* in the country
 Nex_(T) = annual average N excretion per head of species/category *T* in the country, kg N animal⁻¹ yr⁻¹
 MS_(T,S) = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless
 Frac_{GasMS} = percent of managed manure nitrogen for livestock category *T* that volatilises as NH₃ and NO_x in the manure management system *S*, %

EQUATION 10.27
INDIRECT N₂O EMISSIONS DUE TO VOLATILISATION OF N FROM MANURE MANAGEMENT

$$N_2O_{G(mm)} = (N_{volatilization-MMS} \cdot EF_4) \cdot \frac{44}{28}$$

Where:

- N₂O_{G(mm)} = indirect N₂O emissions due to volatilization of N from Manure Management in the country, kg N₂O yr⁻¹
 EF₄ = emission factor for N₂O emissions from atmospheric deposition of nitrogen on soils and water surfaces, kg N₂O-N (kg NH₃-N + NO_x-N volatilised)⁻¹; default value is 0.01 kg N₂O-N (kg NH₃-N + NO_x-N volatilised)⁻¹, given in Chapter 11, Table 11.3

EQUATION 10.28
N LOSSES DUE TO LEACHING FROM MANURE MANAGEMENT SYSTEMS

$$N_{leaching-MMS} = \sum_S \left[\sum_T \left[\left(N_{(T)} \cdot Nex_{(T)} \cdot MS_{(T,S)} \right) \cdot \left(\frac{Frac_{leachMS}}{100} \right)_{(T,S)} \right] \right]$$

Where:

- N_{leaching-MMS} = amount of manure nitrogen that leached from manure management systems, kg N yr⁻¹
 N_(T) = number of head of livestock species/category *T* in the country
 Nex_(T) = annual average N excretion per head of species/category *T* in the country, kg N animal⁻¹ yr⁻¹
 MS_(T,S) = fraction of total annual nitrogen excretion for each livestock species/category *T* that is managed in manure management system *S* in the country, dimensionless
 Frac_{leachMS} = percent of managed manure nitrogen losses for livestock category *T* due to runoff and leaching during solid and liquid storage of manure (typical range 1-20%)

EQUATION 10.29
INDIRECT N₂O EMISSIONS DUE TO LEACHING FROM MANURE MANAGEMENT

$$N_2O_{L(mm)} = (N_{leaching-MMS} \cdot EF_5) \cdot \frac{44}{28}$$

Where:

$N_2O_{L(mm)}$ = indirect N₂O emissions due to leaching and runoff from Manure Management in the country, kg N₂O yr⁻¹

EF_5 = emission factor for N₂O emissions from nitrogen leaching and runoff, kg N₂O-N/kg N leached and runoff (default value 0.0075 kg N₂O-N (kg N leaching/runoff)⁻¹, given in Chapter 11, Table 11.3

EQUATION 10.30
ANNUAL N EXCRETION RATES

$$N_{ex(T)} = N_{rate(T)} \cdot \frac{TAM}{1000} \cdot 365$$

Where:

$N_{ex(T)}$ = annual N excretion for livestock category T , kg N animal⁻¹ yr⁻¹

$N_{rate(T)}$ = default N excretion rate, kg N (1000 kg animal mass)⁻¹ day⁻¹ (see Table 10.19)

$TAM_{(T)}$ = typical animal mass for livestock category T , kg animal⁻¹

EQUATION 10.31
ANNUAL N EXCRETION RATES (TIER 2)

$$N_{ex(T)} = N_{intake(T)} \cdot (1 - N_{retention(T)})$$

Where:

$N_{ex(T)}$ = annual N excretion rates, kg N animal⁻¹ yr⁻¹

$N_{intake(T)}$ = the annual N intake per head of animal of species/category T , kg N animal⁻¹ yr⁻¹

$N_{retention(T)}$ = fraction of annual N intake that is retained by animal of species/category T , dimensionless

EQUATION 10.32
N INTAKE RATES FOR CATTLE

$$N_{intake(T)} = \frac{GE}{18.45} \cdot \left(\frac{CP\%}{6.25} \right)$$

Where:

$N_{intake(T)}$ = daily N consumed per animal of category T , kg N animal⁻¹ day⁻¹

GE = gross energy intake of the animal, in enteric model, based on digestible energy, milk production, pregnancy, current weight, mature weight, rate of weight gain, and IPCC constants, MJ animal⁻¹ day⁻¹

18.45 = conversion factor for dietary GE per kg of dry matter, MJ kg⁻¹. This value is relatively constant across a wide range of forage and grain-based feeds commonly consumed by livestock.

CP% = percent crude protein in diet, input

6.25 = conversion from kg of dietary protein to kg of dietary N, kg feed protein (kg N)⁻¹

EQUATION 10.33
N RETAINED RATES FOR CATTLE

$$N_{\text{retention}(T)} = \left[\frac{\text{Milk} \cdot \left(\frac{\text{Milk PR}\%}{100} \right)}{6.38} \right] + \left[\frac{\text{WG} \cdot \left[268 - \left(\frac{7.03 \cdot \text{NE}_g}{\text{WG}} \right) \right]}{\frac{1000}{6.25}} \right]$$

Where:

$N_{\text{retention}(T)}$ = daily N retained per animal of category T , kg N animal⁻¹ day⁻¹

Milk = milk production, kg animal⁻¹ day⁻¹ (applicable to dairy cows only)

Milk PR% = percent of protein in milk, calculated as $[1.9 + 0.4 \cdot \text{\%Fat}]$, where %Fat is an input, assumed to be 4% (applicable to dairy cows only)

6.38 = conversion from milk protein to milk N, kg Protein (kg N)⁻¹

WG = weight gain, input for each livestock category, kg day⁻¹

268 and 7.03 = constants from Equation 3-8 in NRC (1996)

NE_g = net energy for growth, calculated in livestock characterisation, based on current weight, mature weight, rate of weight gain, and IPCC constants, MJ day⁻¹

1000 = conversion from grams per kilogram, g kg⁻¹

6.25 = conversion from kg dietary protein to kg dietary N, kg Protein (kg N)⁻¹

EQUATION 10.34
MANAGED MANURE N AVAILABLE FOR APPLICATION TO MANAGED SOILS, FEED, FUEL OR CONSTRUCTION USES

$$N_{\text{MMS_Avb}} = \sum_S \left\{ \sum_{(T)} \left[\frac{\left(N_{(T)} \cdot \text{Nex}_{(T)} \cdot \text{MS}_{(T,S)} \right) \cdot \left(1 - \frac{\text{Frac}_{\text{LossMS}}}{100} \right)}{\left[N_{(T)} \cdot \text{MS}_{(T,S)} \cdot N_{\text{beddingMS}} \right]} \right] + \right\}$$

Where:

$N_{\text{MMS_Avb}}$ = amount of managed manure nitrogen available for application to managed soils or for feed, fuel, or construction purposes, kg N yr⁻¹

$N_{(T)}$ = number of head of livestock species/category T in the country

$\text{Nex}_{(T)}$ = annual average N excretion per animal of species/category T in the country, kg N animal⁻¹ yr⁻¹

$\text{MS}_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S in the country, dimensionless

$\text{Frac}_{\text{LossMS}}$ = amount of managed manure nitrogen for livestock category T that is lost in the manure management system S , % (see Table 10.23)

$N_{\text{beddingMS}}$ = amount of nitrogen from bedding (to be applied for solid storage and deep bedding MMS if known organic bedding usage), kg N animal⁻¹ yr⁻¹

S = manure management system

T = species/category of livestock

I. EQUATIONS FOR N₂O AND OTHER CO₂ EMISSIONS FROM MANAGED SOILS

EQUATION 11.1

DIRECT N₂O EMISSIONS FROM MANAGED SOILS (TIER 1)

$$N_2O_{Direct-N} = N_2O-N_{N\text{ inputs}} + N_2O-N_{OS} + N_2O-N_{PRP}$$

Where:

$$N_2O-N_{N\text{ inputs}} = \left[\left[(F_{SN} + F_{ON} + F_{CR} + F_{SOM}) \cdot EF_1 \right] + \left[(F_{SN} + F_{ON} + F_{CR} + F_{SOM})_{FR} \cdot EF_{1FR} \right] \right]$$

$$N_2O-N_{OS} = \left[\left(F_{OS,CG,Temp} \cdot EF_{2CG,Temp} \right) + \left(F_{OS,CG,Trop} \cdot EF_{2CG,Trop} \right) + \left(F_{OS,F,Temp,NR} \cdot EF_{2F,Temp,NR} \right) + \left(F_{OS,F,Temp,NP} \cdot EF_{2F,Temp,NP} \right) + \left(F_{OS,F,Trop} \cdot EF_{2F,Trop} \right) \right]$$

$$N_2O-N_{PRP} = \left[\left(F_{PRP,CPP} \cdot EF_{3PRP,CPP} \right) + \left(F_{PRP,SO} \cdot EF_{3PRP,SO} \right) \right]$$

Where:

- $N_2O_{Direct-N}$ = annual direct N₂O–N emissions produced from managed soils, kg N₂O–N yr⁻¹
- $N_2O-N_{N\text{ inputs}}$ = annual direct N₂O–N emissions from N inputs to managed soils, kg N₂O–N yr⁻¹
- N_2O-N_{OS} = annual direct N₂O–N emissions from managed organic soils, kg N₂O–N yr⁻¹
- N_2O-N_{PRP} = annual direct N₂O–N emissions from urine and dung inputs to grazed soils, kg N₂O–N yr⁻¹
- F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr⁻¹
- F_{ON} = annual amount of animal manure, compost, sewage sludge and other organic N additions applied to soils (Note: If including sewage sludge, cross-check with Waste sector to ensure there is no double counting of N₂O emissions from the N in sewage sludge), kg N yr⁻¹
- F_{CR} = annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils, kg N yr⁻¹
- F_{SOM} = annual amount of N in mineral soils that is mineralised, in association with loss of soil C from soil organic matter as a result of changes to land use or management, kg N yr⁻¹
- F_{OS} = annual area of managed/drained organic soils, ha (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)
- F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr⁻¹ (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)
- EF_1 = emission factor for N₂O emissions from N inputs, kg N₂O–N (kg N input)⁻¹ (Table 11.1)
- EF_{1FR} = emission factor for N₂O emissions from N inputs to flooded rice, kg N₂O–N (kg N input)⁻¹ (Table 11.1)
- EF_2 = emission factor for N₂O emissions from drained/managed organic soils, kg N₂O–N ha⁻¹ yr⁻¹; (Table 11.1) (Note: the subscripts CG, F, Temp, Trop, NR and NP refer to Cropland and Grassland, Forest Land, Temperate, Tropical, Nutrient Rich, and Nutrient Poor, respectively)
- EF_{3PRP} = emission factor for N₂O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals, kg N₂O–N (kg N input)⁻¹; (Table 11.1) (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)

EQUATION 11.2**DIRECT N₂O EMISSIONS FROM MANAGED SOILS (TIER 2)**

$$N_2O_{Direct-N} = \sum_i (F_{SN} + F_{ON})_i \cdot EF_{i1} + (F_{CR} + F_{SOM}) \cdot EF_1 + N_2O-N_{OS} + N_2O-N_{PRP}$$

Where:

EF_{i1} = emission factors developed for N₂O emissions from synthetic fertiliser and organic N application under conditions i (kg N₂O-N (kg N input)⁻¹); $i = 1, \dots, n$.

EQUATION 11.3**N FROM ORGANIC N ADDITIONS APPLIED TO SOILS (TIER 1)**

$$F_{ON} = F_{AM} + F_{SEW} + F_{COMP} + F_{OOA}$$

Where:

F_{ON} = total annual amount of organic N fertiliser applied to soils other than by grazing animals, kg N yr⁻¹

F_{AM} = annual amount of animal manure N applied to soils, kg N yr⁻¹

F_{SEW} = annual amount of total sewage N (coordinate with Waste sector to ensure that sewage N is not double-counted) that is applied to soils, kg N yr⁻¹

F_{COMP} = annual amount of total compost N applied to soils (ensure that manure N in compost is not double-counted), kg N yr⁻¹

F_{OOA} = annual amount of other organic amendments used as fertiliser (e.g., rendering waste, guano, brewery waste, etc.), kg N yr⁻¹

EQUATION 11.4**N FROM ANIMAL MANURE APPLIED TO SOILS (TIER 1)**

$$F_{AM} = N_{MMS_Avb} \cdot \left[1 - \left(\text{Frac}_{FEED} + \text{Frac}_{FUEL} + \text{Frac}_{CNST} \right) \right]$$

Where:

F_{AM} = annual amount of animal manure N applied to soils, kg N yr⁻¹

N_{MMS_Avb} = amount of managed manure N available for soil application, feed, fuel or construction, kg N yr⁻¹ (see Equation 10.34 in Chapter 10)

Frac_{FEED} = fraction of managed manure used for feed

Frac_{FUEL} = fraction of managed manure used for fuel

Frac_{CNST} = fraction of managed manure used for construction

EQUATION 11.5**N IN URINE AND DUNG DEPOSITED BY GRAZING ANIMALS ON PASTURE, RANGE AND PADDOCK (TIER 1)**

$$F_{PRP} = \sum_T \left[(N_{(T)} \cdot \text{Nex}_{(T)}) \cdot MS_{(T,PRP)} \right]$$

Where:

F_{PRP} = annual amount of urine and dung N deposited on pasture, range, paddock and by grazing animals, kg N yr⁻¹

$N_{(T)}$ = number of head of livestock species/category T in the country (see Chapter 10, Section 10.2)

$\text{Nex}_{(T)}$ = annual average N excretion per head of species/category T in the country, kg N animal⁻¹ yr⁻¹ (see Chapter 10, Section 10.5)

$MS_{(T,PRP)}$ = fraction of total annual N excretion for each livestock species/category T that is deposited on pasture, range and paddock (see Chapter 10, Section 10.5)

EQUATION 11.6
N FROM CROP RESIDUES AND FORAGE/PASTURE RENEWAL (TIER 1)

$$F_{CR} = \sum_T \left\{ \begin{aligned} &Crop_{(T)} \bullet (Area_{(T)} - Area_{burnt(T)} \bullet C_f) \bullet Frac_{Renew(T)} \bullet \\ &\left[R_{AG(T)} \bullet N_{AG(T)} \bullet (1 - Frac_{Remove(T)}) + R_{BG(T)} \bullet N_{BG(T)} \right] \end{aligned} \right\}$$

Where:

F_{CR} = annual amount of N in crop residues (above and below ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually, kg N yr⁻¹

$Crop_{(T)}$ = harvested annual dry matter yield for crop T , kg d.m. ha⁻¹

$Area_{(T)}$ = total annual area harvested of crop T , ha yr⁻¹

$Area_{burnt(T)}$ = annual area of crop T burnt, ha yr⁻¹

C_f = combustion factor (dimensionless) (refer to Chapter 2, Table 2.6)

$Frac_{Renew(T)}$ = fraction of total area under crop T that is renewed annually. For countries where pastures are renewed on average every X years, $Frac_{Renew} = 1/X$. For annual crops $Frac_{Renew} = 1$

$R_{AG(T)}$ = ratio of above-ground residues dry matter ($AG_{DM(T)}$) to harvested yield for crop T ($Crop_{(T)}$), kg d.m. (kg d.m.)⁻¹,

$$= AG_{DM(T)} \bullet 1000 / Crop_{(T)} \text{ (calculating } AG_{DM(T)} \text{ from the information in Table 11.2)}$$

$N_{AG(T)}$ = N content of above-ground residues for crop T , kg N (kg d.m.)⁻¹, (Table 11.2)

$Frac_{Remove(T)}$ = fraction of above-ground residues of crop T removed annually for purposes such as feed, bedding and construction, kg N (kg crop-N)⁻¹. Survey of experts in country is required to obtain data. If data for $Frac_{Remove}$ are not available, assume no removal.

$R_{BG(T)}$ = ratio of below-ground residues to harvested yield for crop T , kg d.m. (kg d.m.)⁻¹. If alternative data are not available, $R_{BG(T)}$ may be calculated by multiplying R_{BG-BIO} in Table 11.2 by the ratio of total above-ground biomass to crop yield ($= [(AG_{DM(T)} \bullet 1000 + Crop_{(T)}) / Crop_{(T)}]$, (also calculating $AG_{DM(T)}$ from the information in Table 11.2).

$N_{BG(T)}$ = N content of below-ground residues for crop T , kg N (kg d.m.)⁻¹, (Table 11.2)

T = crop or forage type

EQUATION 11.7
DRY-WEIGHT CORRECTION OF REPORTED CROP YIELDS

$$Crop_{(T)} = Yield_{Fresh(T)} \bullet DRY$$

Where:

$Crop_{(T)}$ = harvested dry matter yield for crop T , kg d.m. ha⁻¹

$Yield_{Fresh(T)}$ = harvested fresh yield for crop T , kg fresh weight ha⁻¹

DRY = dry matter fraction of harvested crop T , kg d.m. (kg fresh weight)⁻¹

EQUATION 11.7A
ALTERNATIVE APPROACH TO ESTIMATE F_{CR} (USING TABLE 11.2)

$$F_{CR} = \sum_T \left\{ \begin{aligned} &AG_{DM(T)} \bullet (Area_{(T)} - Area_{burnt(T)} \bullet CF) \bullet Frac_{Renew(T)} \bullet \\ &\left[N_{AG(T)} \bullet (1 - Frac_{Remove(T)}) + R_{BG-BIO(T)} \bullet N_{BG(T)} \right] \end{aligned} \right\}$$

Where:

F_{CR} = annual amount of N in crop residues (above and below ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually, kg N yr⁻¹

EQUATION 11.8
N MINERALISED IN MINERAL SOILS AS A RESULT OF LOSS OF SOIL C THROUGH CHANGE IN LAND USE OR MANAGEMENT (TIERS 1 AND 2)

$$F_{SOM} = \sum_{LU} \left[\left(\Delta C_{Mineral, LU} \cdot \frac{1}{R} \right) \cdot 1000 \right]$$

Where:

F_{SOM} = the net annual amount of N mineralised in mineral soils as a result of loss of soil carbon through change in land use or management, kg N

$\Delta C_{Mineral, LU}$ = average annual loss of soil carbon for each land-use type (LU), tonnes C (Note: for Tier 1, $\Delta C_{mineral, LU}$ will have a single value for all land-uses and management systems. Using Tier 2 the value for $\Delta C_{mineral, LU}$ will be disaggregated by individual land-use and/or management systems.

R = C:N ratio of the soil organic matter. A default value of 15 (uncertainty range from 10 to 30) for the C:N ratio (R) may be used for situations involving land-use change from Forest Land or Grassland to Cropland, in the absence of more specific data for the area. A default value of 10 (range from 8 to 15) may be used for situations involving management changes on *Cropland Remaining Cropland*. C:N ratio can change over time, land use, or management practice. If countries can document changes in C:N ratio, then different values can be used over the time series, land use, or management practice.

LU = land-use and/or management system type

EQUATION 11.9
N₂O FROM ATMOSPHERIC DEPOSITION OF N VOLATILISED FROM MANAGED SOILS (TIER 1)

$$N_2O_{(ATD)-N} = [(F_{SN} \cdot Frac_{GASF}) + ((F_{ON} + F_{PRP}) \cdot Frac_{GASM})] \cdot EF_4$$

Where:

$N_2O_{(ATD)-N}$ = annual amount of N₂O–N produced from atmospheric deposition of N volatilised from managed soils, kg N₂O–N yr⁻¹

F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N yr⁻¹

$Frac_{GASF}$ = fraction of synthetic fertiliser N that volatilises as NH₃ and NO_x, kg N volatilised (kg of N applied)⁻¹ (Table 11.3)

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils, kg N yr⁻¹

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, kg N yr⁻¹

$Frac_{GASM}$ = fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH₃ and NO_x, kg N volatilised (kg of N applied or deposited)⁻¹ (Table 11.3)

EF_4 = emission factor for N₂O emissions from atmospheric deposition of N on soils and water surfaces, [kg N–N₂O (kg NH₃–N + NO_x–N volatilised)⁻¹] (Table 11.3)

EQUATION 11.10
N₂O FROM N LEACHING/RUNOFF FROM MANAGED SOILS IN REGIONS WHERE LEACHING/RUNOFF OCCURS (TIER 1)

$$N_2O_{(L)-N} = (F_{SN} + F_{ON} + F_{PRP} + F_{CR} + F_{SOM}) \cdot Frac_{LEACH-(H)} \cdot EF_5$$

Where:

$N_2O_{(L)-N}$ = annual amount of N_2O-N produced from leaching and runoff of N additions to managed soils in regions where leaching/runoff occurs, $kg N_2O-N yr^{-1}$

F_{SN} = annual amount of synthetic fertiliser N applied to soils in regions where leaching/runoff occurs, $kg N yr^{-1}$

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils in regions where leaching/runoff occurs, $kg N yr^{-1}$

F_{PRP} = annual amount of urine and dung N deposited by grazing animals in regions where leaching/runoff occurs, $kg N yr^{-1}$ (from Equation 11.5)

F_{CR} = amount of N in crop residues (above- and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually in regions where leaching/runoff occurs, $kg N yr^{-1}$

F_{SOM} = annual amount of N mineralised in mineral soils associated with loss of soil C from soil organic matter as a result of changes to land use or management in regions where leaching/runoff occurs, $kg N yr^{-1}$ (from Equation 11.8)

$Frac_{LEACH-(H)}$ = fraction of all N added to/mineralised in managed soils in regions where leaching/runoff occurs that is lost through leaching and runoff, $kg N (kg \text{ of } N \text{ additions})^{-1}$ (Table 11.3)

EF_5 = emission factor for N_2O emissions from N leaching and runoff, $kg N_2O-N (kg N \text{ leached and runoff})^{-1}$ (Table 11.3)

EQUATION 11.11

N_2O FROM ATMOSPHERIC DEPOSITION OF N VOLATILISED FROM MANAGED SOILS (TIER 2)

$$N_2O_{(ATD)-N} = \left\{ \sum_i (F_{SN_i} \cdot Frac_{GASF_i}) + [(F_{ON} + F_{PRP}) \cdot Frac_{GASM}] \right\} \cdot EF_4$$

Where:

$N_2O_{(ATD)-N}$ = annual amount of N_2O-N produced from atmospheric deposition of N volatilised from managed soils, $kg N_2O-N yr^{-1}$

F_{SN_i} = annual amount of synthetic fertiliser N applied to soils under different conditions i , $kg N yr^{-1}$

$Frac_{GASF_i}$ = fraction of synthetic fertiliser N that volatilises as NH_3 and NO_x under different conditions i , $kg N \text{ volatilised } (kg \text{ of } N \text{ applied})^{-1}$

F_{ON} = annual amount of managed animal manure, compost, sewage sludge and other organic N additions applied to soils, $kg N yr^{-1}$

F_{PRP} = annual amount of urine and dung N deposited by grazing animals on pasture, range and paddock, $kg N yr^{-1}$

$Frac_{GASM}$ = fraction of applied organic N fertiliser materials (F_{ON}) and of urine and dung N deposited by grazing animals (F_{PRP}) that volatilises as NH_3 and NO_x , $kg N \text{ volatilised } (kg \text{ of } N \text{ applied or deposited})^{-1}$ (Table 11.3)

EF_4 = emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, $[kg N-N_2O (kg NH_3-N + NO_x-N \text{ volatilised})^{-1}]$ (Table 11.3)

EQUATION 11.12

ANNUAL CO_2 EMISSIONS FROM LIME APPLICATION

$$CO_2-C \text{ Emission} = (M_{Limestone} \cdot EF_{Limestone}) + (M_{Dolomite} \cdot EF_{Dolomite})$$

Where:

$CO_2-C \text{ Emission}$ = annual C emissions from lime application, tonnes C yr^{-1}

M = annual amount of calcic limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$), tonnes yr^{-1}

EF = emission factor, tonne of C (tonne of limestone or dolomite) $^{-1}$

$$\text{EQUATION 11.13}$$

$$\text{ANNUAL CO}_2\text{ EMISSIONS FROM UREA APPLICATION}$$

$$\text{CO}_2\text{-C Emission} = M \cdot EF$$

Where:

$\text{CO}_2\text{-C Emission}$ = annual C emissions from urea application, tonnes C yr⁻¹

M = annual amount of urea fertilisation, tonnes urea yr⁻¹

EF = emission factor, tonne of C (tonne of urea)⁻¹

J. EQUATIONS FOR HARVESTED WOOD PRODUCTS

$$\text{EQUATION 12.1}$$

$$\text{ESTIMATION OF CARBON STOCK AND ITS ANNUAL CHANGE IN HWP POOLS OF THE REPORTING COUNTRY}$$

Starting with $i = 1900$ and continuing to present year, compute

$$(A) \quad C(i+1) = e^{-k} \cdot C(i) + \left[\frac{1 - e^{-k}}{k} \right] \cdot \text{Inflow}(i) \quad \text{with } C(1900) = 0.0$$

$$(B) \quad \Delta C(i) = C(i+1) - C(i)$$

Note: For an explanation of technique used in Equations 12.1A to estimate first-order decay see Pingoud and Wagner (2006).

Where:

i = year

$C(i)$ = the carbon stock of the HWP pool in the beginning of year i , Gg C

k = decay constant of first-order decay given in units, yr⁻¹ ($k = \ln(2) / \text{HL}$, where HL is half-life of the HWP pool in years. A half-life is the number of years it takes to lose one-half of the material currently in the pool.)

$\text{Inflow}(i)$ = the inflow to the HWP pool during year i , Gg C yr⁻¹

$\Delta C(i)$ = carbon stock change of the HWP pool during year i , Gg C yr⁻¹

$$\text{EQUATION 12.2}$$

$$\text{ESTIMATION OF HWP PRODUCTS PRODUCED ANNUALLY FROM DOMESTIC CONSUMPTION}$$

$$\text{Inflow}_{DC} = P + \text{SFP}_{IM} - \text{SFP}_{EX}$$

Where:

Inflow_{DC} = carbon in annual consumption of solidwood or paper products that came from wood harvested in the reporting country (that is, from domestic harvest), Gg C yr⁻¹

P = carbon in annual production of solidwood or paper products in the reporting country, Gg C yr⁻¹

SFP_{IM} and SFP_{EX} = imports and exports of semi-finished wood and paper products. For solidwood, this includes sawnwood, panels, and other industrial roundwood. For paper products, this includes paper and paperboard, Gg C yr⁻¹

EQUATION 12.3
ESTIMATION OF HWP PRODUCTS PRODUCED ANNUALLY FROM DOMESTIC HARVEST

$$Inflow_{DH} = P \cdot \left[\frac{IRW_H}{IRW_H + IRW_{IM} - IRW_{EX} + WCH_{IM} - WCH_{EX} + WR_{IM} - WR_{EX}} \right]$$

Where:

$Inflow_{DH}$ = carbon in annual production of solidwood or paper products that came from wood harvested in the reporting country (that is, from domestic harvest), Gg C yr⁻¹

P = carbon in annual production of solidwood or paper products in the reporting country, Gg C yr⁻¹. Note that paper product production includes wood fibre and excludes non-wood fibre. An equation to estimate the wood fibre in paper products production is shown in Note 1 of Table 12.5.

IRW_H = industrial roundwood harvest in the reporting country. This is the harvest of wood to make solidwood and paper products including IRW for export. [The FAO variable is called Industrial RW Production], Gg C yr⁻¹

IRW_{IM} , IRW_{EX} = industrial roundwood imports and exports, respectively, Gg C yr⁻¹

WCH_{IM} , WCH_{EX} = wood chip imports and exports, respectively, Gg C yr⁻¹

WR_{IM} , WR_{EX} = wood residues from wood products mills imports and exports, respectively, Gg C yr⁻¹

EQUATION 12.4
ESTIMATION OF ANNUAL CHANGE IN CARBON IN HWP IN DOMESTIC SWDS WHERE HWP CAME FROM DOMESTIC HARVEST

$$\Delta C_{HWP\ SWDS_{DH}} = \Delta C_{HWP\ SWDS_{DC}} \cdot \left[1 - \left(\frac{\text{Imported wood material}}{\text{Produced wood material} + \text{Imported wood material}} \right) \right]$$

$$\text{Imported wood material} = \left[\begin{array}{l} IRW_{IM} + WCH_{IM} + WR_{IM} + \text{Sawn}W_{IM} + \text{WPan}_{IM} + \\ P\&PB_{IM} + \text{WPulp\&RecPap}_{IM} \end{array} \right]$$

$$\text{Produced wood material} = IRW_H$$

Where:

$\Delta C_{HWP\ SWDS_{DH}}$ = Variable 2B = annual change in carbon in HWP in domestic SWDS where HWP came from domestic wood harvest, Gg C yr⁻¹

$\Delta C_{HWP\ SWDS_{DC}}$ = Variable 1B = annual change in carbon in HWP in SWDS in the reporting country, Gg C yr⁻¹

IRW_H and IRW_{IM} = industrial roundwood harvest in the reporting country and industrial roundwood imports, respectively, Gg C yr⁻¹

WCH_{IM} = wood chip imports, Gg C yr⁻¹

WR_{IM} = wood residues from wood products mills imports, Gg C yr⁻¹

$\text{Sawn}W_{IM}$ = sawn wood imports and, Gg C yr⁻¹

WPan_{IM} = wood panel imports, Gg C yr⁻¹

$P\&PB_{IM}$ = paper and paperboard imports, Gg C yr⁻¹

$\text{WPulp\&RecPap}_{IM}$ = wood pulp and recovered paper imports, Gg C yr⁻¹

EQUATION 12.5**ESTIMATION OF CARBON RELEASE USING HWP VARIABLES**

For annual carbon release from wood stocks in the reporting country

$$(A) \quad \uparrow C_{HWPDC} = H + P_{IM} - P_{EX} - \Delta C_{HWP IU DC} - \Delta C_{HWP SWDS DC}$$

For annual carbon release from wood harvested in the reporting country

$$(B) \quad \uparrow C_{HWP DH} = H - \Delta C_{HWP IU DH} - \Delta C_{HWP SWDS DH}$$

EQUATION 12.6**EQUATION TO ESTIMATE PRODUCTION, IMPORTS OR EXPORT VARIABLES IN TABLE 12.5 FOR YEARS BEFORE 1961**

$$V_t = V_{1961} \cdot e^{[U \cdot (t-1961)]}$$

Where:

V_t = annual production, imports or exports for a solidwood or paper product for year t , Gg C yr⁻¹

t = year

V_{1961} = annual production, imports or exports for a solidwood or paper product for the year 1961, Gg C yr⁻¹

U = estimated continuous rate of change in industrial roundwood consumption for the region that includes the reporting country between 1900 and 1961 (see Table 12.3), yr⁻¹