Annex 1: *Ex ante* estimation of the project net emissions

Title of the JCM project: Prey Lang Wildlife Sanctuary - Stung Treng REDD+ project

In this document, equation numberings correspond to those described in the applied methodology, i.e., JCM_KH_AM004 ver01.1.

I. Selection of the Option

Option 1 provided in the applied methodology, which uses the National FRL transition probabilities from forest to non-forest classes only, was selected for the establishment of the project reference level in JCM Project Design Document Form for REDD-plus (PDD) and therefore was used for *ex ante* estimation of the project net emissions.

II. *Ex ante* carbon stock change in the project area in year *y* ($\Delta CS_{pj\,y}$)

In *ex post* calculation, the actual areas converted from forest to non-forest, $CA_{pj\,i\,y}$, will be determined using Cambodia's official forest map. However, because Cambodia's official forest map is only created every two years and was not available for *ex ante* estimation, we used the result of own remote sensing analysis using Sentinel 2A imagery in *ex ante* calculation. This remote sensing analysis was performed mainly for the implementation of effective patrolling, and its result will not be used in *ex post* calculation. Visual delineation of land entities (digitization) is listed in Chapter 2.1 MONITORING CHANGES IN FOREST AREA under Step 5.2: analysis methods of the GOFC-GOLD Source book COP 22 version 1[1]. This method was selected because (a) data already being collected for law enforcement monitoring of the forest area, (b) it is possible to complete the manual digitization in monthly intervals due to the relatively small size of the project area, (c) does not require advanced levels of technical expertise, and (d) the high degree of familiarity of the forest area by the digitizers. Note that the project reference level has been established and available in PDD.

Sentinel 2A imagery was downloaded from http://glovis.usgs.gov and used to detect and estimate deforestation in the project site. The Ministry of Environment's official forest cover map for 2016 was used as the base map, and non-forested areas in the map was excluded from the analysis. Every month where cloud cover was low enough for analysis, a set of two satellite images (Table A-1) were compared using ArcGIS 10.8. Visually detected areas of deforestation were manually digitized by drawing polygons using editor tool, image analysis tool, composite band tool and drawing tool in ArcGIS 10.8. Monthly, twenty point locations were opportunistically selected for field-checking by ranger teams. Additionally, polygons with unclear classification, (e.g. deforestation and older agricultural fields) were ground-truthed by project teams using GPS units and Drones (DJI Phantom and Mavic).

[1] http://www.gofcgold.wur.nl/redd/sourcebook/GOFC-GOLD_Sourcebook.pdf

Table A- 1 Sets of remote sensing images used to detect areas of deforestation during each monitoring period

ID	**Satellite**	**Start date**	**End date**
1	Sentinel 2	01 Jan 2018	25 Feb 2018
2	Sentinel 2	25 Feb 2018	22 December 2018
3	Sentinel 2	22 December 2018	21 Jan 2019
4	Sentinel 2	21 Jan 2019	15 Feb 2019
5	Sentinel 2	15 Feb 2019	22 Mar 2019
6	Sentinel 2	22 Mar 2019	16 Apr 2019
7	Sentinel 2	16 Apr 2019	21 Oct 2019
8	Sentinel 2	21 Oct 2019	02 Dec 2019
9	Sentinel 2	02 Dec 2019	27 Dec 2019
10	Sentinel 2	27 Dec 2019	19 Jan 2020

The project was started in March 2018, and the remote sensing analysis was performed to the project area for 2018 and 2019. Table A-2 shows the deforestation areas estimated from the analysis, and these results were used as *ex ante* areas converted from forest to non-forest in the project area, $CA_{pj\ i\ y}$, in 2018 and 2019. From 2020 to 2024 and then from 2025 onwards, we applied a reduction of 10% and 20%, respectively, each year from the deforestation area in the previous year, based on expectation that deforestation will decrease as a result of project activities. The percentages were determined based on professional judgment. Table A- 3 shows the *ex ante* estimations of carbon stock change in the project area in year y, $\Delta CS_{pj\ y}$, which were calculated with $CA_{pj\ i\ y}$, emission factors in Table 2 in the applied methodology and Equation 11.

Table A- 2 *Ex ante* estimation of areas converted from forest *i* to non-forest, $CA_{pj\ i\ y}$

Estimation method	Year	Area converted from forest class *i* to non-forest in the project area, ha				
		Evergreen forest	Semi-evergreen forest	Deciduous forest	Bamboo	Forest regrowth
Remote sensing analysis	2018	43	185	3	2	4
	2019	149	380	20	1	28
10% reduction from the previous year	2020	134	342	18	1	25
	2021	120	308	16	1	23
	2022	108	277	14	1	21
	2023	98	249	13	1	19
	2024	88	225	12	1	17
20% reduction	2025	70	180	9	1	13

from the previous year	2026	56	144	7	0	11
	2027	45	115	6	0	9
	2028	36	92	5	0	7
	2029	29	74	4	0	5

Table A- 3 *Ex ante* carbon stock change in the project area in year *y*, $\Delta CS_{pj\ y}$

Year	*Ex ante* estimation of $\Delta CS_{pj\ y}$, tC
2018	29,243
2019	67,114
2020	60,402
2021	54,362
2022	48,926
2023	44,033
2024	39,630
2025	31,704
2026	25,363
2027	20,290
2028	16,232
2029	12,986
Total	450,285

III. CO_2 emissions from fossil fuel combustion in year y ($E_{fuel\ y}$)

The only planned activity which results in fossil fuel combustion is for patrolling and for community supports with motorbikes, and the *ex ante* $E_{fuel\ y}$ was calculated based on the actual fossil fuel use, which was recorded as the purchase receipts.

In 2018, 2019 and 2020, the project used 4,602, 5,846 and 6,957 liter of motor gasoline respectively, and these values were applied for the 1st, 2nd and 3rd year estimation. For the *ex ante* estimation from the 4th year onward, we used the amount of fuel consumption in the 3rd year. The amount in volume was conservatively converted to that in mass by applying 0.783 g/cm^3, which is the highest density allowed under Japanese Industrial Standard[2].

For *ex ante* estimation, we assume that similar level of activities and the same quantity of fuel consumption continue for the entire monitoring period. $E_{fuel\ y}$ was calculated with the direct method and 2006 IPCC default numbers 0.0443 and 0.0693 for net calorific value (NCV) and CO_2 emission factor (EF_{fuel}) respectively (2006 IPCC Guidelines Volume 2, Table 1.2 of Chapter 1 and Table 3.2.1 of Chapter 3) by applying Equation 14. Table A- 4 shows the results.

[2] https://www.jisc.go.jp/app/jis/general/GnrJISUseWordSearchList?toGnrJISStandardDetailList

Table A- 4 Quantity of fuel type *f* consumed in year *y*, $FC_{f\ y}$, and *ex ante* estimation for CO_2 emissions from fossil fuel combustion in year *y*, $E_{fuel\ y}$

Year	$FC_{f\ y}$, kg	*Ex ante* estimation for $E_{fuel\ y}$, tCO_2
2018	3,603	11.1
2019	4,577	14.1
2020	5,447	16.7
2021	5,447	16.7
2022	5,447	16.7
2023	5,447	16.7
2024	5,447	16.7
2025	5,447	16.7
2026	5,447	16.7
2027	5,447	16.7
2028	5,447	16.7
2029	5,447	16.7
Total	62,654	192.3

IV. GHG emissions from fertilizer application within the activity area as a part of the project activities in year y ($E_{fertilizer\ y}$)

The project plans to utilize green manure in local villagers' farms to improve agricultural production, and candidate species for green manure are listed below:

- *Canavalia ensiformes*
- *Crotalaria juncea* L.
- *Panicum purpurascens* Mez.
- *Brachiaria brizantha*
- *Eleusine coracana* Gaern
- *Cajanus cajan*
- *Stylosanthes guianensis*

Based on the project management record, *Crotalaria juncea* L., which is a legume, was applied in 2 ha of cashew plantation and 0.2 ha of rice field in 2020 as a demonstration, but no green manure was utilized in 2018 and 2019. In all cases, *Crotalaria juncea* L. was harvested twice a year, making the annual harvested area double, i.e., 4 ha in cashew plantation and 0.4 ha in a rice field in 2020. This information was used for the 1st, 2nd and 3rd year estimation. For the *ex ante* estimation from the 4th year onward, we assume that beans would be used as N-fixing crop throughout the area under the project's support, though there would be some area where no green manure, in particular early stage of the project, or other types of green manure is utilized, or non-paddy area where green manure is utilized. We assume that the area under the project's support will be increased 200 ha every 2 years until 600 ha and be all rice field. Same as for 2020, the areas were doubled to calculate the annual harvested areas.

We calculated 1) direct N_2O emissions as a result of nitrogen application within the project area and the activity area for the implementation of the project activities in year *y*, $E_{direct\text{-}N\ y}$, 2) indirect N_2O emissions as a result of nitrogen application within the project area and the activity area for implementation of the project activities in year *y*, $E_{indirect\text{-}N\ y}$, and 3) GHG emissions from fertilizer application within the project area and the activity area for implementation of the project activities in year *y*, $E_{fertilizer\ y}$ by applying the parameters described in Table A- 5, Equations 16, 17, 20, 21 and 24. The results are summarized in Table A- 6.

In addition to green manure, the project also plans to use organic fertilizer. According to the methodology, organic fertilizer which is made from organic materials sourced from inside the project area and the activity area are NOT accounted, and this is the case for the project. Therefore, green manure is the only source of N_2O emissions from fertilizer application.

Table A- 5 Parameters applied to calculate emissions as a result of fertilizer application

Parameter	Value	Source
Harvested annual dry matter yield for N-fixing crop *T*, introduced during the implementation of the project activities in cropland type *c* in the activity area in year *y*, $Crop_{c\ T\ y}$, t d.m./ha	1.1579	FAOSTAT, Bean yield of Cambodia in 2019
Total annual area harvested of N-fixing crop *T*, introduced during the implementation of the project activities in cropland type *c* in the activity area in year *y*, $Area_{\ c\ T\ y}$, ha	In rice paddy, 0 ha in the 1st and 2nd year, 0.4 ha in the 3rd year, 400 ha in 4th and 5th year, 800 ha in 6th and 7th year, and 1200 ha in the following years. In general (non paddy), 0 ha in the 1st and 2nd year, 4 ha in the 3rd year, and 0 ha in the following years.	Project management record
Fraction of total area under N-fixing crop *T* that is renewed annually, $Frac_{Renew\ T}$	1 dimentionless	Interview for local agriculture expert (available in Project management record)
Ratio of above-ground residues to harvested	1.864 t d.m. (t d.m.)$^{-1}$ (*)	$Crop_{c\ T\ y}$ and values for

yield for N-fixing crop *T*, $R_{AG\ T}$		"Beans & pulses" in Table 11.2 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines
N content of above-ground residues for N-fixing crop *T*, $N_{AG\ T}$	0.008 t N (t d.m.)$^{-1}$	Value for "Beans & pulses" in Table 11.2 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines
Ratio of below-ground residues to harvested yield for crop *T*, $R_{BG\ T}$	0.544 t d.m. (t d.m.)$^{-1}$ (**)	$Crop_{c\ T\ y}$ and values for "Beans & pulses" in Table 11.2 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines
N content of below-ground residues for crop *T*, $N_{BG\ T}$	0.008 t N (t d.m.)$^{-1}$	Value for "Beans & pulses" in Table 11.2 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines
Global Warming Potential for N_2O, GWP_{N2O}	298 tCO_2 tN_2O^{-1}	Table 2.14 in Ch.2 of Working Group I contribution to the IPCC Forth Assessment Report
Fraction of N that area lost through leaching and runoff, $Frac_{leach}$	0.3 dimensionless	Table 11.3 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines
Emission factor for N_2O emissions from N leaching and runoff, $EF_{leach\text{-}N}$	0.0075 tN_2O-N (t leaching and runoff)$^{-1}$	Table 11.3 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines
Emission factor for N_2O emission from N inputs for Rice paddy (flooded rice field), $EF_{direct\text{-}N\ (paddy)}$	0.003 tN_2O-N (tN-input)$^{-1}$	Table 11.1 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines
Fraction that volatilized as NH_3 and NOx for organic fertilizers, $Frac_{ON}$	0.20 dimentionless	Table 11.3 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines
Emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces, $EF_{indirect\text{-}N}$	0.010 tN_2O-N (tNH_3-N and NO_X-N volatilized)$^{-1}$	Table 11.3 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines

Fraction of N that is lost through leaching and runoff, $Frac_{leach}$	0.30 dimentionless	Table 11.3 of Ch. 11, Vol, 4 of 2006 IPCC Guidelines

(*) $R_{AG\ T}$ was calculated as ratio of above-ground residues dry matter for crop T, $AG_{DM\ T}$, to harvested yield for crop T, $Crop_{c\ T\ y}$ by following the method described under equation 11.6 of Ch. 11, Vol. 4 of 2006 IPCC Guidelines. $AG_{DM\ T}$ was calculated by applying the coefficients for "Beans & pulses", 1.13 and 0.85, in Table 11.2 of Ch. 11, Vol. 4 of 2006 IPCC Guidelines and $Crop_{c\ T\ y}$, 1.1579, in Table A-5 above. $R_{AG\ T} = AG_{DM\ T} / 1.1579$; $AG_{DM\ T} = 1.1579 * 1.13 + 0.85$.

(**) $R_{BG\ T}$ was calculated by following a method described under equation 11.6 of Ch. 11, Vol. 4 of 2006 IPCC Guidelines, i.e., multiplying R_{BG-BIO}, 0.19, in Table 11.2 of Ch. 11, Vol. 4 of 2006 IPCC Guidelines by the ratio of total above-ground biomass to $Crop_{c\ T\ y}$.,1.1579. $R_{BG\ T} = 0.19 * (AG_{DM\ T} + 1.1570) / 1.1579$; $AG_{DM\ T} = 1.1579 * 1.13 + 0.85$.

Table A- 6 Emissions as a result of fertilizer application

Year	$E_{direct-N\ y}$, tCO_2-eq	$E_{indirect-N\ y}$, tCO_2-eq	$E_{liming\ y}$, tCO_2-eq	$E_{urea\ y}$, tCO_2-eq	$E_{fertilizer\ y}$, tCO_2-eq
2018	0.0	0.0	0.0	0.0	0.0
2019	0.0	0.0	0.0	0.0	0.0
2020	0.4	0.1	0.0	0.0	0.5
2021	12.5	9.4	0.0	0.0	21.9
2022	12.5	9.4	0.0	0.0	21.9
2023	25.1	18.8	0.0	0.0	43.9
2024	25.1	18.8	0.0	0.0	43.9
2025	37.6	28.2	0.0	0.0	65.8
2026	37.6	28.2	0.0	0.0	65.8
2027	37.6	28.2	0.0	0.0	65.8
2028	37.6	28.2	0.0	0.0	65.8
2029	37.6	28.2	0.0	0.0	65.8
Total	263.7	197.5	0.0	0.0	461.2

V. Estimation of displaced emissions

Displaced emissions will be estimated as increases of emissions from reference emissions in the displacement belt. Please refer PDD for the reference emissions in the displacement belt. In *ex post* calculation, the actual areas converted from forest to non-forest in the displacement belt, $CA_{d\ pj\ i\ y}$, will be determined using Cambodia's official forest map. However, because Cambodia's official forest map is only created every two years and was not available for *ex ante* estimation, we used the result of own remote sensing analysis using Sentinel 2A imagery in *ex ante* calculation. As described above, this remote sensing analysis was performed mainly for the implementation of effective patrolling and its result will not be used in *ex post* calculation.

As with the project area, the remote sensing analysis was performed on the displacement belt for 2018 and 2019. Table A- 7 shows the deforestation areas estimated from the analysis, and these results were used as *ex ante* areas converted from forest to non-forest in the displacement belt, $CA_{d\ pj\ i\ y}$, in 2018 and 2019. From 2020 to 2024 and then from 2025 onwards, we applied a 10% and 20% reduction each year from the deforestation area in the previous year. The *ex ante* estimations of carbon stock change in the displacement belt in year *y*, $\Delta CS_{d\ pj\ y}$ were calculated with $CA_{d\ pj\ i\ y}$, emission factors in Table 2 in the applied methodology and Equation 34. Table A- 8 shows the results.

Table A- 7 *Ex ante* estimation of areas converted from forest *i* to non-forest in the displacement belt, $CA_{d\ pj\ i\ y}$

Estimation method	Year	Area converted from forest class *i* to non-forest in the displacement belt, ha				
		Evergreen forest	Semi-evergreen forest	Deciduous forest	Bamboo	Forest regrowth
Remote sensing analysis	2018	62	318	54	0	28
	2019	287	710	71	3	60
10% reduction from the previous year	2020	258	639	64	3	54
	2021	232	575	58	2	49
	2022	209	517	52	2	44
	2023	188	466	47	2	40
	2024	169	419	42	2	36
20% reduction from the previous year	2025	135	335	34	1	29
	2026	108	268	27	1	23
	2027	87	215	22	1	18
	2028	69	172	17	1	15
	2029	55	137	14	1	12

Ex ante project emissions from the displacement belt in year *y*, DP_y, were then calculated with Equation 29. DP_y was compared with reference emissions from the displacement belt in year $_y$, DR_y (Table F in PDD), and *ex ante* displaced emissions to the displacement belt in year *y*, DE_y, was estimated with Equation 27. Table A- 8 shows the results.

Table A- 8 *Ex ante* displaced emissions to the displacement belt

Year	$\Delta CS_{d\ pj\ y}$, tC	DP_y, tCO_2	DE_y, tCO_2
2018	52,394	192,111.7	56,919.8

2019	128,081	469,629.5	306,867.2
2020	115,273	422,666.5	265,298.2
2021	103,745	380,399.9	228,207.1
2022	93,371	342,359.9	195,136.5
2023	84,034	308,123.9	165,674.9
2024	75,630	277,311.5	139,452.2
2025	60,504	221,849.2	88,404.7
2026	48,403	177,479.4	48,283.6
2027	38,723	141,983.5	16,878.7
2028	30,978	113,586.8	0.0
2029	24,783	90,869.4	0.0
Total	855,919	3,138,371.2	1,511,122.8

VI. *Ex ante* estimation of the project net emissions in year *y*, PE_y

Based on *ex ante* estimation of $\Delta CS_{pj\ y}$, $E_{fuel\ y}$, $E_{fertilizer\ y}$ and DE_y, project net emissions in year *y*, PE_y, was estimated by applying Equation 10. Table A- 9 summarizes the results.

Table A- 9 *Ex ante* estimation of project net emissions in year *y*

Year	$\Delta CS_{pj\ y}$ * 44/12, tCO_2	$E_{fuel\ y}$, tCO_2	$E_{fertilizer\ y}$, tCO_2-eq	DE_y, tCO_2	PE_y, tCO_2
2018	107,224	11.1	0.0	56,919.8	164,154.5
2019	246,083	14.1	0.0	306,867.2	552,964.1
2020	221,475	16.7	0.5	265,298.2	486,790.0
2021	199,327	16.7	21.9	228,207.1	427,572.9
2022	179,394	16.7	21.9	195,136.5	374,569.6
2023	161,455	16.7	43.9	165,674.9	327,190.4
2024	145,309	16.7	43.9	139,452.2	284,822.3
2025	116,248	16.7	65.8	88,404.7	204,734.8
2026	92,998	16.7	65.8	48,283.6	141,364.2
2027	74,398	16.7	65.8	16,878.7	91,359.7
2028	59,519	16.7	65.8	0.0	59,601.3
2029	47,615	16.7	65.8	0.0	47,697.6
Total	1,651,045	192.3	461.2	1,511,122.8	3,162,821.5