Improved uncertainties analysis of Indonesia's Forest Reference Emission Level 2016

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List of acronyms

AD	Activity Data
CIFOR	Center for International Forestry Research
CO_2e	Carbon Dioxide Equivalent
EF	Emission Factor
FAO	Food and Agriculture Organization of the United Nations
FREL	Forest Reference Emission Level
GHGs	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
ITPC	International Tropical Peatlands Center
LCT	Land-Cover Transition
MCS	Monte Carlo Simulation
MoEF	Ministry of Environment and Forestry
MRV	Monitoring, Reporting, and Verification
NDC	Nationally Determined Contribution
NFI	National Forest Inventory
NFMS	National Forest Monitoring System
PD	Peat Decomposition
PDF	Probability Density Function
PEA	Propagation of Error Approach
REDD	Reducing Emissions from Deforestation and forest Degradation
SLMS	Satellite Land Monitoring System
UNFCCC	United Nations Framework Convention on Climate Change

Foreword

According to the Intergovernmental Panel on Climate Change (IPCC), uncertainty estimation is the essential element of a complete greenhouse gas (GHG) inventory. Uncertainty analysis is also part of the UNFCCC reporting requirement for GHG inventories.

Uncertainties of Indonesia's Forest Reference Emission Level 2016 (FREL-2016) were estimated using the propagation of error approach (PEA). This working paper is written as a scientific-based recommendation and suggestion to improve the uncertainty analysis of the FREL-2016 by combining PEA and Monte Carlo simulations (MCs). To improve the uncertainty analysis of Indonesia's FREL–2016, the activity data (AD) and emission factors (EFs) (associated uncertainties) were compiled; AD and EFs databases were then standardized, and quality controls were implemented.

We hope that the information in this working paper could be beneficial for policymakers and practitioners. Unless otherwise stated, the authors have generated some of the information in the tables and figures.

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Summary

Uncertainties of Indonesia's Forest Reference Emission Level 2016 (FREL–2016) were estimated using Intergovernmental Panel on Climate Change (IPCC) Approach 1 (propagation of error, or PEA). This approach is adequate when uncertainties are not large. However, uncertainties of emission factors (EFs) of Indonesia's FREL–2016 from peat decomposition and forest degradation are large. In such cases, IPCC Approach 2 – Monte Carlo simulation (MCS) – is more suitable for detailed category-by-category assessment of uncertainty. For this reason, an improved uncertainty analysis of the FREL–2016 used MCS. This approach combined uncertainties of activity data (AD) and EFs to estimate overall emissions uncertainties per activity and period. Uncertainties estimated using MCS were higher than those reported in FREL–2016. Proper implementation of MCS attempted to address this bias.

Following decision 12/CP.17, the most recent IPCC guidelines should inform the FREL and/or the Forest Reference Level. This should include transparent, complete, consistent, and accurate information. This effort to improve Indonesia's FREL–2016 has stressed accuracy. In so doing, it aimed to demonstrate the improvement of uncertainty when MCS is applied.

To improve the uncertainty analysis of Indonesia's FREL–2016, the AD and EF (associated uncertainties) were compiled; AD and EF databases were then standardized and quality controls were implemented; the methodology to combine uncertainties using MCS (following the 2006 IPCC Guidelines) was designed; an algorithm (code in the statistical software R) was developed; finally, estimated emissions of the FREL–2016 and associated uncertainties were re-run using the AD and EF databases and the R-code.

The analysis found:

- Uncertainties of emissions from deforestation at island level have values between 20% and 30% when MCS was used, which are higher than the 14% value reported in Indonesia´s FREL–2016. This suggests an underestimation of 1.5 to 2 times.
- Uncertainties of emissions from degradation at island level have values between 20% and 50% when MCS was used, which are higher than the 15%–20% values reported in Indonesia´s FREL–2016. This means an underestimation of at least 2 times.
- Uncertainties of emissions from peat decomposition have values between 35% and 83% with a median of 50% when MCS was used, which are higher than the 31%–36% (with a median of 36%) values reported in Indonesia's FREL–2016. This means an underestimation of at least 1.5 times in the first four periods (1990–1996, 1996–2000, 2000–2003 and 2003–2006).

Using MCS, the overall emissions uncertainties per period have values between 13% and 36%. Meanwhile, the values reported in FREL–2016 are between 8% and 21%, which implies an underestimation. On the other hand, the FREL uncertainty reported in Indonesia's FREL–2016 has a value of 16%. Using MCS, FREL uncertainty has a value of –9.1% and +9.3. This means an overestimation of FREL uncertainty reported in Indonesia's FREL–2016.

Finally, there are several cases where (i) uncertainties of annual emissions from peat decomposition at transition level are large and distributions are not normal, and (ii) distributions of annual emissions from degradation at transition level are non-normal. Consequently, it is more appropriate to combine the uncertainties of FREL–2016 using MCS rather than IPCC Approach 1.

This improved analysis also found that uncertainties of emissions due to deforestation, degradation and peat decomposition at forest type, island and/or period and overall are larger than those values reported in Indonesia's FREL–2016. This is mainly because the current analysis used MCS to combine uncertainties, while PEA was applied in Indonesia's FREL–2016 to combine uncertainties.

1 Background

Under its Nationally Determined Contribution (NDC), Indonesia has committed to reduce its greenhouse gas (GHG) emissions unconditionally by 26% by 2020, and by 29% by 2030 compared with a business-as-usual scenario. Following the Indonesian Biennial Update Report from 2016, Indonesia reported that 51.6% of its emissions were from the land sector (land-use change, degradation, and peat/forest fires), with energy (fossil fuel combustion) contributing approximately 36.9% of total emissions (MoEF 2018). Therefore, Reducing Emissions from Deforestation and forest Degradation, and the sustainable management of forests, and conservation and enhancement of forest carbon stocks (REDD+) is a key component of the NDC target from the land-use sector. The Forest Reference Emission Level (FREL) for REDD+ submitted by Indonesia to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat in January 2016 (hereafter "FREL–2016") covers emissions from deforestation, forest degradation and peat decomposition. The FREL, set at 0.57 $GtCO_2e$ yr^{-1} using 1990–2012 as its reference period, is the benchmark for evaluating REDD+ performance against actual emissions during the 2013–2020 implementation period (MoEF 2016).

While the Indonesian FREL is a laudable first effort, UNFCCC reviewers identified areas for technical improvement. These encompassed inclusion of peatland fires, non-CO_2 emissions, and post-conversion/-intervention removals, among others. Indonesia's FREL accounts for CO_2 emissions from changes in above-ground biomass and soil carbon in peatlands resulting from deforestation and forest degradation. Emissions are reported at a Tier 2 level using country-specific data. In addition to the already adopted emission factors (EFs), Indonesia uses its own high-resolution land-cover dynamics, known as activity data (AD) for the most important land-cover categories, which are country specific.

Carbon reservoirs comprise tropical wetlands such as peatlands and mangroves. Consequently, a major area for improvement in the FREL and national monitoring, reporting, and verification (MRV) systems is the refinement of GHG accounting in these wetlands. Emissions from peatland fires, which accounted for 27% of national emissions in 2014 (Republic of Indonesia 2017), must be included in the FREL. Annual non-CO_2 emissions from drained peatlands can be substantial depending on the land-use category and should not be omitted. As per the IPCC Wetlands Supplement, mangrove ecosystems in Indonesia are important carbon sinks. Therefore, the FREL should consider land-use change dynamics (deforestation, degradation, regeneration) and emissions/removal in biomass and also in soil.

The proposed strategy for improving the FREL and updating the existing MRV system for wetlands is aimed at further characterizing underrepresented forest dynamics, such as peatland fires and mangrove deforestation, degradation, and regeneration. There is a need to reduce EF and AD uncertainties, including non-CO_2 GHGs, and to reinforce sink monitoring. This pathway should be in line with efforts to enhance Indonesia's ambitions for its NDC as stipulated in the Paris Agreement.

2 Objective

To improve and re-run the uncertainty in Indonesia's FREL–2016. The revision of the baseline FREL uncertainty will rely on MCS using the AD and EF and associated uncertainties provided by the Government of Indonesia.

3 Justification

The Annex to decision 12/CP.17 establishes that the most recent IPCC Guidelines (2006) should guide information established in the FREL and/or Forest Reference Level, and include transparent, complete, consistent, and accurate information, including the methodology selected to prepare these reports. According to IPCC (2006), estimates of emissions should not contain bias (avoiding incorrect conceptualizations, mode inputs, and assumptions) to the extent practical and possible. Once bias has been corrected as much as possible, the uncertainty analysis should focus on the quantification of random errors regarding the average estimate.

Once uncertainties of the different sources for a category have been correctly determined, they can be combined to obtain the uncertainties of emissions. According to IPCC (2006), there are two combination methods: Method 1 uses simple propagation of error approach (PEA) equations, while Method 2 uses the Monte Carlo simulation (MCS). The latter is suitable for a detailed assessment, category by category, of uncertainty. This is especially relevant in cases where uncertainties are large, distribution is not normal, algorithms are complex functions and/or there are correlations between some of the sets of activities, EFs or both. Furthermore, it is good practice to use Method 2 instead of Method 1 (IPCC 2006).

Here the aim is to re-run FREL–2016 with higher transparency, accuracy, completeness, and comparability to ensure higher confidence in Indonesia´s land-use sectors under its NDC for potential conditional support. One activity of this strategy is to improve the accuracy of FREL–2016 estimates through a combination of uncertainties using more accurate methods like MCS.

4 Methods

Improving and re-running the submitted Indonesian FREL–2016 uncertainty followed several steps. First, AD and EFs (associated uncertainties) used in the estimation of Improved uncertainties analysis of FREL–2016 were compiled. Second, AD and EF databases were standardized and quality controls were implemented. Third, the methodological approach to combine uncertainties using MCS (following the 2006 IPCC Guidelines) was designed. Finally, an algorithm (code in the statistical software R) was developed and implemented to re-run the estimations of emissions of the FREL–2016 and associated uncertainties. These steps are presented in detail in sections 4.1 and 4.2.

4.1 Inputs

4.1.1 Databases of activity data

Tables 1 and 2 present AD and associated uncertainties per activity (deforestation, degradation, peat decomposition due to deforestation, peat decomposition due to degradation, and peat decomposition due to secondary forest) and periods (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011 and 2011–2012) used in the improved uncertainties analysis of FREL–2016.

No data to obtain approximations of uncertainties for AD were available for information in Table 3 (decomposition due to deforestation), Table 4 (decomposition due to degradation), and Table 5 (decomposition due to secondary forest).

Table 1. Activity data (and associated uncertainties) from deforestation per island, forest type, and period used in the Improved uncertainties analysis of Indonesia's FREL–2016

Island	Code	Forest Type	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
			AD	U	AD	U	AD	U	AD	U	AD	U	AD	U	AD	U
SUMATERA	2001	Primary dry land forest	218	24	12,427	33	862	30	4,502	30	8,063	28	7,871	25	7,300	28
	2002	Secondary dry land forest	427,906	24	2,132,848	33	162,499	30	291,180	30	775,125	28	185,085	25	206,338	28
	2005	Primary swamp forest	9,906	24	129,460	33	16	30	3,806	30	99,109	28	10,994	25	5,855	28
	20051	Secondary swamp forest	823,209	24	1,535,223	33	206,079	30	647,190	30	664,746	28	298,350	25	141,812	28
	2004	Primary mangrove forest	198	24	2,666	33			256	30	1,212	28	108	25	710	28
	20041	Secondary mangrove forest	7,766	24	54,932	33	10,870	30	10,263	30	25,192	28	4,020	25	5,916	28
KALIMANTAN	2001	Primary dry land forest	38,885	24	140,128	33	465	30	5,496	30	3,051	28	554	25	6,968	28
	2002	Secondary dry land forest	1,170,928	24	1,440,058	33	388,456	30	557,503	30	598,708	28			198,472	28
	2005	Primary swamp forest	37,520	24	35,130	33	14	30	849	30	7,073	28	10,994	25	940	28
	20051	Secondary swamp forest	1,216,014	24	44,9270	33	227,236	30	311,268	30	410006	28	298,350	25	79,719	28
	2004	Primary mangrove forest	0	24	17,874	33	2,705	30	1,373	30	483	28	108	25	159	28
	20041	Secondary mangrove forest	65,546	24	8,345	33	51,515	30	85,583	30	22,298	28	4,020	25	8,781	28
PAPUA	2001	Primary dry land forest	263	24	301,517	33	2,543	30	46,430	30	17,483	28	14,347	25	9,704	28
	2002	Secondary dry land forest			338,032	33	34,067	30	158,537	30	71,260	28	11,309	25	22,871	28
	2005	Primary swamp forest			186,292	33	590	30	3,497	30	13,293	28	5,079	25	1,598	28
	20051	Secondary swamp forest			320,213	33	43,840	30	45,055	30	12,397	28	702	25	8,308	28
	2004	Primary mangrove forest	214	24	38,115	33			33	30	93	28	88	25	209	28
	20041	Secondary mangrove forest			34,696	33	2,663	30	8,215	30	793	28	344	25	287	28
SULAWESI	2001	Primary dry land forest	849	24	186,956	33	5,390	30	13,508	30	4327	28	18,985	25	1,888	28
	2002	Secondary dry land forest	21680	24	777,265	33	202,451	30	257,310	30	121,439	28	55,046	25	17,584	28
	2005	Primary swamp forest			6,148	33										28
	20051	Secondary swamp forest	3724	24	31,199	33	401	30	1,809	30	11,239	28	105	25	65	28
	2004	Primary mangrove forest	10	24	8,809	33	59	30	75	30	186	28	116	25		28
	20041	Secondary mangrove forest	831	24	17,132	33	3,135	30	6,141	30	3,521	28	549	25	215	28

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Table 1. Continued

Island	Code	Forest Type	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
			AD	U	AD	U	AD	U	AD	U	AD	U	AD	U	AD	U
JAVA	2001	Primary dry land forest			44,402	33	58	30	2,872	30	84	28	150	25		28
	2002	Secondary dry land forest	35	24	161,504	33	11,128	30	39,949	30	6,341	28	6,297	25	1,264	28
	2005	Primary swamp forest			30	33										28
	20051	Secondary swamp forest														28
	2004	Primary mangrove forest			1,498	33			6	30						28
	20041	Secondary mangrove forest			978	33	228	30	523	30	6,075	28	6	25		28
NUSA	2001	Primary dry land forest			34,126	33	3838	30	1097	30	190	28	146	25	1,409	28
	2002	Secondary dry land forest	1552	24	17,8991	33	4156	30	32485	30	4,685	28	3,189	25	52,017	28
	2005	Primary swamp forest							99	30						28
	20051	Secondary swamp forest			224	33			2	30						28
	2004	Primary mangrove forest			579	33							152	25	1,541	28
	20041	Secondary mangrove forest			1,091	33	17	30	38	30			115	25	3	28
MALUKU	2001	Primary dry land forest			41,616	33	38	30	36	30	309	28	1,732	25	10	28
	2002	Secondary dry land forest	0	24	321,931	33	26015	30	28339	30	25,406	28	21,953	25	6,573	28
	2005	Primary swamp forest			2,400	33										28
	20051	Secondary swamp forest			18,411	33					50	28	1,021	25		28
	2004	Primary mangrove forest			219	33	18	30	13	30	188	28	1	25	105	28
	20041	Secondary mangrove forest			529	33	23	30	170	30	48	28	22	25	0	28

AD = activity data in hectares
U = Uncertainties in percentage

Table 2. Activity data (and associated uncertainties) from degradation per island, land-cover transition, and period used in the Improved uncertainties analysis of Indonesia's FREL–2016

Island	Code t1	Code t2	Primary Forest Type t1	Secondary Forest Type t2	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
					AD	U	AD	U	AD	U	AD	U	AD	U	AD	U	AD	U
SUMATERA	2001	2002	Dry land	Dry land	796	19	362,070	24	147	22	10,520	24	3,595	21	24,472	20	26	24
		20041		Swamp	-		-		-		-		-		-		-	
		20051		Mangrove	-		-		-		-		-		-		-	
	2005	2002	Swamp	Dry land	-		-		-		-		-		-		-	
		20041		Swamp	-		-		-		-		-		-		-	
		20051		Mangrove	21,580	19	990	24	3,506	22	19,531	24	38,422	21	18,045	20	2,320	24
	2004	2002	Mangrove	Dry land	-		80	24	-		-		-		-			
		20041		Swamp	10,836	19	9,261	24	181	22	503	24	28,044	21	248	20		
		20051		Mangrove	-		104	24	-		-		-		2,672	20		
KALIMANTAN	2001	2002	Dry land	Dry land	227,463	19	1,093,551	24	801,687	22	373,224	24	67,601	21	17,713	20	10,210	24
		20041		Swamp	-		-		-		-		-		-		-	
		20051		Mangrove	4,348	19	1,339	24	-		-		-		-		-	
	2005	2002	Swamp	Dry land	-		-		-		-		-		-			
		20041		Swamp	5,963	19	-		-		-		-		-			
		20051		Mangrove	16,082	19	1,480	24	2,860	22	7,129	24	747	21	305	20		
	2004	2002	Mangrove	Dry land	-		-		-		-		-					
		20041		Swamp	72	19	5	24	5,522	22	8,304	24	1,840	21				
		20051		Mangrove	-		-		-		-		-					

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Table 2. Continued

Island	Code t1	Code t2	Primary Forest Type t1	Secondary Forest Type t2	1990–1996 AD	1990–1996 U	1996–2000 AD	1996–2000 U	2000–2003 AD	2000–2003 U	2003–2006 AD	2003–2006 U	2006–2009 AD	2006–2009 U	2009–2011 AD	2009–2011 U	2011–2012 AD	2011–2012 U
PAPUA	2001	2002	Dry land	Dry land			1,526,772	24	698,916	22	523,468	24	832,207	21	38,524	20	1,007	24
		20041		Swamp			373	24	-		-		-		-		-	
		20051		Mangrove			15,150	24	-		-		-		-		-	
	2005	2002	Swamp	Dry land			-		-		-		-		-		-	
		20041		Swamp			-		-		104	24	-		-		-	
		20051		Mangrove			2,062	24	101,644	22	159,246	24	151,224	21	23,344	20	514,724	
	2004	2002	Mangrove	Dry land			-	-	-	-	-	-	-		-		-	
		20041		Swamp			78	24	8,605	22	13,453	24	8,542	21	305	20		
		20051		Mangrove			-		-		-		-		-		-	
SULAWESI	2001	2002	Dry land	Dry land	97,950	19	1,897,146	24	403,464	22	829,066	24	95,649	21	186,689	20	1,046,224	
		20041		Swamp														
		20051		Mangrove														
	2005	2002	Swamp	Dry land														
		20041		Swamp														
		20051		Mangrove														
	2004	2002	Mangrove	Dry land	-		-		-		-		-		-		-	
		20041		Swamp	420	19	409	24	2,972	22	2,674	24	1,790	21	92	20		
		20051		Mangrove	-		-		-		-		-		-		-	
JAVA	2001	2002	Dry land	Dry land			28,450	24	710	22	28,279	24	265,950	21				
		20041		Swamp			-		-		-		-					
		20051		Mangrove			-		-		-		-					
	2005	2002	Swamp	Dry land														
		20041		Swamp														
		20051		Mangrove														

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Table 2. Continued

Island	Code t1	Code t2	Primary Forest Type t1	Secondary Forest Type t2	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
					AD	U	AD	U	AD	U	AD	U	AD	U	AD	U	AD	U
	2004	2002	Mangrove	Dry land														
		20041		Swamp														
		20051		Mangrove														
NUSA	2001	2002	Dry land	Dry land					-				-					
		20041		Swamp					64	22			922	21				
		20051		Mangrove					-				-					
	2005	2002	Swamp	Dry land			274,638	24	3,295	22	3,369	24	59,426	21	2,107	20	1,437,924	
		20041		Swamp			-		-		-		-		-		-	
		20051		Mangrove			-		-		-		-		-		-	
	2004	2002	Mangrove	Dry land														
		20041		Swamp	82	19			256	22			26	21			61,824	
		20051		Mangrove	-		-		-		-		-		-		-	
MALUKU	2001	2002	Dry land	Dry land			219,109	24	11,830	22	10,359	24	56	21	7,375	20	0	
		20041		Swamp			-		-		-		-		-		0	
		20051		Mangrove			-		-		-		-		-		-	
	2005	2002	Swamp	Dry land														
		20041		Swamp														
		20051		Mangrove														
	2004	2002	Mangrove	Dry land	-		-		-		170,022	24	-		-		0	
		20041		Swamp			70	24			11	24	5,150	21	85	20	0	
		20051		Mangrove	-		-				-		-		-		-	

AD = Activity data in hectares   U = Uncertainties in percentage t1 = time 1   t2 = time 2

Table 3. Activity data from peat decomposition due to deforestation per island, land-cover transition, and period used in the Improved uncertainties analysis of Indonesia's FREL–2016 (in hectares)

Period	LC	2006	2007	2010	2012	2014	2500	3000	5001	20071	20091	20092	20093	20094	20121	20122	20141	50011
1990–1996	2001		2,400	39		98				811		61						
	2002	3,938	10,823	1,029		2,363				74,073	306	6,905	17,375					17,159
	2004									21								
	2005	4,447	143	208		3,168				16,328	663	3	2					19
	20041			95		27			2	25,109	5		29					
	20051	19,260	15,056	129,489	3,434	57,226		11	63	362,270	25,661	43,013	21,914		47			79,365
1996–2000	2001		7,351	977	11	268			2	10,220	148	3,515						2,460
	2002	3,287	21,707	39,916	529	10,433		2,394	364	5,012	5,517	4,402				669	25	112
	2004		594			205			124	1,721	5	5		1				25
	2005		2,707	14,771	292	1,363	638	2,359	111	102,649	500	757					4	17,594
	20041		274			106				292		19		20				
	20051	8,665	26,057	284,534	1,009	100,552	1,753	35,218	143	806,672	14,534	20,932	5,573	1,101			401	36,527
2000–2003	2001		338									256						
	2002	81	5,275	1,451	4	1,646				123	30	1,171					336	
	2004									1								
	2005									454								
	20041					44				1,431								
	20051	1,004	217	9,192		59,531		141		132,184	106	1,548	249					2,877
2003–2006	2001		301						10		7	350						
	2002	83	6,878	2,252		2,359	10				370	1,462					77	
	2004																	
	2005					820				5,713		7					6	
	20041			246						5,943	5		36					
	20051	29,434	1,249	46,390		148,774				322,963	572	1,804	77				72	919
	2001			30							18	40						

continued on next page

Table 3. Continued

Period	LC	2006	2007	2010	2012	2014	2500	3000	5001	20071	20091	20092	20093	20094	20121	20122	20141	50011
2006–2009	2002	105	12,381	1,456	13	3,345				75	202	4,765						
	2004					52												
	2005	3,084	494	48,806		5,357				33,508		42						
	20041			520		25				781	20							
	20051	74,609	162	102,505		76,484				403,329	12,298	13,274	891	8			196	1,953
2009–2011	2001											229						
	2002		2,017	30		697					18	2,674					39	
	2004					213												
	2005	773	439	552						1,965								
	20041	23								1,031								
	20051	41,395	17	22,532						119,570	777	5,257				81		303
2011–2012	2001			581	9													
	2002		1,140	331	80					5	99	42				196		
	2004				12								25					
	2005	280								22						91		
	20041									309	39	243	1			49		
	20051	19,266	887	19,484				3		62,712	548	185	120			75		130

Note: LC = Land Cover

Table 4. Activity data from peat decomposition due to degradation per island, land-cover transition, and period used in the Improved uncertainties analysis of Indonesia's FREL–2016 (in hectares)

Period	LC	2002 (ha)	20041 (ha)	20051 (ha)
1990–1996	2001	285		1,297
	2004			
	2005		733	32,507
1996–2000	2001	84,571	109	5,036
	2004		313	
	2005			1,826
2000–2003	2001	16,083		
	2004		823	
	2005			20,569
2003–2006	2001	31,447		
	2004		436	
	2005			50,853
2006–2009	2001	14,533		
	2004		3,456	
	2005			64,041
2009–2011	2001	535		
	2004		254	
	2005			20,737
2011–2012	2001			
	2004			
	2005			2,938

Note: LC = Land Cover

Table 5. Activity data from peat decomposition due to secondary forest per island, land-cover transition, and period used in the Improved uncertainties analysis of Indonesia's FREL–2016

Period	LC	2002 (ha)	20041 (ha)	20051 (ha)
1990–1996	2002	315,569		
	20041		95,049	
	20051			6,430,829
1996–2000	2002	221,466		
	20041		95,249	
	20051			5,120,928
2000–2003	2002	295,936		
	20041		94,388	
	20051			4,928,048
2003–2006	2002	298,532		
	20041		89,018	
	20051			4,515,161
2006–2009	2002	293,880		
	20041		88,140	
	20051			3,883,756

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Table 5. Continued

Period	LC	2002 (ha)	20041 (ha)	20051 (ha)
2009–2011	2002	302,937		
	20041		90,488	
	20051			3,680,310
2011–2012	2002	306,235		
	20041		90,106	
	20051			3,564,731

Note: LC = Land Cover

4.1.2 Databases of emission factors

Tables 6, 7, and 8 present EFs (and associated uncertainties) per activity (deforestation, degradation, peat decomposition) used in the present report, where taken from Indonesia´s submitted FREL–2016.

Table 6. Emission factors (and associated uncertainties) from deforestation per island and land cover, taken from Indonesia´s FREL–2016

Island	Code	Forest Type	*Mean AGB (Mg ha^{-1})	N of plot	U_EF (%)	EF (t CO_2 ha^{-1})	U_EF (%)
SUMATERA	2001	Primary dry land forest	269	92	8	463	8
	2002	Secondary dry land forest	182	265	6	314	6
	2005	Primary swamp forest	221	22	21	381	21
	20051	Secondary swamp forest	151	160	7	261	7
	2004	Primary mangrove forest	264	8	21	455	21
	20041	Secondary mangrove forest	202	12	21	348	21
KALIMANTAN	2001	Primary dry land forest	269	333	4	465	4
	2002	Secondary dry land forest	203	608	3	351	3
	2005	Primary swamp forest	275	3	2	474	2
	20051	Secondary swamp forest	171	166	7	294	7
	2004	Primary mangrove forest	264	8	21	455	21
	20041	Secondary mangrove forest	202	12	21	348	21
PAPUA	2001	Primary dry land forest	239	162	5	412	5
	2002	Secondary dry land forest	180	60	12	311	12
	2005	Primary swamp forest	179	67	10	308	10
	20051	Secondary swamp forest	146	16	27	251	27
	2004	Primary mangrove forest	264	8	21	455	21
	20041	Secondary mangrove forest	202	12	21	348	21
SULAWESI	2001	Primary dry land forest	275	221	5	475	5
	2002	Secondary dry land forest	207	197	6	356	6
	2005	Primary swamp forest	214	3	21	370	21
	20051	Secondary swamp forest	128	12	42	221	42
	2004	Primary mangrove forest	264	8	21	455	21
	20041	Secondary mangrove forest	202	12	21	348	21

continued on next page

Table 6. Continued

Island	Code	Forest Type	*Mean AGB (Mg ha^{-1})	N of plot	U_EF (%)	EF (t CO_2 ha^{-1})	U_EF (%)
JAVA	2001	Primary dry land forest	-	-	-	-	-
	2002	Secondary dry land forest	171	1	-	294	-
	2005	Primary swamp forest	-	-	-	-	-
	20051	Secondary swamp forest	-	-	-	-	-
	2004	Primary mangrove forest	-	-	-	-	-
	20041	Secondary mangrove forest	-	-	-	-	-
NUSA	2001	Primary dry land forest	274	52	10	473	10
	2002	Secondary dry land forest	163	69	14	281	14
	2005	Primary swamp forest	-	-	-	-	-
	20051	Secondary swamp forest	-	-	-	-	-
	2004	Primary mangrove forest	264	8	21	455	21
	20041	Secondary mangrove forest	202	12	21	348	21
MALUKU	2001	Primary dry land forest	301	14	27	520	27
	2002	Secondary dry land forest	222	99	8	383	8
	2005	Primary swamp forest	-	-	-	-	-
	20051	Secondary swamp forest	-	-	-	-	-
	2004	Primary mangrove forest	264	8	21	455	21
	20041	Secondary mangrove forest	202	12	21	348	21

*The value mean AGB (Mg ha^{-1}) is obtained by converting AGB to C in Mg ha^{-1} by multiplying by 0.47 as the conversion factor. The biomass was converted to CO_2eq by multiplying by 44/12.
Source: MoEF 2016.

Table 7. Emission factors (and associated uncertainties) from degradation per island and land cover, taken from Indonesia's FREL–2016

Island	Code t1	Code t2	Primary Forest Type t1	Secondary Forest Type t2	Mean AGB-t1 (Mg ha^{-1})	U_EF (%)	*Mean AGB-t2 (Mg ha^{-1})	U_EF (%)	EF (tCO^2 ha^{-1})	U_EF (%)
SUMATERA	2001	2002	Dry land forest	Dry land forest	269	8	182	6	149	28
		20041		Swamp forest	269	8	151	7	202	21
		20051		Mangrove forest	269	8	202	21	115	71
	2005	2002	Swamp forest	Dry land forest	221	21	182	6	67	122
		20041		Swamp forest	221	21	151	7	120	68
		20051		Mangrove forest	221	21	202	21	33	328
	2004	2002	Mangrove forest	Dry land forest	264	21	182	6	141	68
		20041		Swamp forest	264	21	151	7	194	50
		20051		Mangrove forest	264	21	202	21	107	111
KALIMANTAN	2001	2002	Dry land forest	Dry land forest	269	4	203	3	114	20
		20041		Swamp forest	269	4	171	7	171	17
		20051		Mangrove forest	269	4	202	21	117	65
	2005	2002	Swamp forest	Dry land forest	275	2	203	3	123	13
		20041		Swamp forest	275	2	171	7	180	13
		20051		Mangrove forest	275	2	202	21	126	59
	2004	2002	Mangrove forest	Dry land forest	264	21	203	3	105	91
		20041		Swamp forest	264	21	171	7	161	60
		20051		Mangrove forest	264	21	202	21	107	111
PAPUA	2001	2002	Dry land forest	Dry land forest	239	5	180	12	101	42
		20041		Swamp forest	239	5	146	27	161	44
		20051		Mangrove forest	239	5	202	21	64	117
	2005	2002	Swamp forest	Dry land forest	179	10	180	12	–3	1,805
		20041		Swamp forest	179	10	146	27	57	131
		20051		Mangrove forest	179	10	202	21	–40	202
	2004	2002	Mangrove forest	Dry land forest	264	21	180	12	144	71
		20041		Swamp forest	264	21	146	27	204	57
		20051		Mangrove forest	264	21	202	21	107	111
SULAWESI	2001	2002	Dry land forest	Dry land forest	275	5	207	6	119	26
		20041		Swamp forest	275	5	128	42	253	38
		20051		Mangrove forest	275	5	202	21	127	60
	2005	2002	Swamp forest	Dry land forest	214	21	207	6	14	587
		20041		Swamp forest	214	21	128	42	149	81
		20051		Mangrove forest	214	21	202	21	22	486
	2004	2002	Mangrove forest	Dry land forest	264	21	207	6	99	98
		20041		Swamp forest	264	21	128	42	234	57
		20051		Mangrove forest	264	21	202	21	107	111

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Table 7. Continued

Island	Code t1	Code t2	Primary Forest Type t1	Secondary Forest Type t2	Mean AGB-t1 (Mg ha⁻¹)	U_EF (%)	*Mean AGB-t2 (Mg ha⁻¹)	U_EF (%)	EF (tCO² ha⁻¹)	U_EF (%)
JAVA		2002		Dry land forest	-	-		-		-
	2001	20041	Dry land forest	Swamp forest	-	-	-	-	-	
		20051		Mangrove forest	-	-	-	-	-	
		2002		Dry land forest	-	-		-		-
	2005	20041	Swamp forest	Swamp forest	-	-	-	-	-	
		20051		Mangrove forest	-	-	-	-	-	
		2002		Dry land forest	-	-		-		-
	2004	20041	Mangrove forest	Swamp forest	-	-	-	-	-	
		20051		Mangrove forest	-	-	-	-	-	
NUSA		2002		Dry land forest	274	10	163	14	193	31
	2001	20041	Dry land forest	Swamp forest	274	10	-	-	473	10
		20051		Mangrove forest	274	10	202	21	125	69
		2002		Dry land forest	-	-				
	2005	20041	Swamp forest	Swamp forest	-	-	-	-	-	
		20051		Mangrove forest	-	-				
		2002		Dry land forest	264	21	163	14	175	58
	2004	20041	Mangrove forest	Swamp forest	264	21	-	-	455	21
		20051		Mangrove forest	264	21	202	21	107	111
MALUKU		2002		Dry land forest	301	27	222	8	137	105
	2001	20041	Dry land forest	Swamp forest	301	27	-	-	520	27
		20051		Mangrove forest	301	27	202	21	172	92
		2002		Dry land forest	-	-				
	2005	20041	Swamp forest	Swamp forest	-	-				
		20051		Mangrove forest	-	-				
		2002		Dry land forest	264	21	222	8	72	138
	2004	20041	Mangrove forest	Swamp forest	264	21	-	-	455	21
		20051		Mangrove forest	264	21	202	21	107	111

*The value mean AGB (Mg ha–1) is obtained by converting AGB to C in Mg ha–1 by multiplying by 0.47 as the conversion factor. The biomass was converted to CO2eq by multiplying by 44/12.

Note: LC = Land Cover

Source: MoEF 2016

Table 8. Emission factors (and associated uncertainties) from peat decomposition per land-cover transition, taken from Indonesia's FREL–2016 (in percentage)

LC	2001	2002	2004	2005	2006	2007	2010	2012	2014	2500	3000	5001	20041	20051	20071	20091	20092	20093	20094	20121	20122	20141	50011
2001	-	10	-	-	37	10	20	18	26	-	18	-	10	10	10	26	26	17	-	-	26	26	-
2002	10	19	10	10	46	19	30	27	35	10	27	10	19	19	19	35	35	27	10	10	35	35	10
2004	-	10	-	-	37	10	20	18	26	-	18	-	10	10	10	26	26	17	-	-	26	26	-
2005	-	10	-	-	37	10	20	18	26	-	18	-	10	10	10	26	26	17	-	-	26	26	-
2006	37	46	37	37	73	46	57	54	62	37	54	37	46	46	46	62	62	54	37	37	62	62	37
2007	10	19	10	10	46	19	30	27	35	10	27	10	19	19	19	35	35	27	10	10	35	35	10
2010	20	30	20	20	57	30	40	38	46	20	38	20	30	30	30	46	46	37	20	20	46	46	20
2012	18	27	18	18	54	27	38	35	43	18	35	18	27	27	27	43	43	35	18	18	43	43	18
2014	26	35	26	26	62	35	46	43	51	26	43	26	35	35	35	51	51	43	26	26	51	51	26
2500	-	10	-	-	37	10	20	18	26		18	-	10	10	10	26	26	17	-	-	26	26	-
3000	18	27	18	18	54	27	38	35	43	18	35	18	27	27	27	43	43	35	18	18	43	43	18
5001	-	10	-	-	37	10	20	18	26	-	18	-	10	10	10	26	26	17	-	-	26	26	-
20041	10	19	10	10	46	19	30	27	35	10	27	10	19	19	19	35	35	27	10	10	35	35	10
20051	10	19	10	10	46	19	30	27	35	10	27	10	19	19	19	35	35	27	10	10	35	35	10
20071	10	19	10	10	46	19	30	27	35	10	27	10	19	19	19	35	35	27	10	10	35	35	10
20091	26	35	26	26	62	35	46	43	51	26	43	26	35	35	35	51	51	43	26	26	51	51	26
20092	26	35	26	26	62	35	46	43	51	26	43	26	35	35	35	51	51	43	26	26	51	51	26
20093	17	27	17	17	54	27	37	35	43	17	35	17	27	27	27	43	43	34	17	17	43	43	17
20094	-	10	-	-	37	10	20	18	26	-	18	-	10	10	10	26	26	17	-	-	26	26	-
20121	-	10	-	-	37	10	20	18	26	-	18	-	10	10	10	26	26	17	-	-	26	26	-
20122	26	35	26	26	62	35	46	43	51	26	43	26	35	35	35	51	51	43	26	26	51	51	26
20141	26	35	26	26	62	35	46	43	51	26	43	26	35	35	35	51	51	43	26	26	51	51	26
50011	-	10	-	-	37	10	20	18	26	-	18	-	10	10	10	26	26	17	-	-	26	26	-

Source: MoEF 2016

Note: LC = Land Cover

4.2 Methods to combine uncertainties

This document reports on an improved baseline estimate of Indonesia's FREL–2016 uncertainty using MCS. Nevertheless, according to IPCC (2006), when Approach 2 (MCS) is selected, agencies are also encouraged to apply Approach 1 (PEA) because of the insights it provides to quality assurance/ quality control (QA/QC) activities inventory. Consequently, this section shows methods used for both Approach 1 (4.2.1) and Approach 2 (4.2.2).

4.2.1 IPCC Approach 1: Propagation of error

According to IPCC (2006), Approach 1 is based upon error propagation to estimate uncertainty in individual categories in the inventory as a whole. In Approach 1, uncertainty in emissions or removals can be propagated from uncertainties in the AD and EFs through the error propagation equation. In theory, it also requires the standard deviation divided by the mean value to be less than 0.3. In practice, however, the approach will give informative results even if this criterion is not strictly met and some correlations remain.

Improving the uncertainties analysis of FREL–2016 using Approach 1 required estimates of the mean and the standard deviation for each AD and EF. In addition, it required the approach used to estimate the emissions at subcategory and category levels. Once the uncertainties in the categories were determined, they were combined to provide uncertainty estimates for the entire country in any period. As discussed further below, these uncertainty estimates were combined using two convenient rules for combining uncorrelated uncertainties under addition and multiplication.

The Approach 1 analysis estimates uncertainties by using the error propagation equation in two steps. First, the IPCC equation 3.1 approximation was used to combine EFs and AD by category. Second, the IPCC equation 3.2 approximation was used to arrive at the overall uncertainty in national emissions each year.

EQUATION 3.1

COMBINING UNCERTAINTIES – APPROACH 1 – MULTIPLICATION

$$U\ total = \sqrt{U1^2 + U2^2 + \cdots + Un^2}$$

Where:

$U\ total$ = the percentage uncertainty in the product of the quantities (half the 95% confidence interval divided by the total and expressed as a percentage).

U_1 = the percentage uncertainties associated with each of the quantities.

EQUATION 3.2

COMBINING UNCERTAINTIES – APPROACH 1 – ADDITION AND SUBTRACTION

$$U\ total = \frac{\sqrt{(U1 \cdot X1)^2 + (U2 \cdot X2)^2 + \cdots + (Un \cdot Xn)^2}}{|X1 + X2 + \cdots Xn|}$$

Where:

U total = the percentage uncertainty in the sum of the quantities (half the 95% confidence interval divided by the total [i.e., mean] and expressed as a percentage). This term ‘uncertainty’ is thus based upon the 95% confidence interval.

X_1 and U_1 = the uncertain quantities and the percentage uncertainties associated with them respectively.

Table 9 shows an example of the process to combine uncertainties using IPCC equations 3.1 and 3.2. Rows A, B, and C of Table 9 show the process to combine uncertainties of AD and EFs at subcategory level using the IPCC equation 3.1. The last row of Table 9 shows the process to combine uncertainties of total emissions using the IPCC equation 3.2.

Table 9. Example of error propagation using IPCC equations 3.1 and 3.2 to: (i) combine uncertainties of activity data and emission factors and (ii) combine uncertainties of emissions at subcategory level

Transition (FL - L)						
Subcategory	Emission factor	Uncertainty of EF (UEF)	Activity data	Uncertainty of AD (UDA)	Emission (at component level)	Uncertainty of E (UE)
A	EF 1A	U EF 1A	AD 1A	U AD 1A	E 1A = EF 1A * AD 1A	$U_{E\,1A} = \sqrt{U_{EF\,1A}{}^2 + U_{AD\,1A}{}^2}$
B	EF 1B	U EF 1B	AD 1B	U AD 1B	E 1B = EF 1B * AD 1B	$U_{E\,1B} = \sqrt{U_{EF\,1B}{}^2 + U_{AD\,1B}{}^2}$
C	EF 1C	U EF 1C	AD 1C	U AD 1C	E 1C = EF 1C * AD 1C	$U_{E\,1C} = \sqrt{U_{EF\,1C}{}^2 + U_{AD\,1C}{}^2}$
Total emission / Propagated uncertainty of transition 1					E 1 = E 1A + E 1B + E 1C	$U_{E\,1} = \frac{\sqrt{(E_{1A} + U_{E1A})^2 + (E_{1B} + U_{E1B})^2 + (E_{1C} + U_{}}}{\lvert E_{1A} + E_{1B} + E_{1C} \rvert}$

4.2.2 IPCC Approach 2: Monte Carlo simulation

General approach

According to IPCC (2006), the Monte Carlo analysis is suitable for detailed category-by-category assessment of uncertainty, particularly where uncertainties are large, distribution is non-normal, algorithms are complex functions, and/or there are correlations between some of the activity sets, EF, or both. In MCS, pseudo-random samples of model inputs are generated according to the probability distribution function (PDF) specified for each input. The samples are called ‘pseudo-random’ because they are generated by an algorithm – known as a pseudo-random number generator – that can provide a reproducible series of numbers but for which any series has properties of randomness. If the model has two or more inputs, then random samples are generated from the PDFs for each one. Subsequently, one random value for each input is entered into the model to arrive at one estimate of the model output. This process is repeated over a desired number of iterations to arrive at multiple estimates of the model output. The multiple estimates are sample values of the PDF of the model output. By analysing samples of the PDF for the model output, the mean, standard deviation, 95% confidence interval, and other properties of the output PDF can be inferred. Because MCS is a numerical method, the precision of the results typically improves as the number of iterations increases.

There are several cases where (i) uncertainties of annual emissions from peat decomposition (mainly due to degradation and secondary forest) at the transition level are large and distributions are non-normal; and (ii) distributions of annual emissions from degradation at the transition level are non-normal. Consequently, to improve the uncertainties analysis of FREL–2016, use of numerical statistical techniques, particularly the Monte Carlo technique, is more appropriate than Approach 1.

The Monte Carlo analysis required several steps. First, the PDF of AD and EF were defined. Second, random values of AD and EF within their individual probability density functions were selected. Finally, emission values were estimated using the random values of AD and EF. This procedure was repeated many times, and the results of each calculation built up the overall emission PDF. Monte Carlo analysis was performed at the subcategory level (forest type and land-cover transitions, or LCT), for aggregations of categories (deforestation, degradation, and peat decomposition) or for the FREL as a whole. Figure 1 shows the general process to run the Monte Carlo analysis.

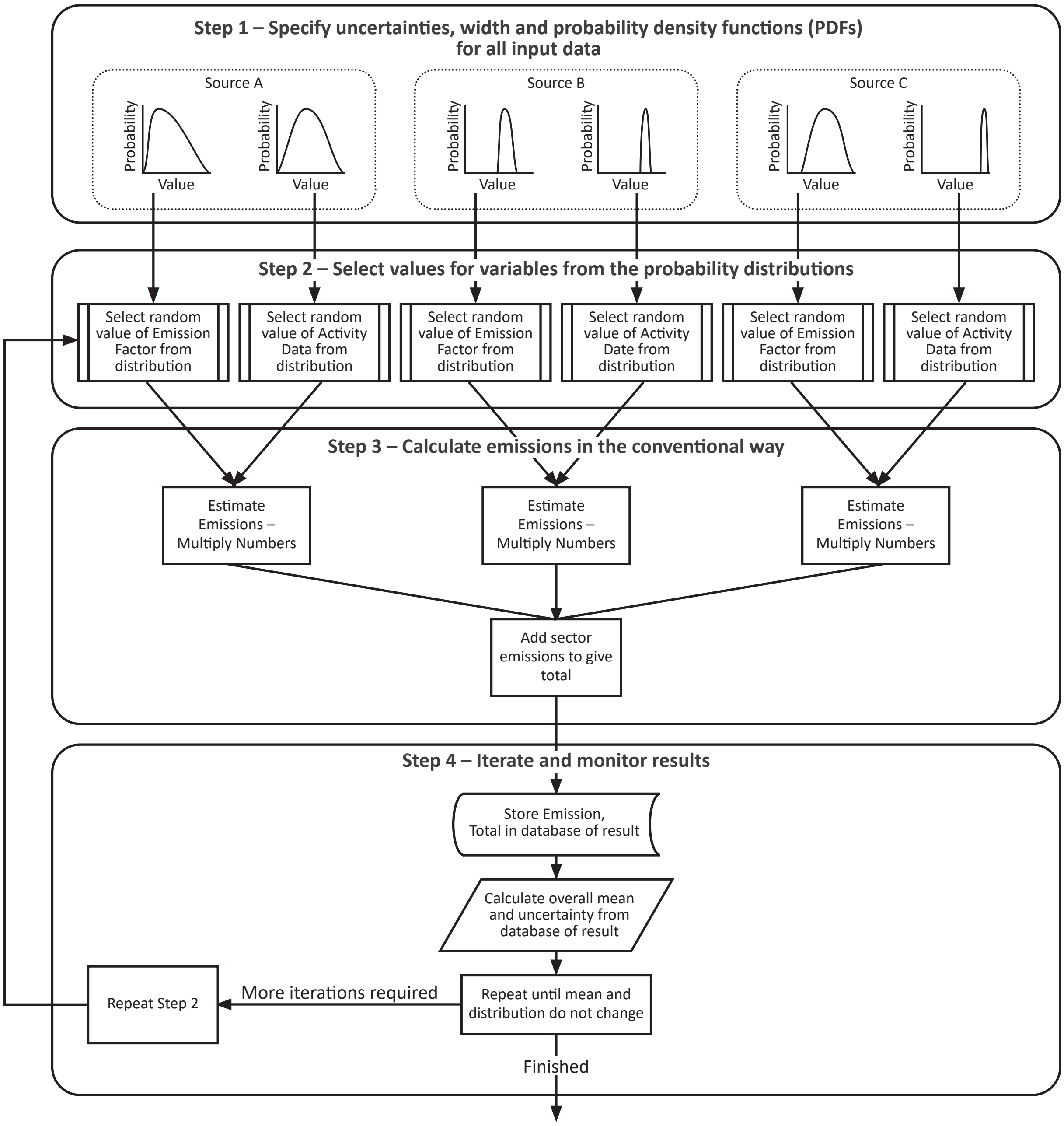

Figure 1. Illustration of MCS

Source: IPCC 2006

Specific steps to run Monte Carlo simulation

The MCS was run by following these steps:

1. **Identification of mean, standard deviation, and PDF of AD and EF**. The means of AD were data taken from the transition matrix for each activity and period. The uncertainties of AD per activity and period were taken from the values shared in tables in Annexes 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, and 8.7 of FREL–2016 (MoEF 2016). The mean and uncertainties of EF were taken from Table Annex 6.1, and Table Annex 7.1 of FREL–2016. The standard deviation of AD and EF were estimated as functions of the uncertainties and means of AD and EF, respectively. Finally, normal distribution was assumed as PDF of AD and EF means.
2. **Selection of random numbers of AD and EF**. For each AD and EF, a number was randomly selected from the PDF of each variable.
3. **Estimation of emissions**. The variables selected in Step 2 were used to estimate annual emissions.
4. **Iteration of simulated emissions**. The calculated emission from Step 3 was stored, and the process was repeated (100,000 times) from Step 2. The results from the repetitions were used to calculate the mean and the PDF.

Implementation of Monte Carlo analysis in the Improved uncertainties analysis of Indonesia's Forest Reference Emission Level 2016

The MCS process described in the previous section was run per activity (deforestation, degradation, peat decomposition due to deforestation, degradation, and secondary forest), period (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011, and 2011–2012) and LCT (forest to non-forest, forest to degraded forest) or remaining degraded forest in the case of peat decomposition due to degradation.

Thus, in the case of emissions from deforestation, for a selected period and island, the MCS process was run for each LCT and vectors of simulated emission from deforestation per LCT were obtained. These vectors were added to obtain simulated total emissions from deforestation at island level. The simulated total emissions from deforestation at island level were added to obtain a vector of total emissions from deforestation at national level. Using this last vector, PDF was defined and quantiles 2.5% and 97.5% were estimated to obtain the lower and upper uncertainties of the total emissions from deforestation at national level according to the following formula:

$$Lower\ U_{\overline{TE}} = abs\left(\frac{Q_{2.5} - \overline{TE}}{\overline{TE}}\right) \times 100$$

$$Upper\ U_{\overline{TE}} = abs\left(\frac{Q_{97.5} - \overline{TE}}{\overline{TE}}\right) \times 100$$

Where:

$Lower\ U_{\overline{TE}}$: Lower uncertainties of the total emissions from deforestation at national level

$Upper\ U_{\overline{TE}}$: Upper uncertainties of the total emissions from deforestation at national level

$Q_{2.5}$: Quantile 2.5% of the total emissions from deforestation at national level

$Q_{97.5}$: Quantile 97.5% of the total emissions from deforestation at national level

$\overline{TE}$: Mean of the total emissions from deforestation at national level

For degradation emissions, the same process described for deforestation was used to estimate the lower and upper uncertainties of the total emissions from degradation at national level. Of course, in the case of degradation, the AD used were referred from LCT from forest to degraded forest.

In the case of emissions from peat decomposition due to deforestation, the MCS process was run for each LCT (occurred inside of Indonesia's peat mask) for a selected period. Vectors of simulated emission from peat decomposition due to deforestation per LCT were obtained. These vectors were added to obtain simulated total emissions from peat decomposition due to deforestation at national level. Using this last vector, a PDF was defined and quantiles 2.5% and 97.5% were estimated to obtain the lower and upper uncertainties of the total emissions from peat decomposition due to deforestation at the national level according to previous equations. In the case of peat decomposition due to degradation and secondary forest, the same process was implemented using AD as its correspondent LCT.


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5 Results

5.1 IPCC Approach 1: Propagation of error

Table 10 shows the uncertainties estimated of emissions from deforestation, forest degradation, peat decomposition, and totals for the improved uncertainties analysis of FREL–2016, using IPCC equations 3.1 and 3.2 (Approach 1: PEA).

Table 10. Uncertainties estimated of emissions from deforestation, forest degradation, peat decomposition, and totals for the Improved uncertainties analysis of Indonesia's FREL–2016, using IPCC Approach 1: PEA

Activity	Estimator	1990–1996	1996–2000	2000–2003	2003–2006	2006–2009	2009–2011	2011–2012
Deforestation	Emissions ($MtCO2e\ yr^{-1}$)	198,820	729,491	149,140	268,294	303,524	146,246	249,785
	Uncertainties (%)	12	12	13	12	12	12	12
Forest Degradation	Emissions ($MtCO2e\ yr^{-1}$)	7,371	158,992	70,665	67,147	14,239	16,635	5,434
	Uncertainties (%)	19	19	24	25	106	24	24
Peat Decomposition	Emissions ($MtCO2e\ yr^{-1}$)	155,089	164,604	168,056	175,765	184,398	189,975	192,543
	Uncertainties (%)	80	60	57	50	42	38	37
Total Emissions	Emissions ($MtCO2e\ yr^{-1}$)	361,280	1,053,087	387,862	511,206	502,161	352,856	447,760
	Uncertainties (%)	35	13	26	19	17	21	17

5.2 IPCC Approach 2: Monte Carlo simulation

Using the MCS and the inputs described in section 4.1, subsection "a" shows the results for uncertainties of emissions from deforestation, degradation, peat decomposition, and total. Subsection "b" shows the results for uncertainties of emissions from peat decomposition due to deforestation, degradation, and secondary forests.

5.2.1 Emissions (and associated uncertainties) from deforestation, degradation, and peat decomposition

Table 11 shows the estimation of CO_2 emissions from deforestation, forest degradation, peat decomposition, and total for the improved uncertainties analysis of FREL–2016. Table 11 shows the uncertainties estimated of emissions from deforestation, forest degradation, peat decomposition and totals for the improved uncertainties analysis of FREL–2016, using MCS. Results of Table 12 show that:

i. In most periods, uncertainties of emissions from deforestation have values around 12%.
ii. In most periods, uncertainties of emissions from degradations have values between 20% and 25%.
iii. In most periods, uncertainties of emissions from PD have values between 37% and 60%.
iv. In most periods, uncertainties of total emissions have values between 17% and 26%

Notice these results are consistent with results obtained with IPCC Approach 1.

Table 11. Estimation of CO_2 emissions from deforestation, forest degradation, peat decomposition, and totals for the improved uncertainties analysis of Indonesia's FREL–2016

Activity	1990–1996	1996–2000	2000–2003	2003–2006	2006–2009	2009–2011	2011–2012
	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$
Deforestation	198,820	729,292	149,140	268,294	303,524	146,246	249,785
Degradation	7,371	158,544	70,665	67,147	14,239	16,635	5,434
Peat Decomposition	155,089	161,611	167,420	175,129	183,761	189,338	196,635
Total	361,281	1,049,447	387,225	510,569	501,524	352,219	451,854

Table 12. Uncertainties estimated of emissions from deforestation, forest degradation, peat decomposition, and totals for the Improved uncertainties analysis of Indonesia's FREL–2016, using IPCC Approach 2: MCS

	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
Activity	Lower U (%)	Upper U (%)	Lower U (%)	Upper U (%)	Lower U (%)	Upper U (%)	Lower U (%)	Upper U (%)	Lower U (%)	Upper U (%)	Lower U (%)	Upper U (%)	Lower U (%)	Upper U (%)
Deforestation	12.4	12.5	11.7	11.8	12.7	12.6	11.7	11.9	12.2	12.3	11.8	12.0	12.1	12.2
Degradation	18.7	20.1	19.1	20.5	21.4	22.9	24.3	25.9	103.0	111.1	23.6	25.3	23.4	25.6
Peat decomposition	77.5	82.6	58.7	61.9	55.7	59.2	49.0	52.6	40.8	43.4	37.7	40.1	35.2	37.8
Total	34.1	36.0	12.6	12.9	24.9	26.4	18.3	19.3	17.0	17.8	21.0	22.1	16.8	17.7

Figure 2 presents the emissions from deforestation and associated uncertainties shown in Tables 11 and 12. Confidence intervals shown in Figure 2 were estimated from the PDF of simulated emissions from deforestation (obtained with MCS) for each period (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011, and 2011–2012). In most periods, PDFs (shown in Figure 3) of emissions from deforestation have a symmetrical shape.

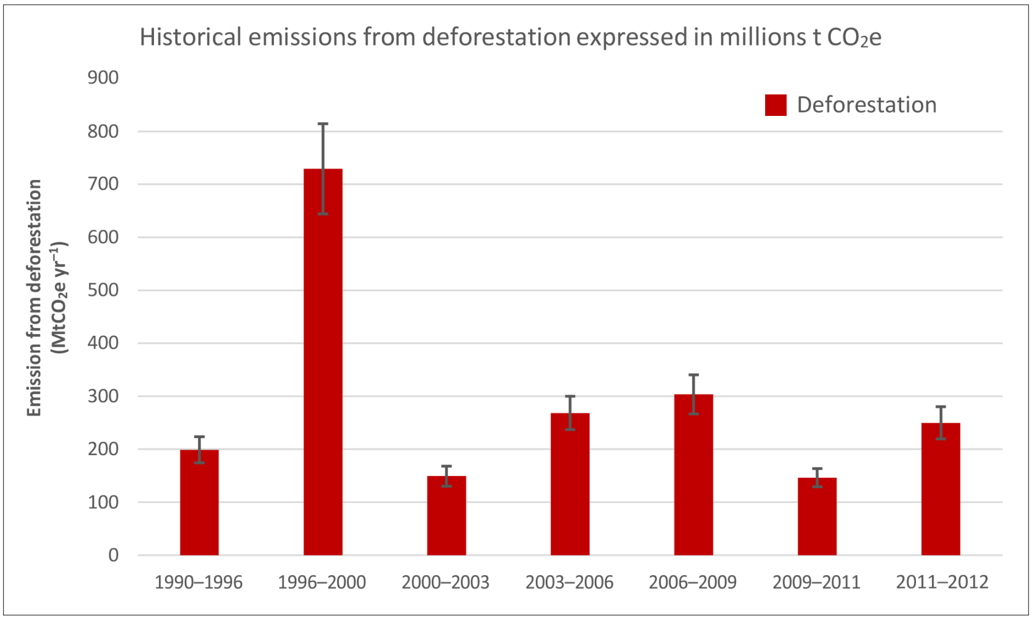
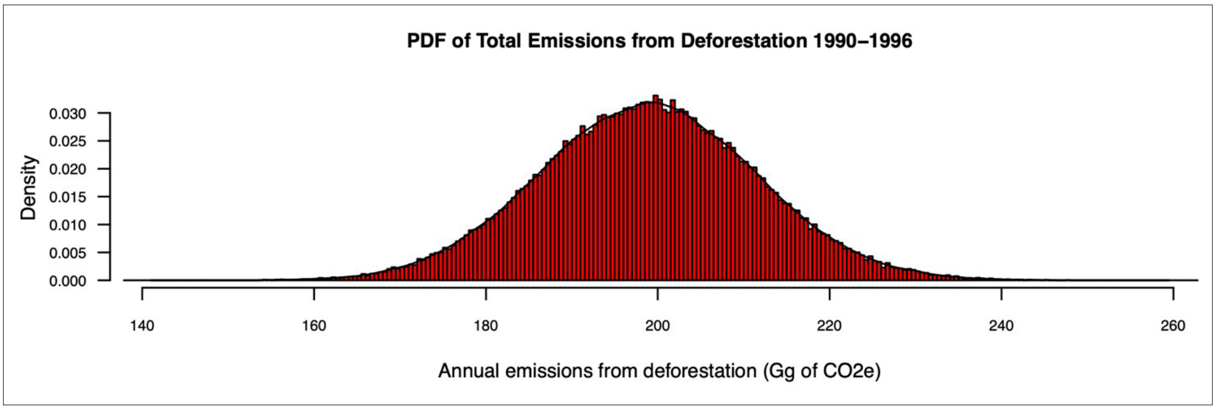
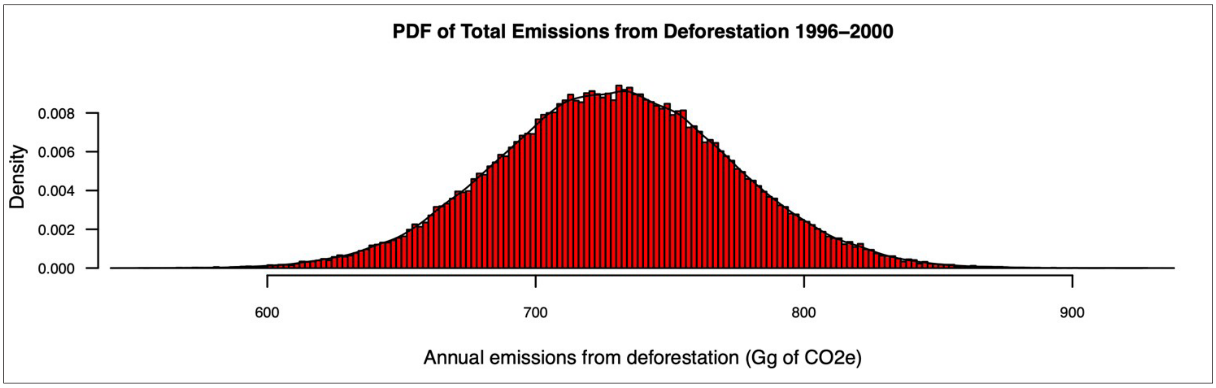


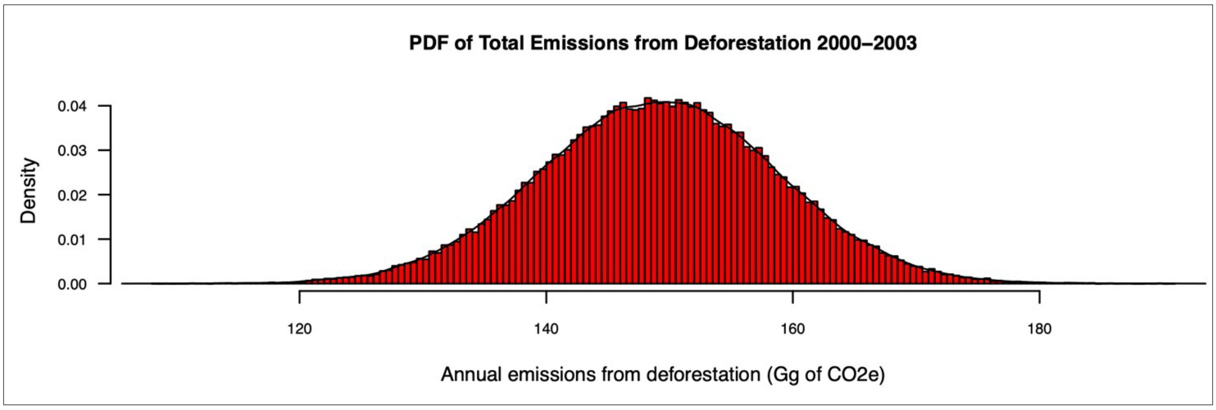
Figure 2. Historical emissions from deforestation and associated uncertainties obtained with MCS



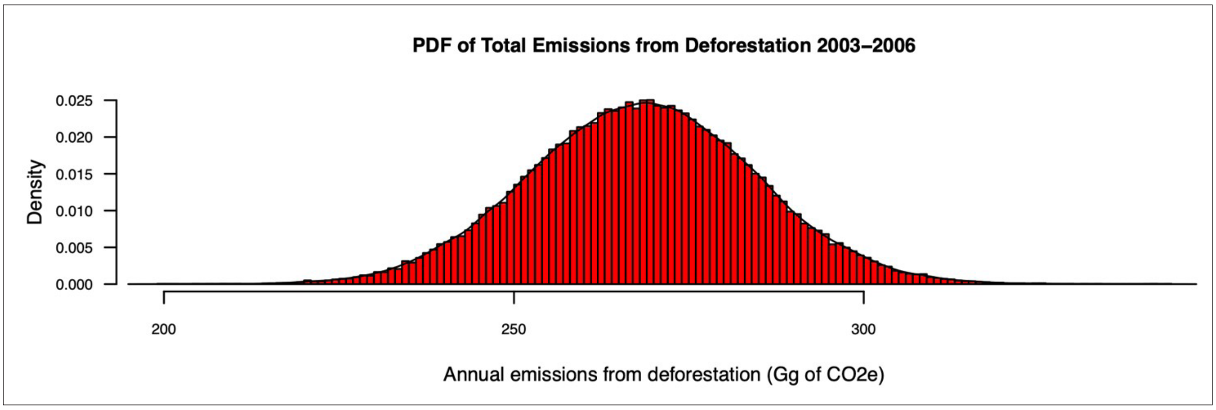
(a)



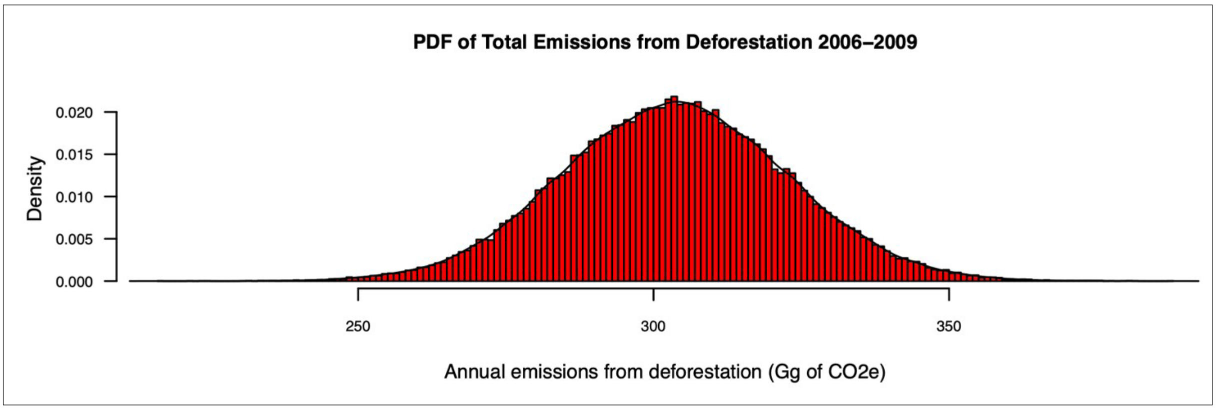
(b)


PDF of Total Emissions from Deforestation 2000–2003
Density
0.04
0.03
0.02
0.01
0.00
120
140
160
180
Annual emissions from deforestation (Gg of CO2e)

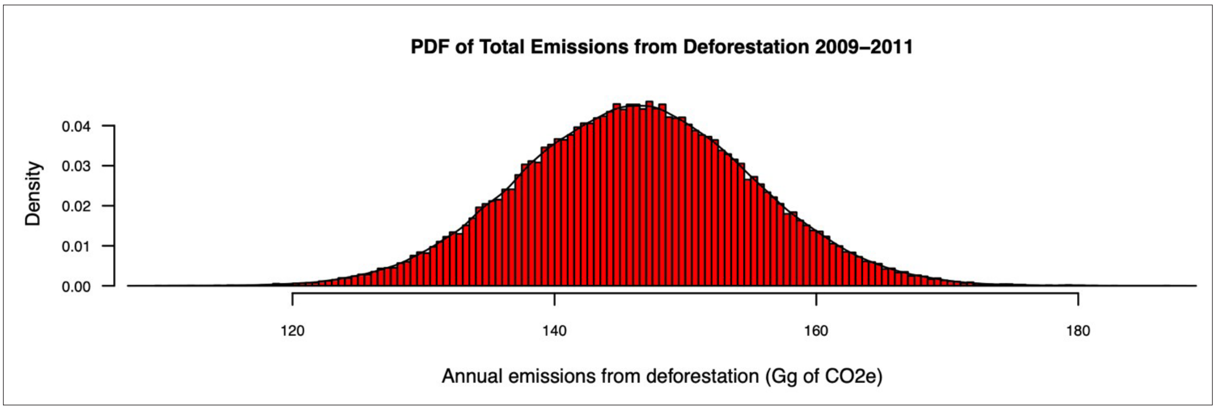
(c)


PDF of Total Emissions from Deforestation 2003–2006
Density
0.025
0.020
0.015
0.010
0.005
0.000
200
250
300
Annual emissions from deforestation (Gg of CO2e)

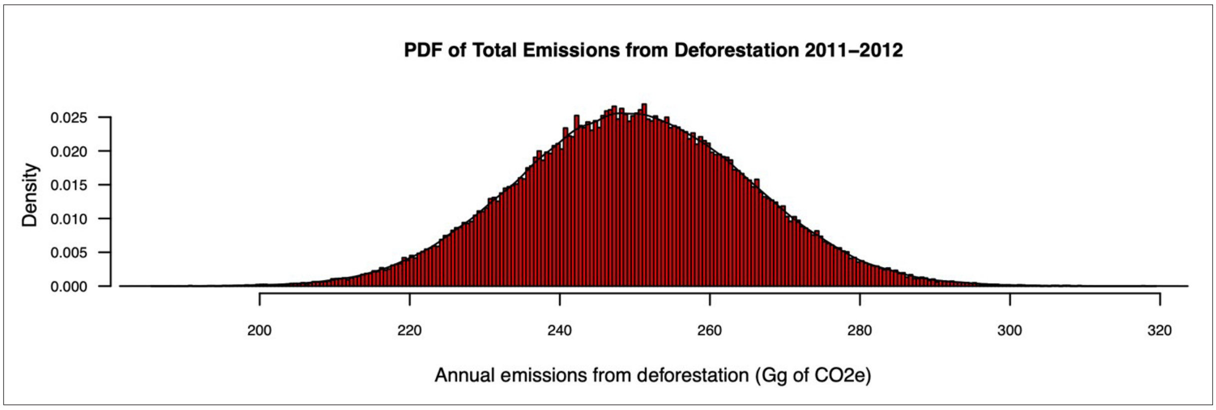
(d)


PDF of Total Emissions from Deforestation 2006–2009
Density
0.020
0.015
0.010
0.005
0.000
250
300
350
Annual emissions from deforestation (Gg of CO2e)

(e)


PDF of Total Emissions from Deforestation 2009–2011
Density
0.04
0.03
0.02
0.01
0.00
120
140
160
180
Annual emissions from deforestation (Gg of CO2e)

(f)



(g)

Figure 3. Density function of emissions from deforestation per period: (a) 1990–1996, (b) 1996–2000, (c) 2000–2003, (d) 2003–2006, (e) 2006–2009, (f) 2009–2011, and (g) 2011–2012

Figure 4 presents the emissions (from degradation) and associated uncertainties shown in Tables 11 and 12. Confidence intervals shown in Figure 4 were estimated from the PDF of simulated emissions from degradation (obtained with MCS) per period (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011, and 2011–2012) presented in Figure 5. In some periods, PDFs of emissions from degradation (shown in Figure 5) are non-normal.

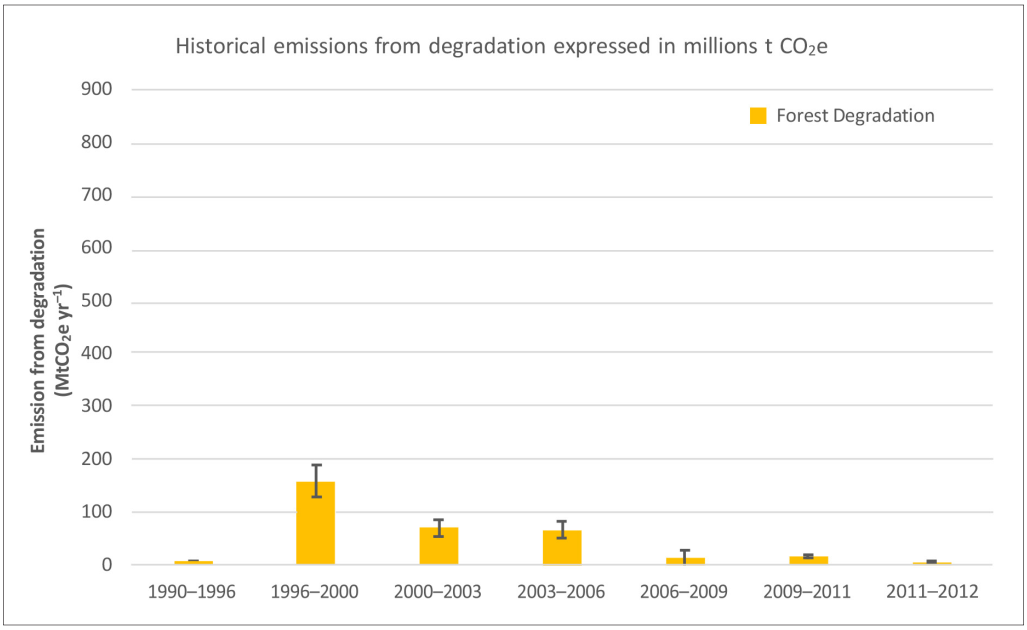
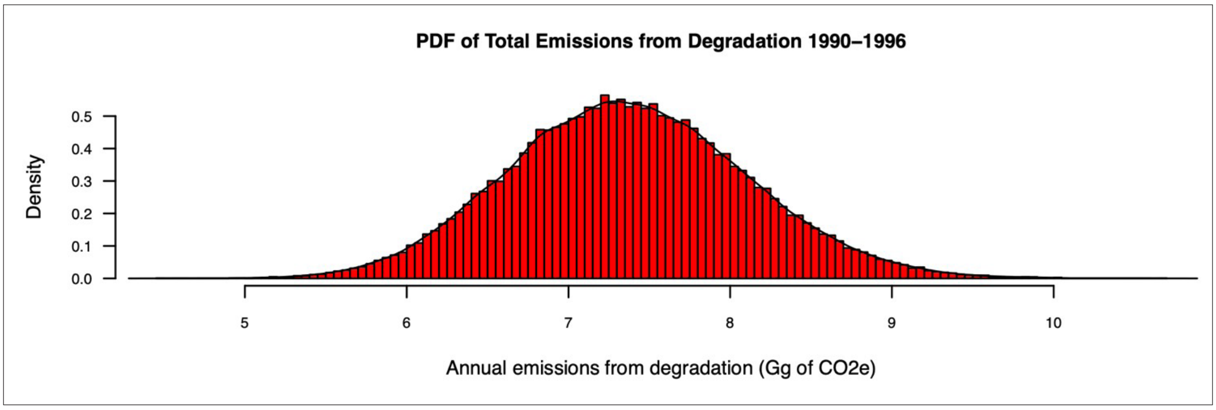
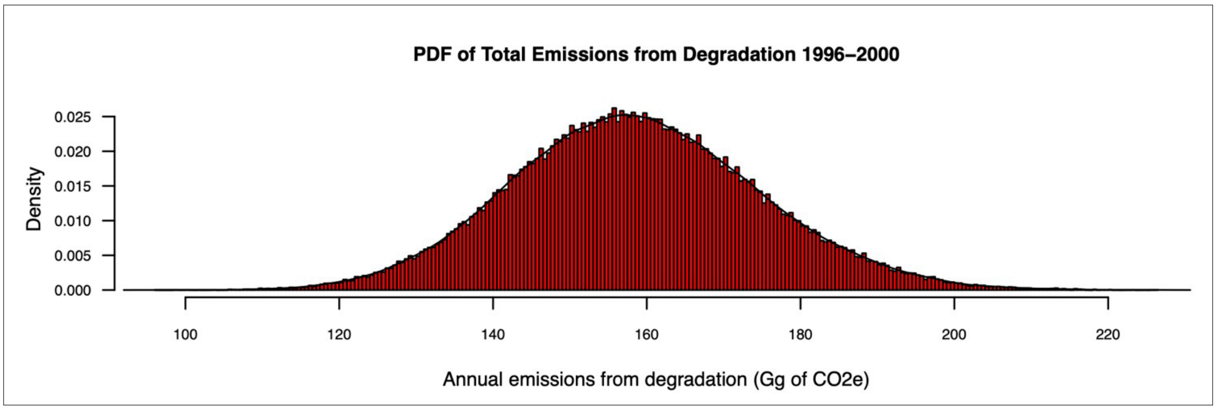


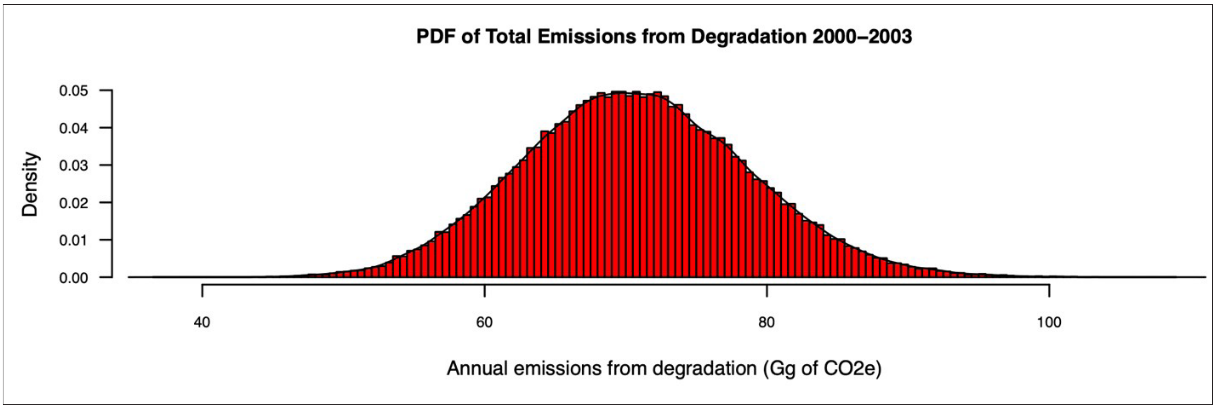
Figure 4. Historical emissions from degradation and associated uncertainties obtained with MCS


PDF of Total Emissions from Degradation 1990–1996
Density
0.0
0.1
0.2
0.3
0.4
0.5
5
6
7
8
9
10
Annual emissions from degradation (Gg of CO2e)

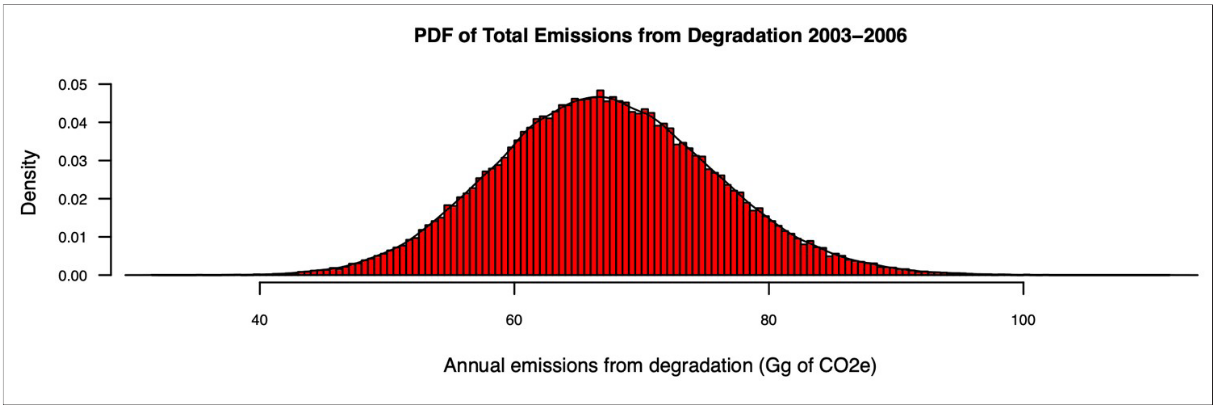
(a)


PDF of Total Emissions from Degradation 1996–2000
Density
0.000
0.005
0.010
0.015
0.020
0.025
100
120
140
160
180
200
220
Annual emissions from degradation (Gg of CO2e)

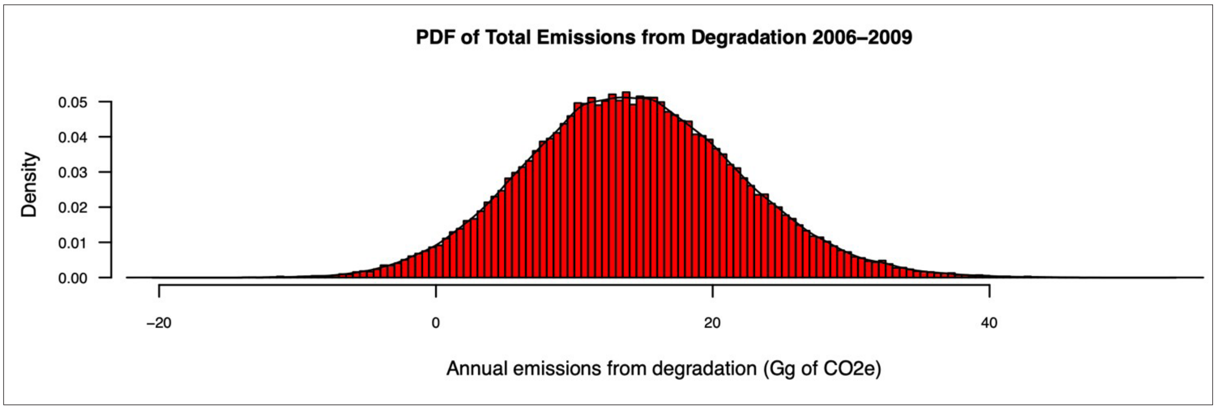
(b)


PDF of Total Emissions from Degradation 2000–2003
Density
0.00
0.01
0.02
0.03
0.04
0.05
40
60
80
100
Annual emissions from degradation (Gg of CO2e)

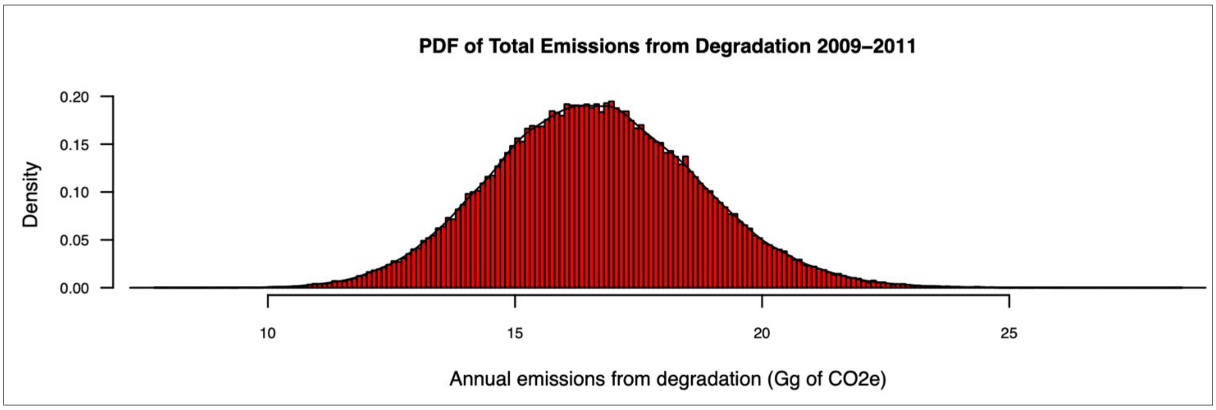
(c)


PDF of Total Emissions from Degradation 2003–2006
Density
0.00
0.01
0.02
0.03
0.04
0.05
40
60
80
100
Annual emissions from degradation (Gg of CO2e)

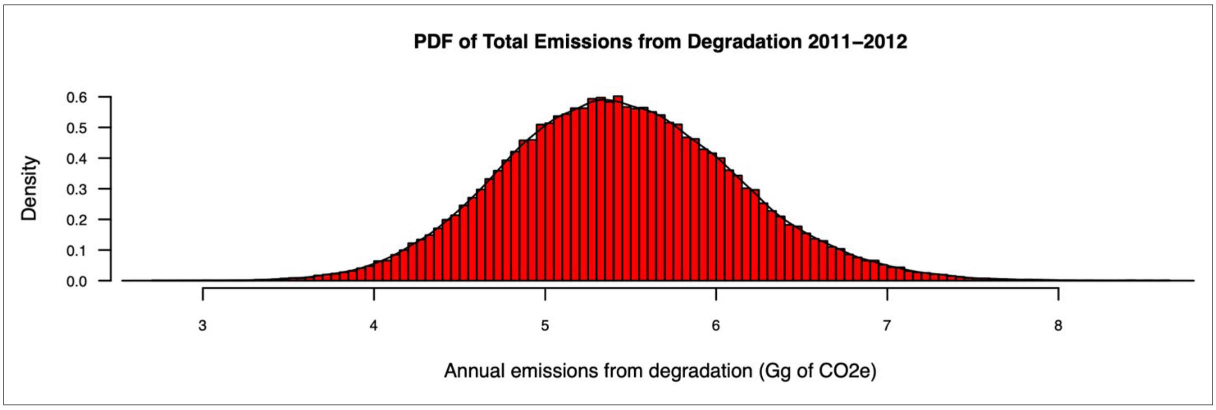
(d)



(e)



(f)



(g)

Figure 5. Density function of emissions from degradation per period: (a) 1990–1996, (b) 1996–2000, (c) 2000–2003, (d) 2003–2006, (e) 2006–2009, (f) 2009–2011, and (g) 2011–2012

Figure 6 presents the emissions (from peat decomposition) and associated uncertainties shown in Tables 11 and 12. Confidence intervals shown in Figure 6 were estimated from the PDF of simulated emissions from peat decomposition (obtained with MCS) per period (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011, and 2011–2012) presented in Figure 7. In most of the periods, PDFs of emissions from peat decomposition (shown in Figure 7) are non-normal and the range of the PDFs is large. This implies large and asymmetrical uncertainties of the estimated emissions from peat decomposition as shown in Table 12 and Figure 6.

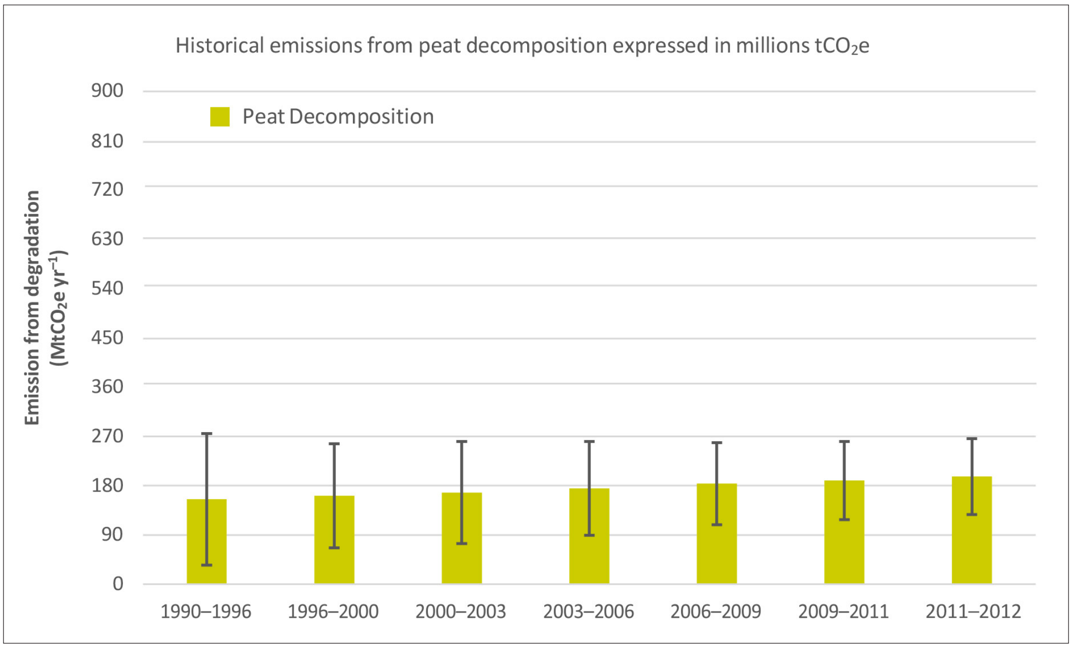
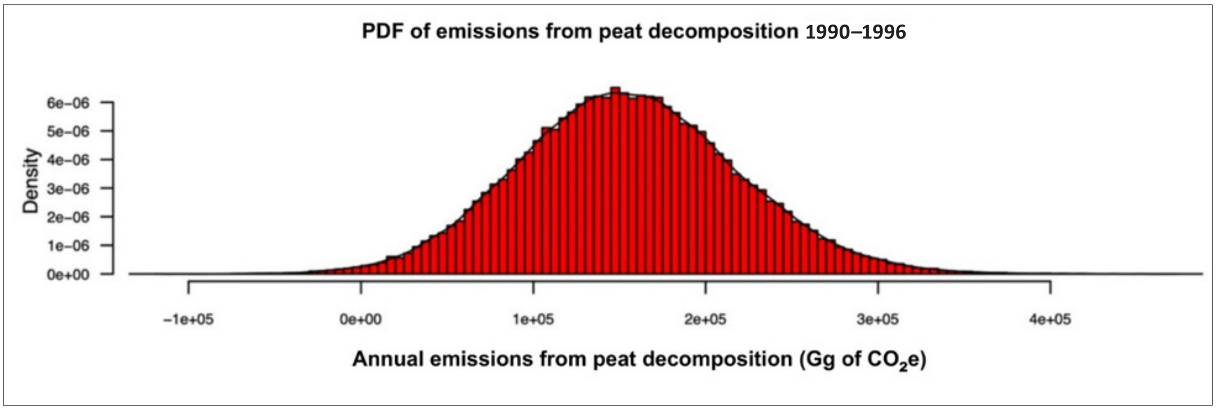
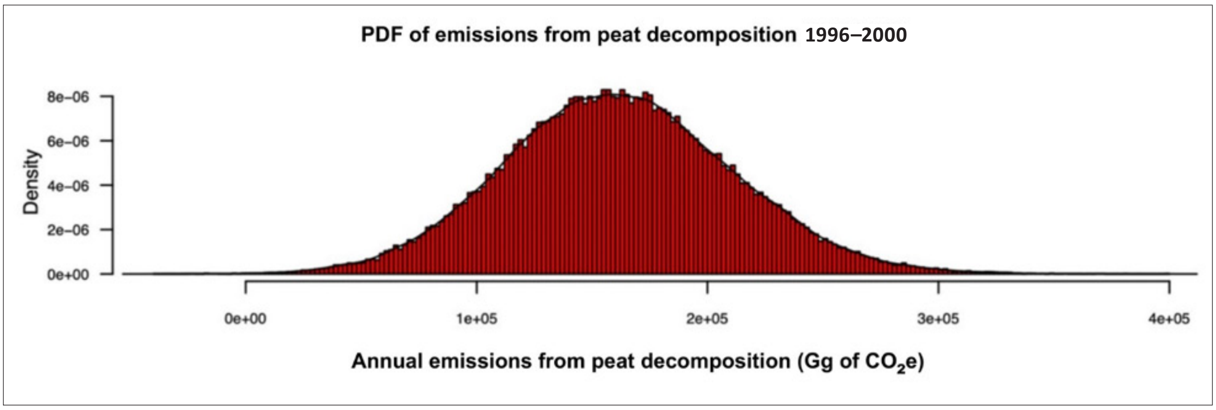


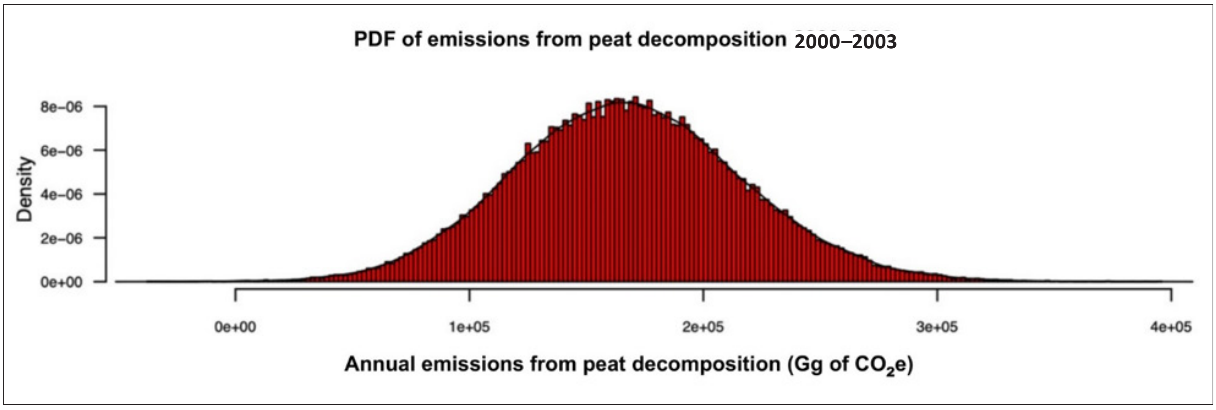
Figure 6. Historical emissions from peat decomposition and associated uncertainties obtained with MCS



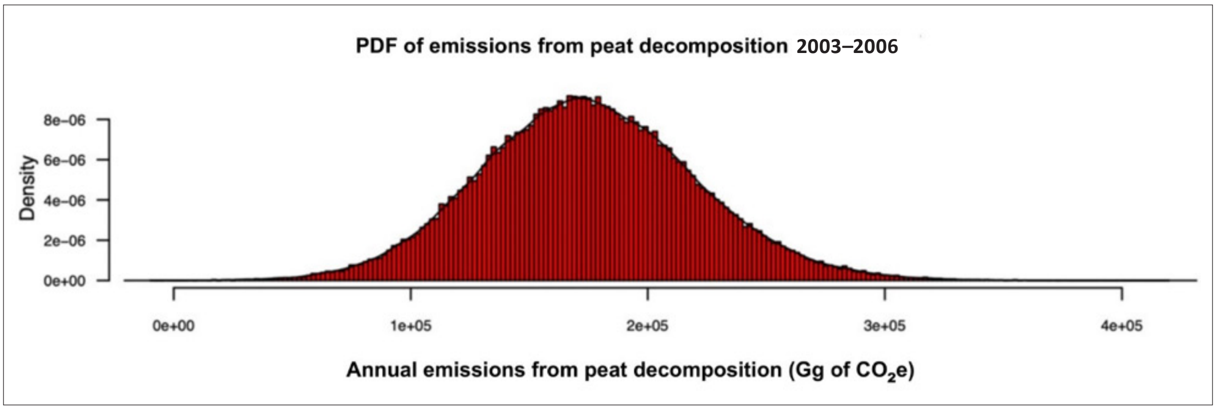
(a)



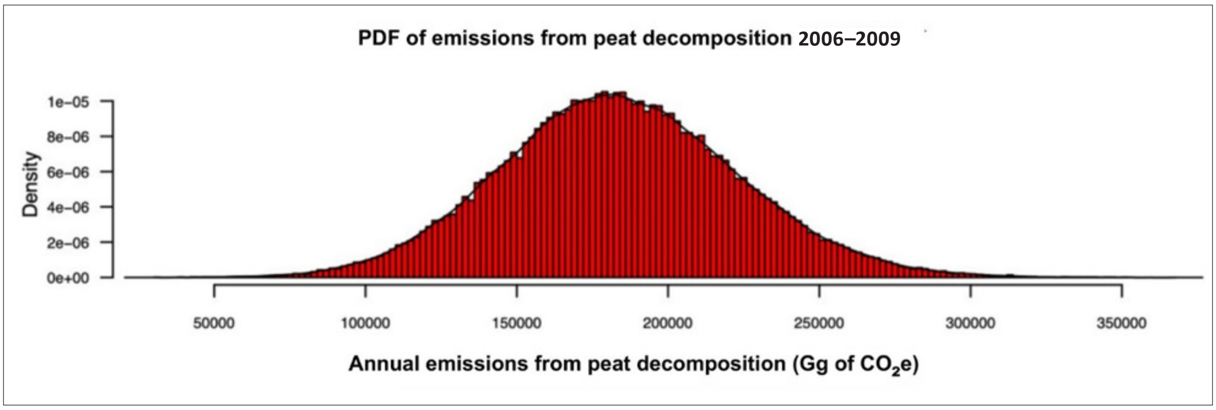
(b)


PDF of emissions from peat decomposition 2000–2003
Density
8e−06
6e−06
4e−06
2e−06
0e+00
0e+00
1e+05
2e+05
3e+05
4e+05
Annual emissions from peat decomposition (Gg of CO_2e)

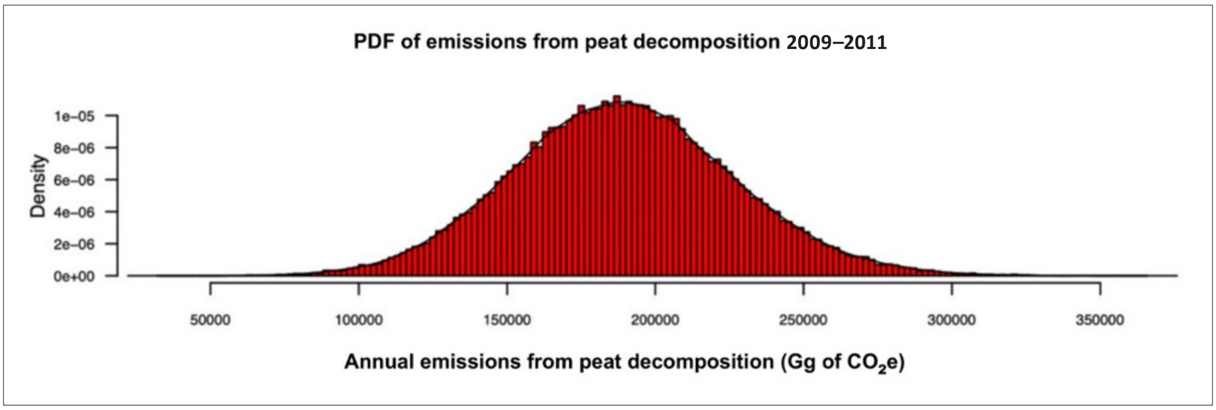
(c)


PDF of emissions from peat decomposition 2003–2006
Density
8e−06
6e−06
4e−06
2e−06
0e+00
0e+00
1e+05
2e+05
3e+05
4e+05
Annual emissions from peat decomposition (Gg of CO_2e)

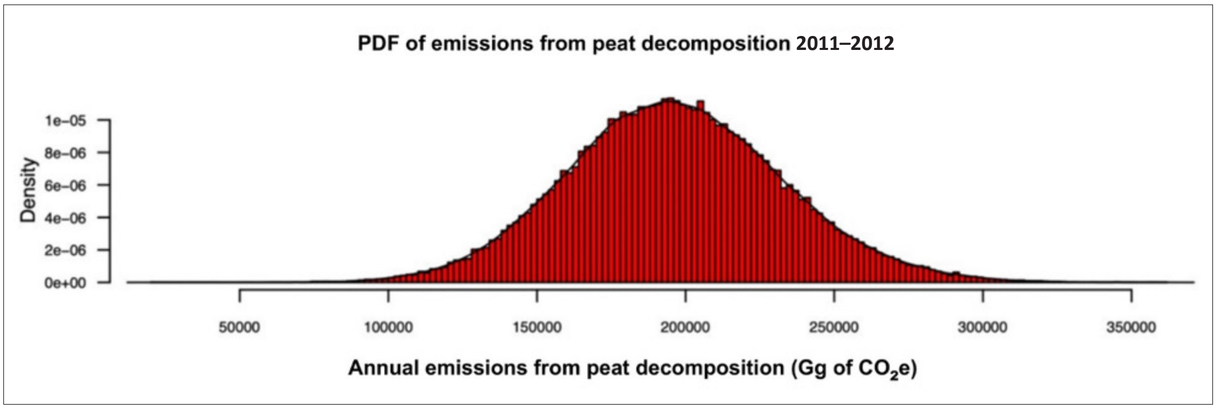
(d)


PDF of emissions from peat decomposition 2006–2009
Density
1e−05
8e−06
6e−06
4e−06
2e−06
0e+00
50000
100000
150000
200000
250000
300000
350000
Annual emissions from peat decomposition (Gg of CO_2e)

(e)


PDF of emissions from peat decomposition 2009–2011
Density
1e−05
8e−06
6e−06
4e−06
2e−06
0e+00
50000
100000
150000
200000
250000
300000
350000
Annual emissions from peat decomposition (Gg of CO_2e)

(f)



(g)

Figure 7. Density function of emissions from peat decomposition per period: (a) 1990–1996, (b) 1996–2000, (c) 2000–2003, (d) 2003–2006, (e) 2006–2009, (f) 2009–2011, and (g) 2011–2012

Figure 8 presents total emissions and associated uncertainties shown in Tables 11 and 12. Confidence intervals shown in Figure 8 estimated from the PDF of simulated total emissions (obtained with MCS) per period (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011, and 2011–2012) presented in Figure 9. Notice that PDFs (shown in Figure 9) of total emissions for the first periods do not have asymmetrical shape.

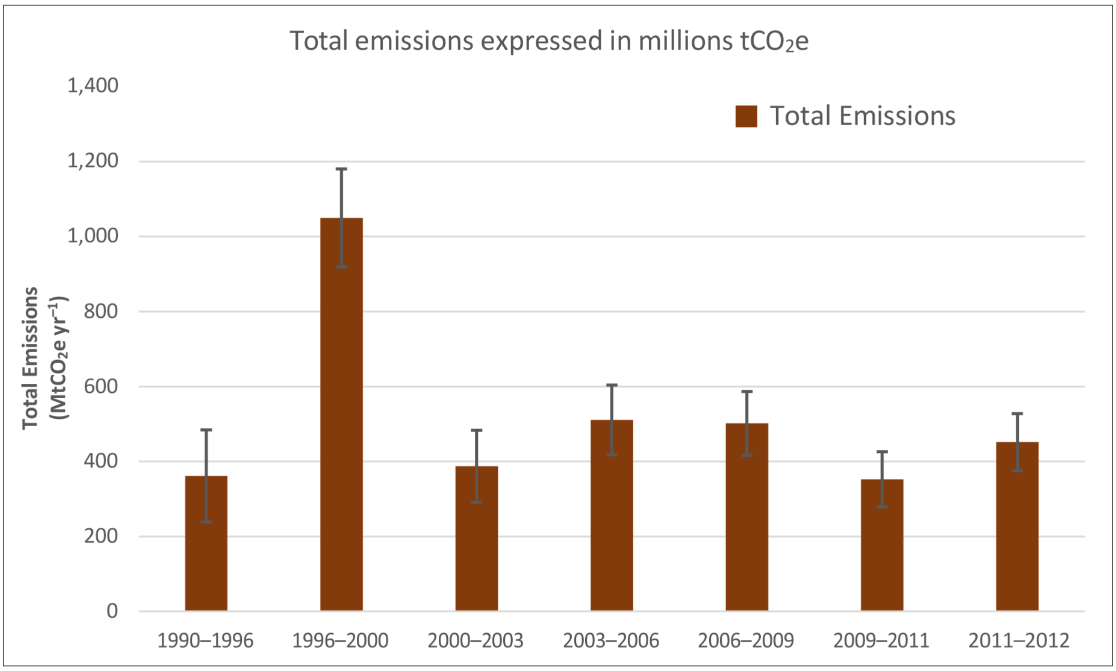
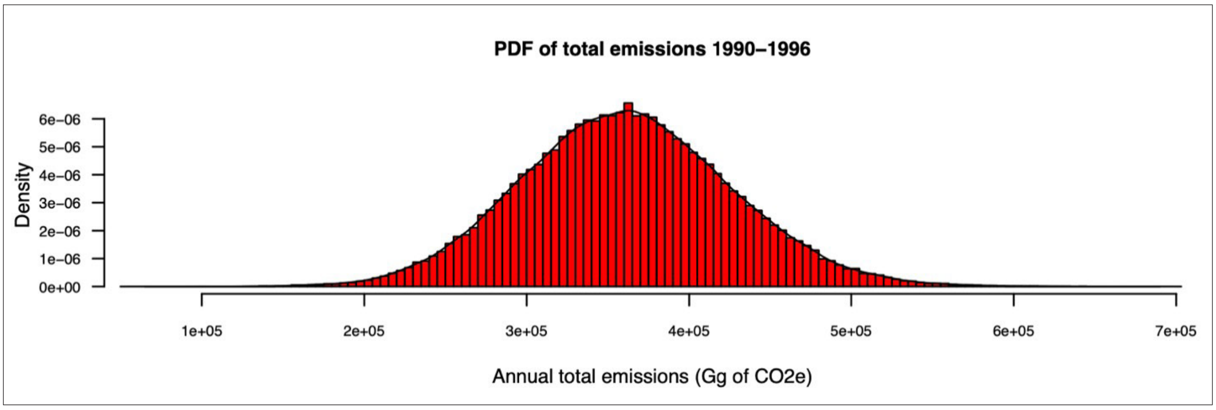
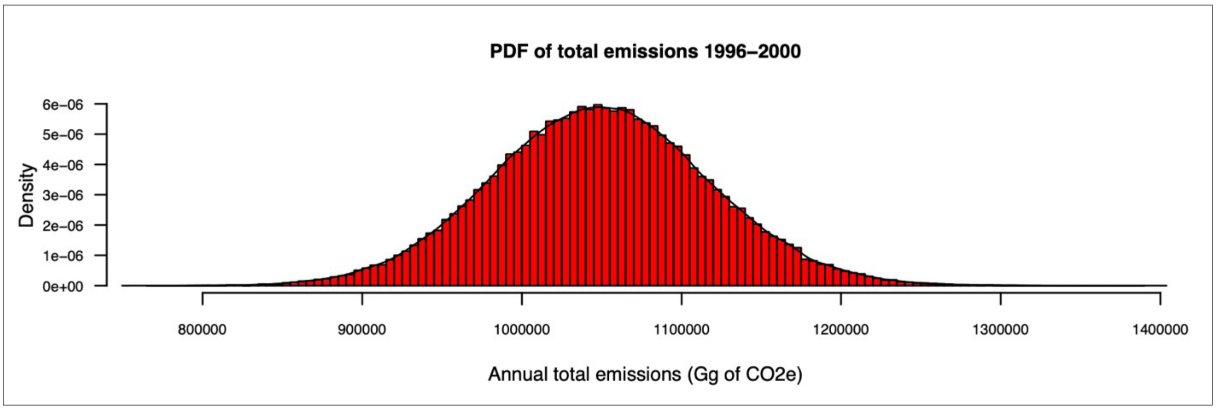


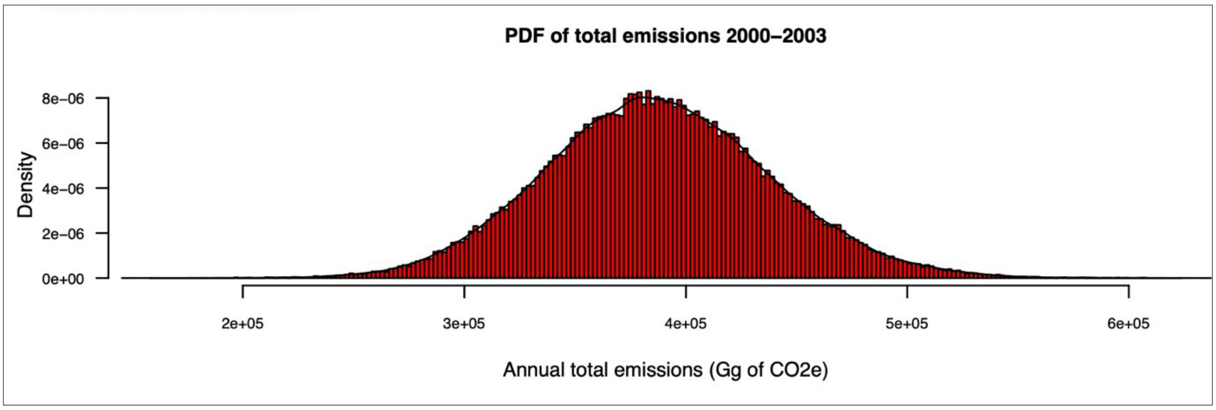
Figure 8. Historical total emissions and associated uncertainties obtained with MCS


PDF of total emissions 1990–1996
Density
6e−06
5e−06
4e−06
3e−06
2e−06
1e−06
0e+00
1e+05
2e+05
3e+05
4e+05
5e+05
6e+05
7e+05
Annual total emissions (Gg of CO2e)

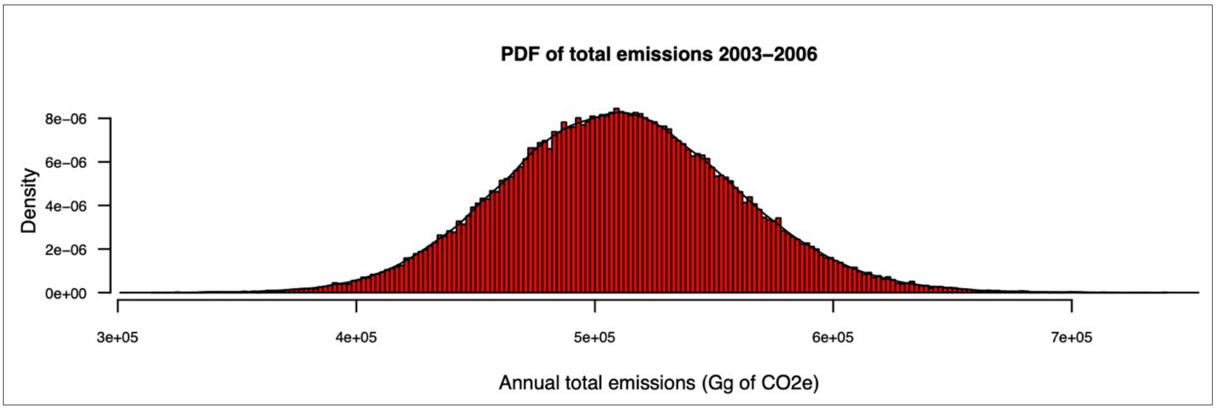
(a)


PDF of total emissions 1996–2000
Density
6e−06
5e−06
4e−06
3e−06
2e−06
1e−06
0e+00
800000
900000
1000000
1100000
1200000
1300000
1400000
Annual total emissions (Gg of CO2e)

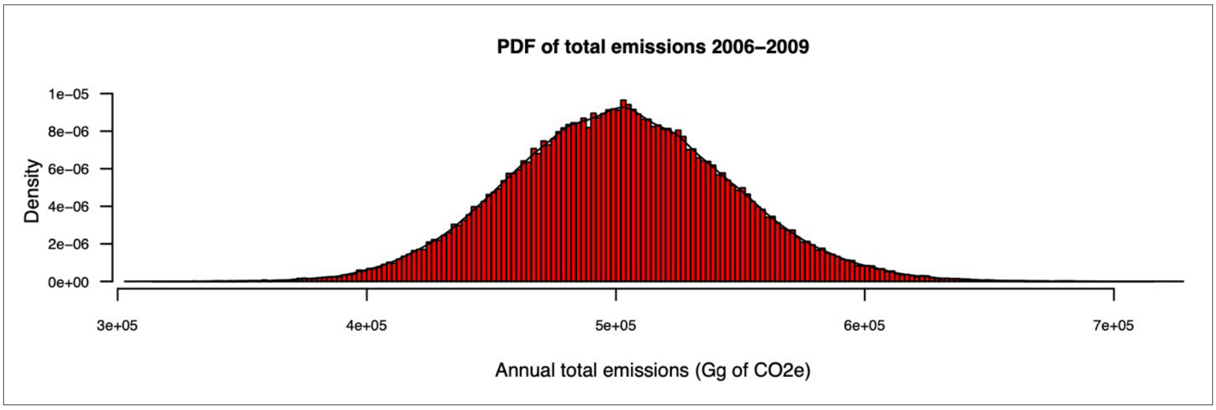
(b)


PDF of total emissions 2000–2003
Density
8e−06
6e−06
4e−06
2e−06
0e+00
2e+05
3e+05
4e+05
5e+05
6e+05
Annual total emissions (Gg of CO2e)

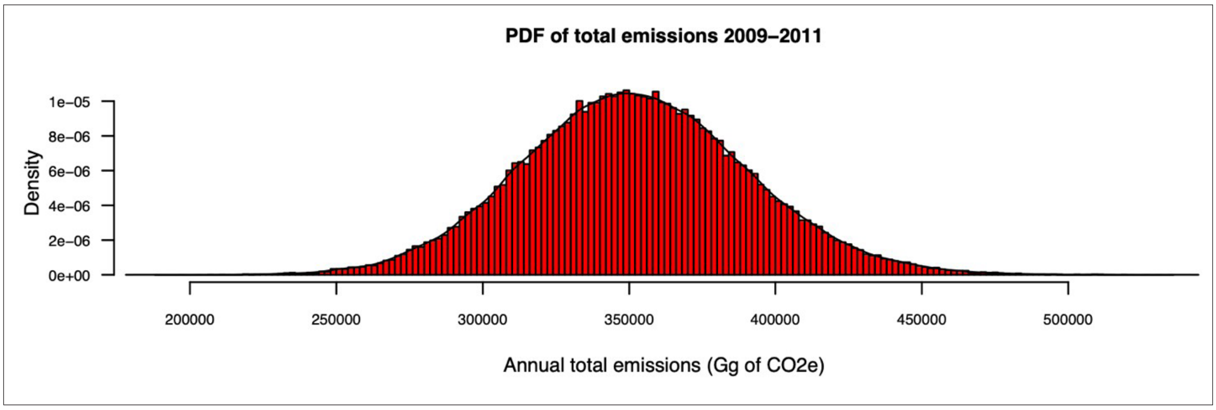
(c)


PDF of total emissions 2003–2006
Density
8e−06
6e−06
4e−06
2e−06
0e+00
3e+05
4e+05
5e+05
6e+05
7e+05
Annual total emissions (Gg of CO2e)

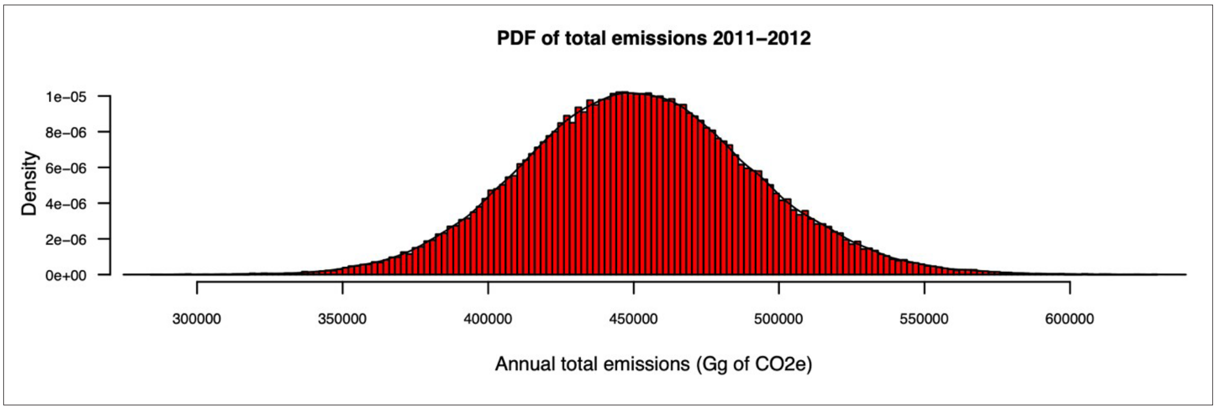
(d)



(e)



(f)



(g)

Figure 9. Density function of total emissions per period: (a) 1990–1996, (b) 1996–2000, (c) 2000–2003, (d) 2003–2006, (e) 2006–2009, (f) 2009–2011, and (g) 2011–2012

5.2.2 Emissions (and associated uncertainties) from peat decomposition due to deforestation, degradation, and secondary forest

Table 13 shows the estimation of CO_2 emissions from peat decomposition due to deforestation, forest degradation, secondary forest, and totals of peat decomposition for the Improved uncertainties analysis of FREL–2016. Table 14 shows uncertainties estimated of emissions from peat decomposition due to deforestation, forest degradation, secondary forest, and totals of peat decomposition for the improved uncertainties analysis of FREL–2016, using MCS. Results of Table 14 follow:

i. In most periods, uncertainties of emissions from peat decomposition due to deforestation have values between 17% and 30%.
ii. In most periods, uncertainties of emissions from peat decomposition due to degradation have values between 36% and 60%.
iii. In most periods, uncertainties of emissions from peat decomposition due to secondary forest have values around 90%.
iv. In most periods, uncertainties of total emissions from peat decomposition have values between 37% and 60%.

These results are consistent with those obtained with IPCC Approach 1.

Table 13. Estimation of CO_2 emissions from peat decomposition (due to deforestation, degradation, and secondary forest) for the Improved uncertainties analysis of Indonesia's FREL–2016

Activity	1990–1996	1996–2000	2000–2003	2003–2006	2006–2009	2009–2011	2011–2012
	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$	$MtCO_2e\ yr^{-1}$
PD by deforestation	21,798.99	57,084.88	62,490.98	77,473.68	97,686.62	106,786.55	116,244.59
PD by degradation	338.35	1,210.97	1,575.10	2,379.03	3,176.09	3,385.25	3,413.79
PD in secondary forest	132,952.10	103,315.22	103,353.68	95,276.02	82,898.23	79,166.25	76,976.80
Total	155,089.44	161,611.07	167,419.77	175,128.73	183,760.94	189,338.05	196,635.18

Note: PD = peat decomposition

Table 14. Uncertainties estimated of emissions from peat decomposition (due to deforestation, degradation, and secondary forest) for the Improved uncertainties analysis of Indonesia's FREL–2016, using IPCC Approach 2: MCS

Activity	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)	U (%)
PD by deforestation	29.3	34.4	24.89	27.9	22.88	25.93	19.98	22.26	17.31	19.1	16.06	17.66	14.96	16.32
PD by degradation	90.1	95.8	69.41	73.64	55.39	58.45	44.04	45.83	38.47	39.89	36.71	37.95	36.37	37.65
PD in secondary forest	90.2	96.0	90.7	95.8	89.0	94.9	88.6	95.2	87.7	93.9	87.5	93.6	87.0	94.0
Total	77.5	82.6	58.7	61.9	55.7	59.2	49.0	52.6	40.8	43.4	37.7	40.1	35.2	37.8

Note: PD = peat decomposition

Figure 10 presents emissions (from peat decomposition due to deforestation) and associated uncertainties shown in Tables 13 and 14. Confidence intervals shown in Figure 10 were estimated from the PDF of simulated emissions from peat decomposition due to deforestation (obtained with MCS) per period (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011, and 2011–2012) presented in Figure 11. In most periods, PDFs of emissions from peat decomposition due to deforestation (shown in Figure 11) are non-normal and the range of the PDFs is large. This implies large and asymmetrical uncertainties of the estimated emissions from peat decomposition due to deforestation as shown in Table 14 and Figure 10.

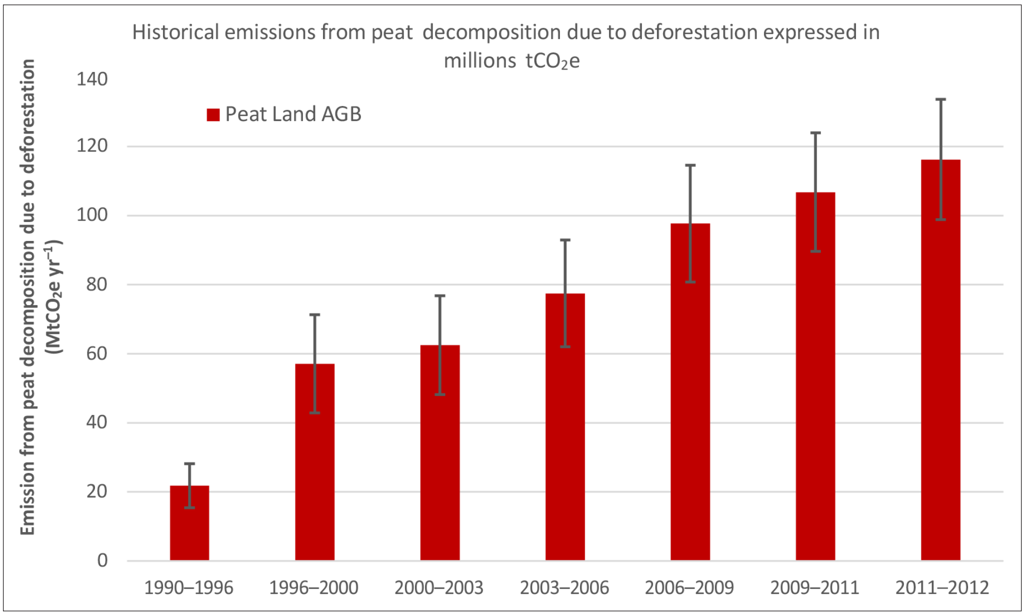
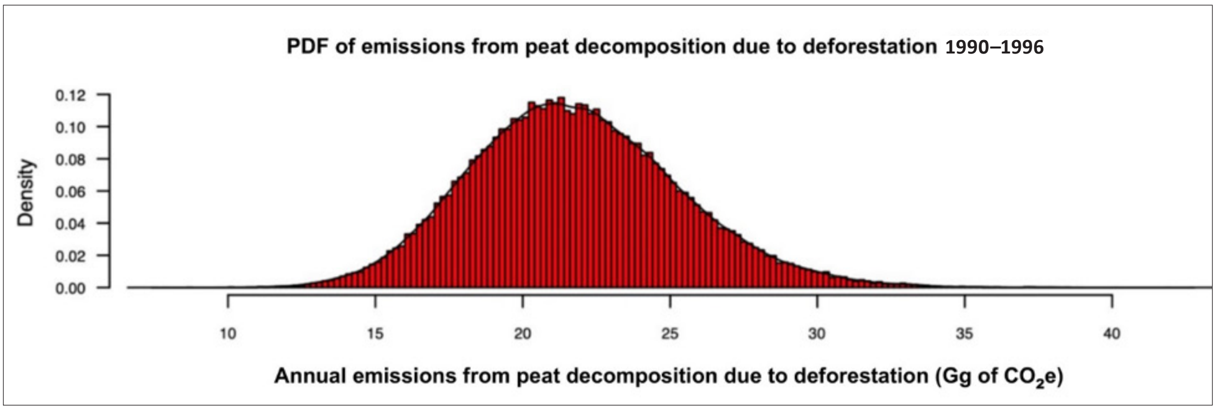
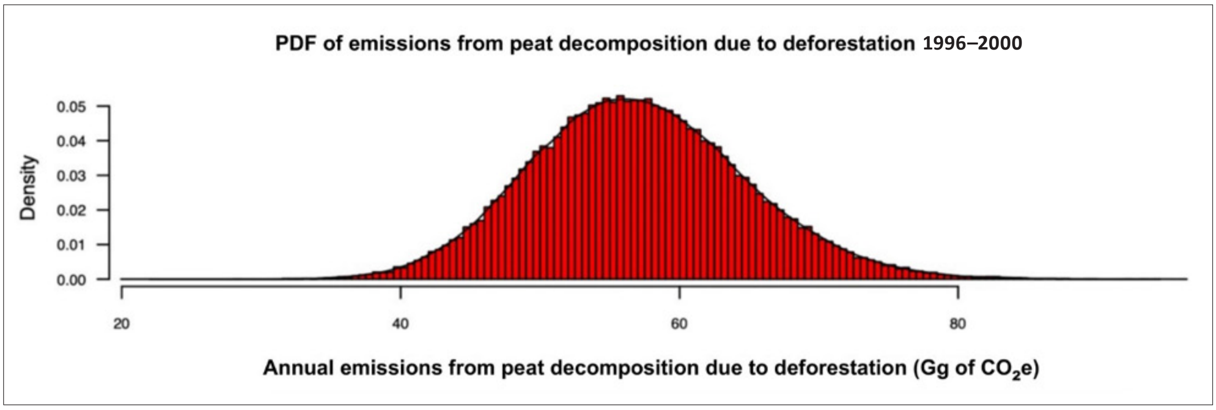


Figure 10. Historical emissions from peat decomposition due to deforestation and associated uncertainties obtained with MCS

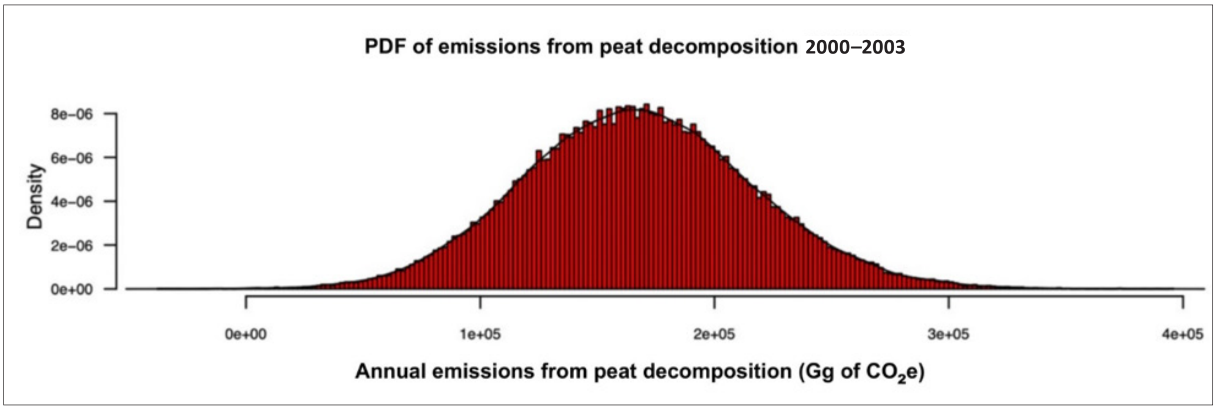
Note: AGB = Aboveground biomass



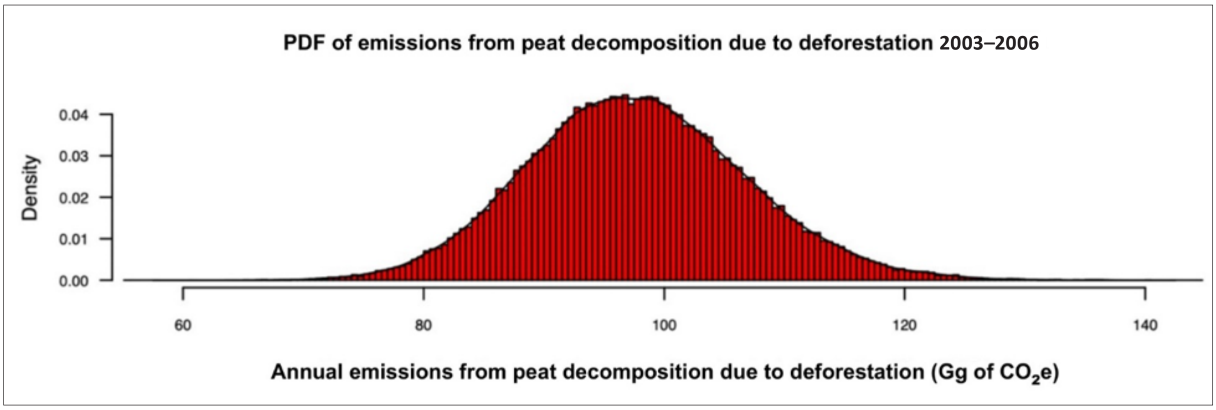
(a)


PDF of emissions from peat decomposition due to deforestation 1996–2000
Density
0.05
0.04
0.03
0.02
0.01
0.00
20
40
60
80
Annual emissions from peat decomposition due to deforestation (Gg of CO2e)

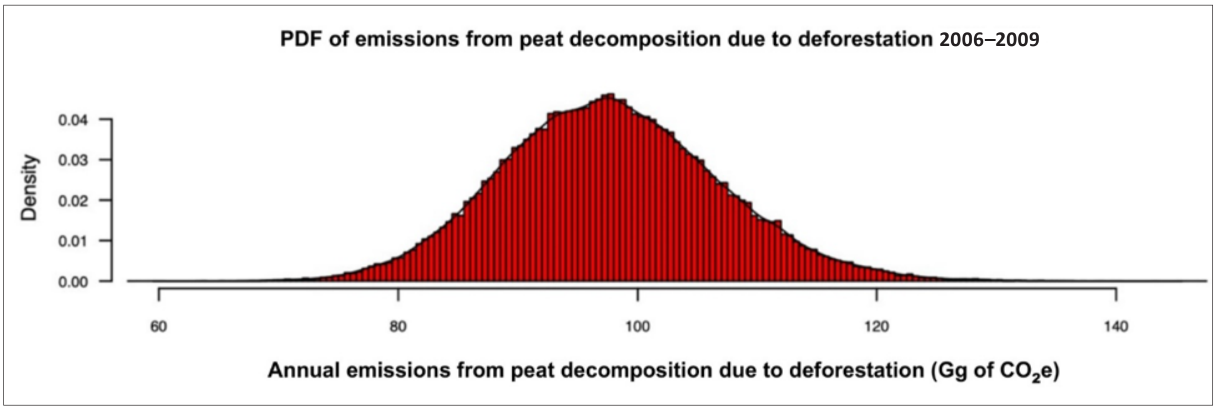
(b)


PDF of emissions from peat decomposition 2000–2003
Density
8e−06
6e−06
4e−06
2e−06
0e+00
0e+00
1e+05
2e+05
3e+05
4e+05
Annual emissions from peat decomposition (Gg of CO2e)

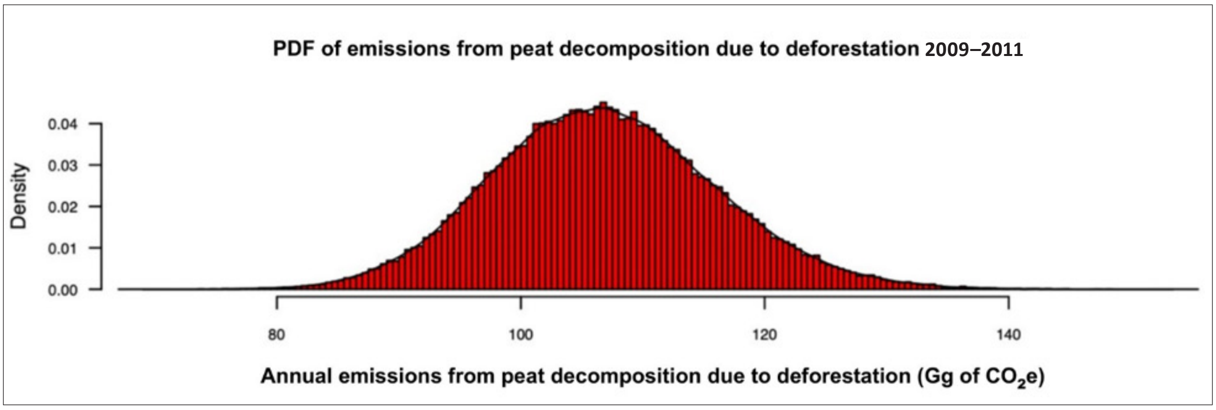
(c)


PDF of emissions from peat decomposition due to deforestation 2003–2006
Density
0.04
0.03
0.02
0.01
0.00
60
80
100
120
140
Annual emissions from peat decomposition due to deforestation (Gg of CO2e)

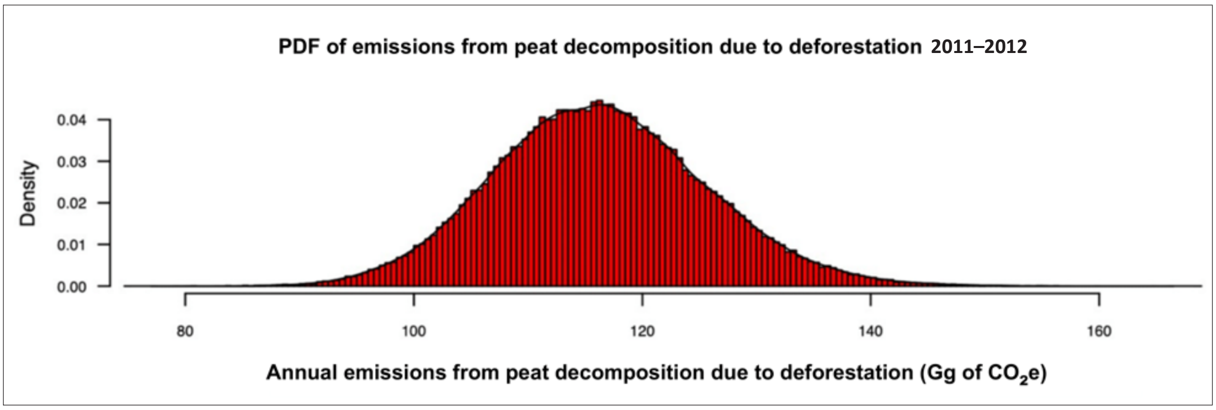
(d)


PDF of emissions from peat decomposition due to deforestation 2006–2009
Density
0.04
0.03
0.02
0.01
0.00
60
80
100
120
140
Annual emissions from peat decomposition due to deforestation (Gg of CO2e)

(e)



(f)



(g)

Figure 11. Density function of emissions from peat decomposition due to deforestation per period: (a) 1990–1996, (b) 1996–2000, (c) 2000–2003, (d) 2003–2006, (e) 2006–2009, (f) 2009–2011, and (g) 2011–2012

Figure 12 presents emissions (from peat decomposition due to degradation) and associated uncertainties shown in Tables 13 and 14. Confidence intervals shown in Figure 12 were estimated from the PDF of simulated emissions from peat decomposition from degradation (obtained with MCS) per period (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011, and 2011–2012) presented in Figure 13. In most periods, PDFs of emissions from peat decomposition due to degradation (shown in Figure 13) are non-normal and the range of PDFs is large. This implies large and asymmetrical uncertainties of the estimated emissions from peat decomposition due to degradation as shown in Table 14 and Figure 12.

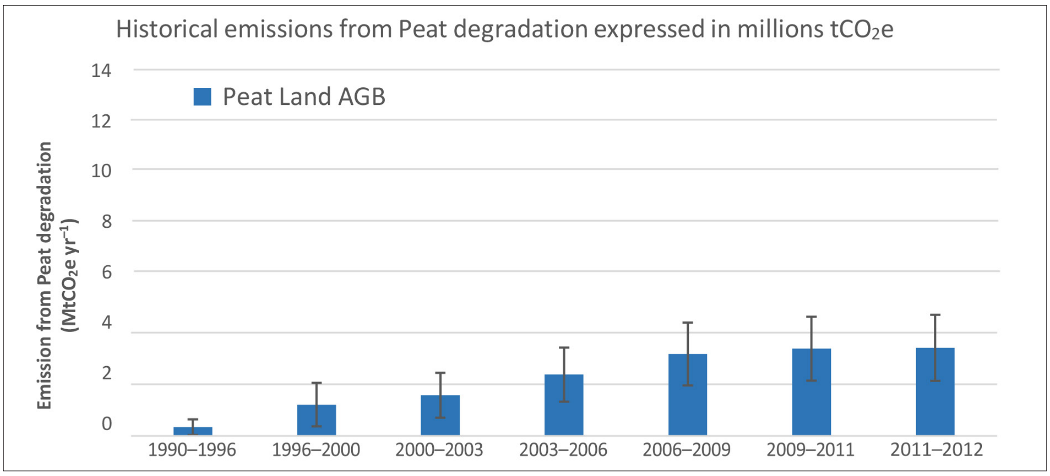
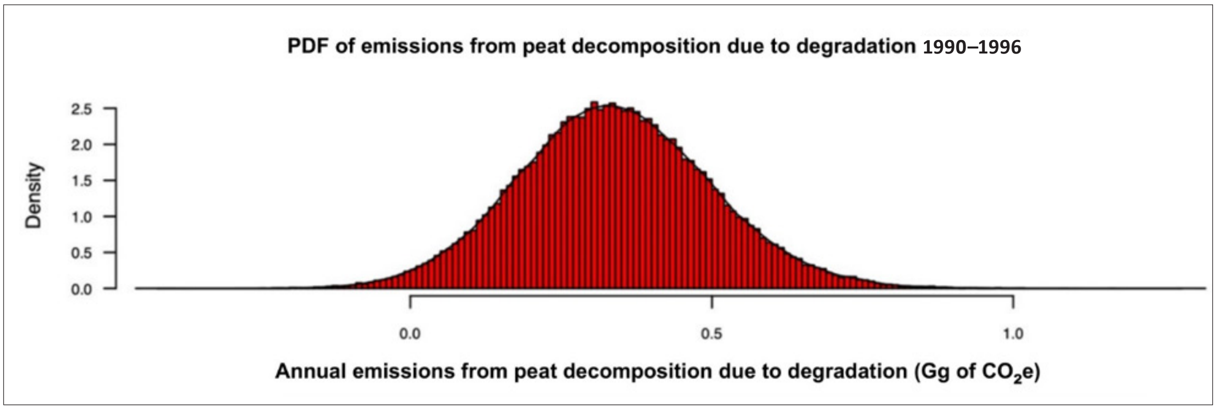
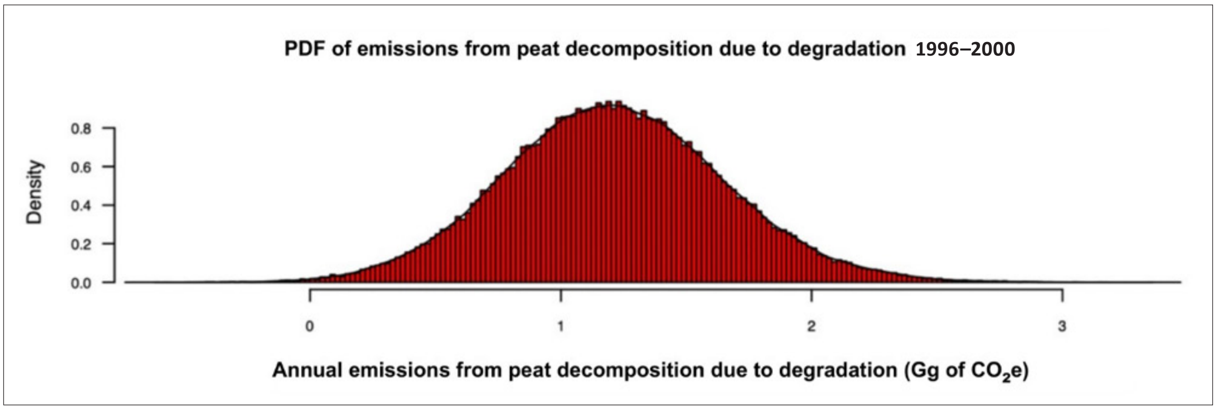


Figure 12. Historical emissions from peat decomposition due to degradation and associated uncertainties obtained with MCS

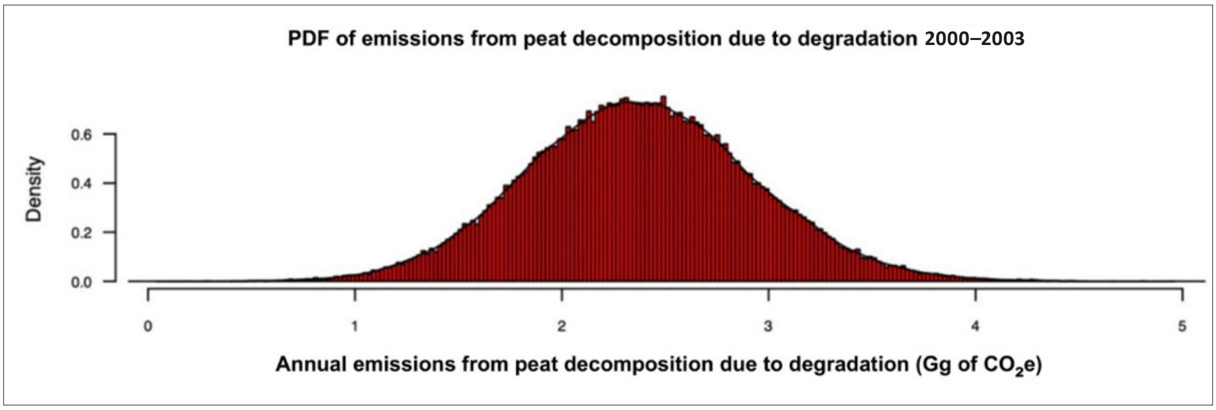
Note: AGB = Aboveground biomass


PDF of emissions from peat decomposition due to degradation 1990–1996
Density
2.5
2.0
1.5
1.0
0.5
0.0
0.0
0.5
1.0
Annual emissions from peat decomposition due to degradation (Gg of CO_2e)

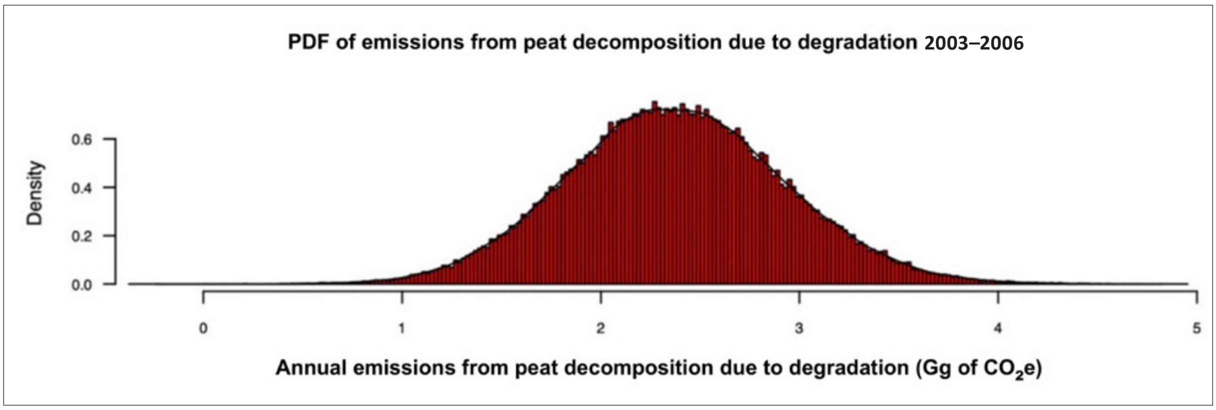
(a)


PDF of emissions from peat decomposition due to degradation 1996–2000
Density
0.8
0.6
0.4
0.2
0.0
0
1
2
3
Annual emissions from peat decomposition due to degradation (Gg of CO_2e)

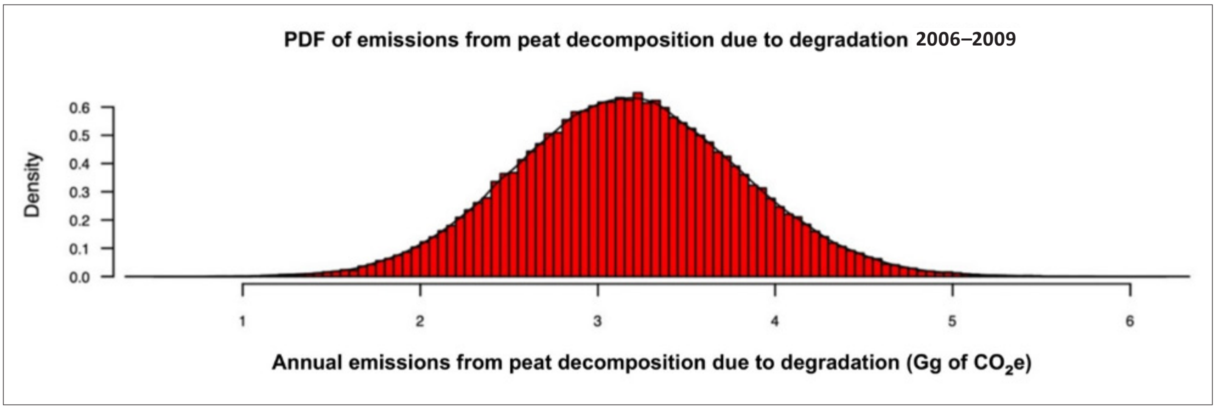
(b)


PDF of emissions from peat decomposition due to degradation 2000–2003
Density
0.6
0.4
0.2
0.0
0
1
2
3
4
5
Annual emissions from peat decomposition due to degradation (Gg of CO_2e)

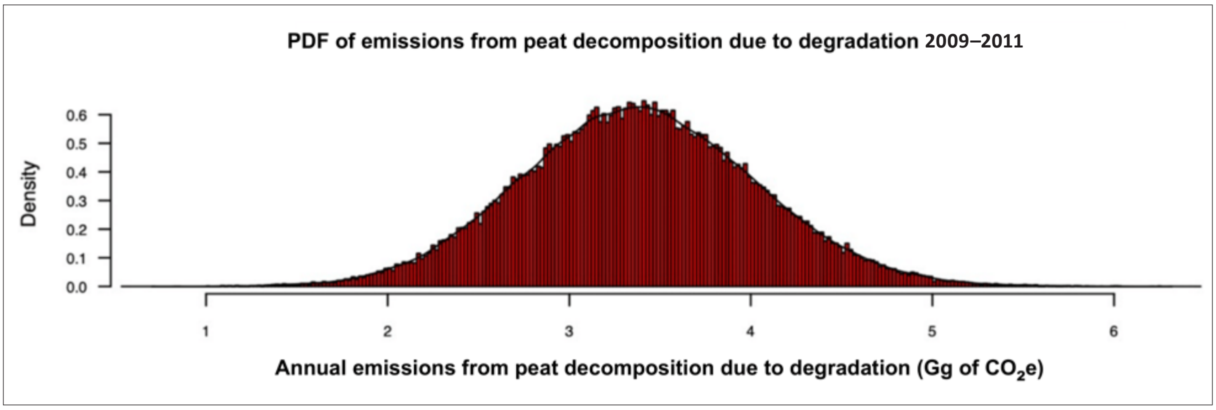
(c)


PDF of emissions from peat decomposition due to degradation 2003–2006
Density
0.6
0.4
0.2
0.0
0
1
2
3
4
5
Annual emissions from peat decomposition due to degradation (Gg of CO_2e)

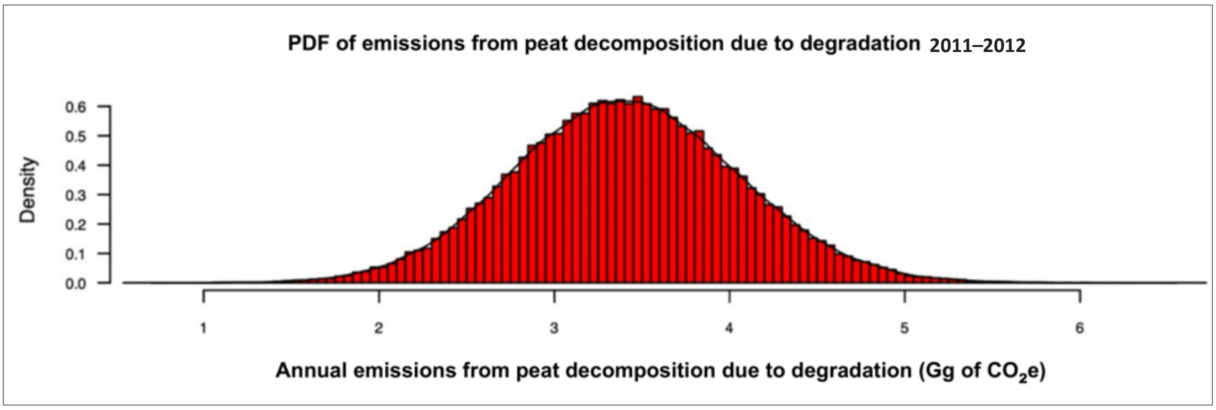
(d)



(e)



(f)



(g)

Figure 13. Density function of emissions from peat decomposition due to degradation per period: (a) 1990–1996, (b) 1996–2000, (c) 2000–2003, (d) 2003–2006, (e) 2006–2009, (f) 2009–2011, and (g) 2011–2012

Figure 14 presents emissions (from peat decomposition due to secondary forest) and associated uncertainties shown in Tables 13 and 14. Confidence intervals shown in Figure 14 were estimated from PDF of simulated emissions from peat decomposition due to secondary forest (obtained with MCS) per period (1990–1996, 1996–2000, 2000–2003, 2003–2006, 2006–2009, 2009–2011, and 2011–2012) presented in Figure 15. In most periods, PDFs of emissions from peat decomposition due to secondary forest (shown in Figure 15) are non-normal and the range of the PDFs is large. This implies large and asymmetrical uncertainties of the estimated emissions from peat decomposition due to secondary forest as shown in Table 14 and Figure 14.

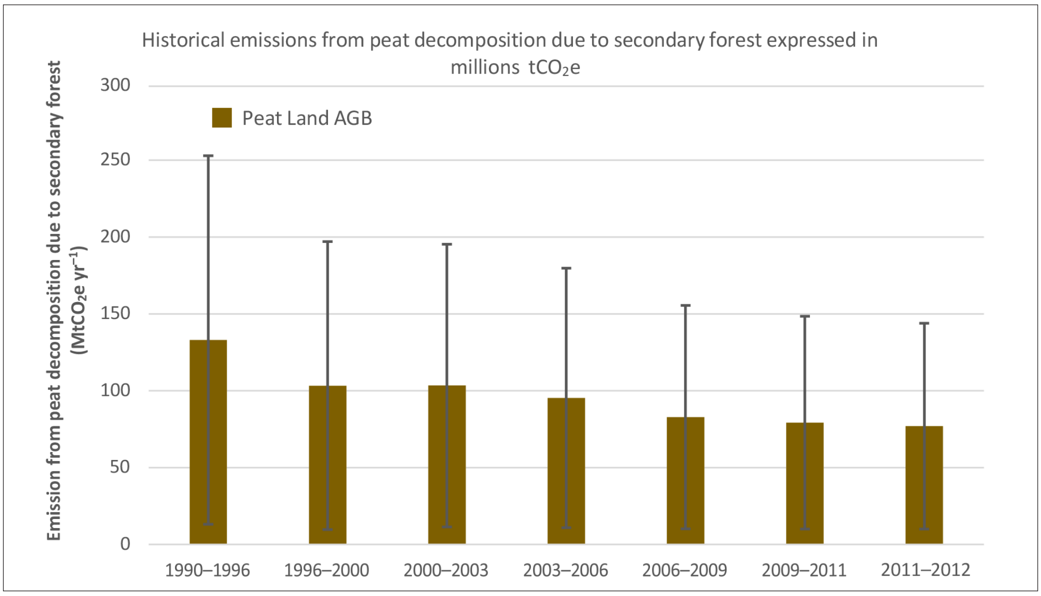
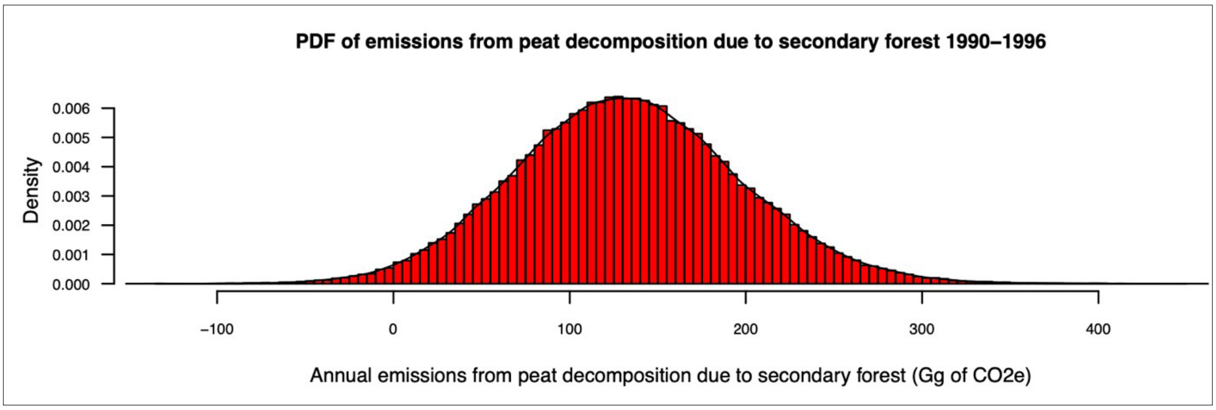
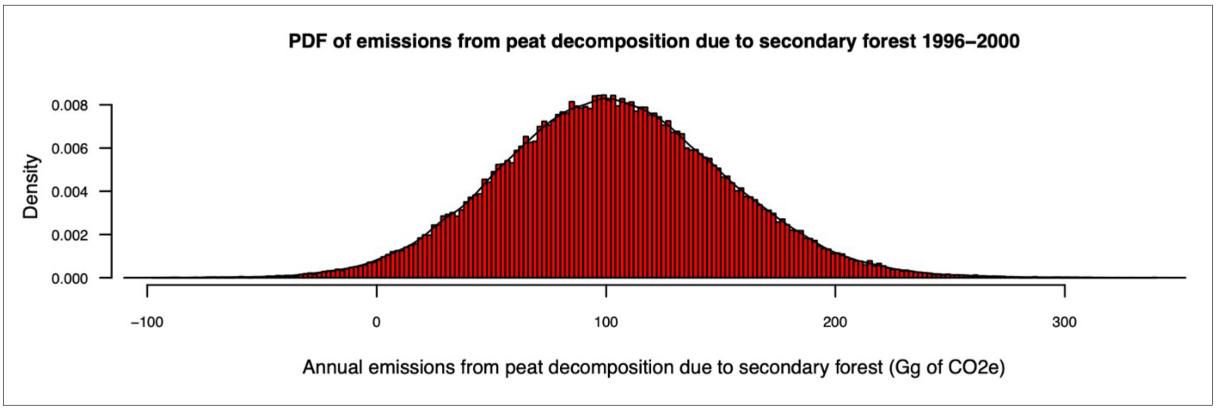


Figure 14. Historical emissions from peat decomposition due to secondary forest and associated uncertainties obtained with MCS

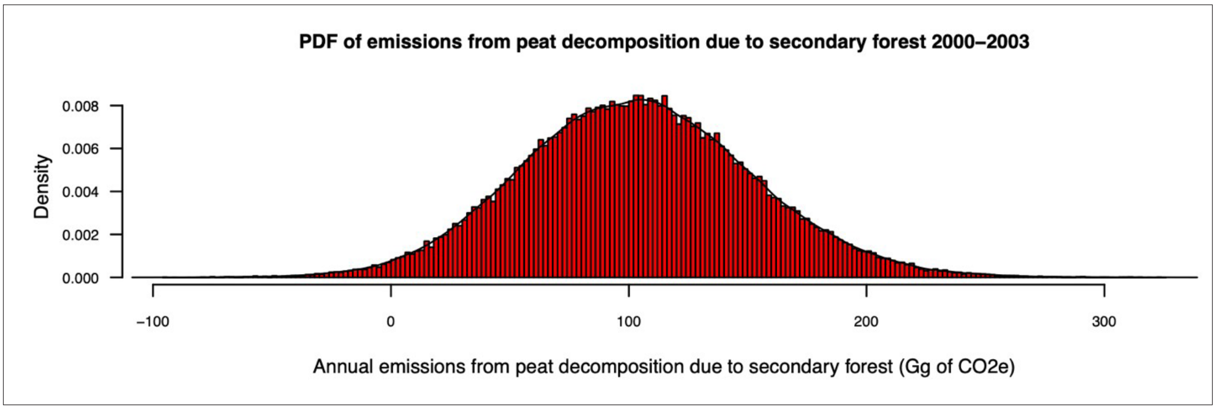
Note: AGB = Aboveground biomass



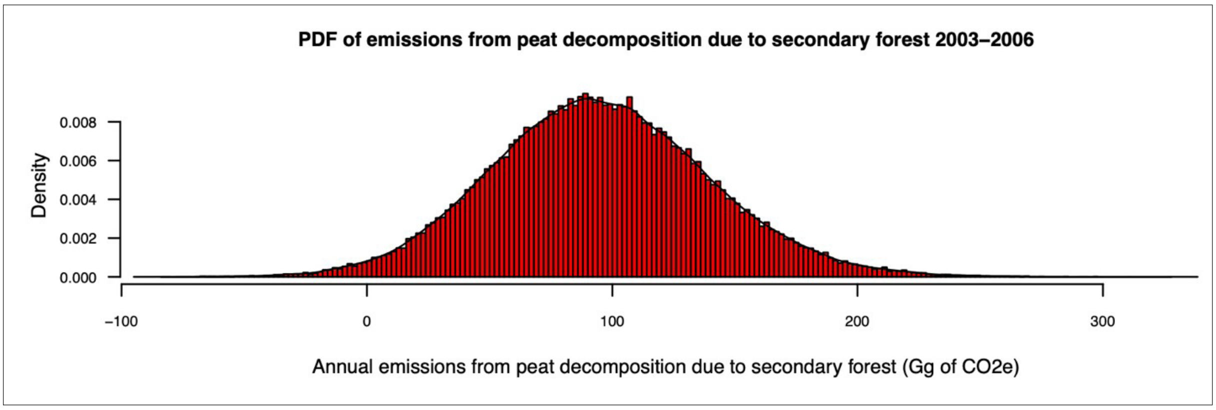
(a)



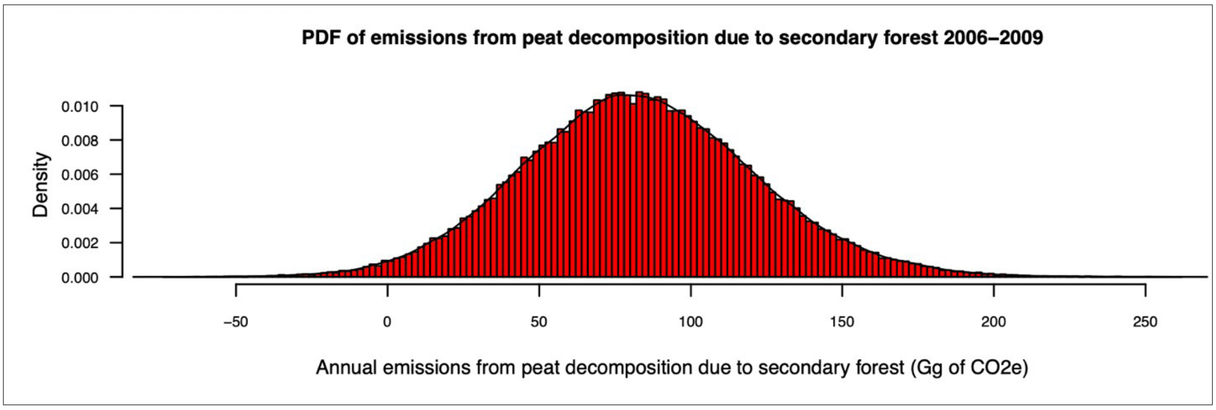
(b)


PDF of emissions from peat decomposition due to secondary forest 2000–2003
Density
0.000
0.002
0.004
0.006
0.008
−100
0
100
200
300
Annual emissions from peat decomposition due to secondary forest (Gg of CO2e)

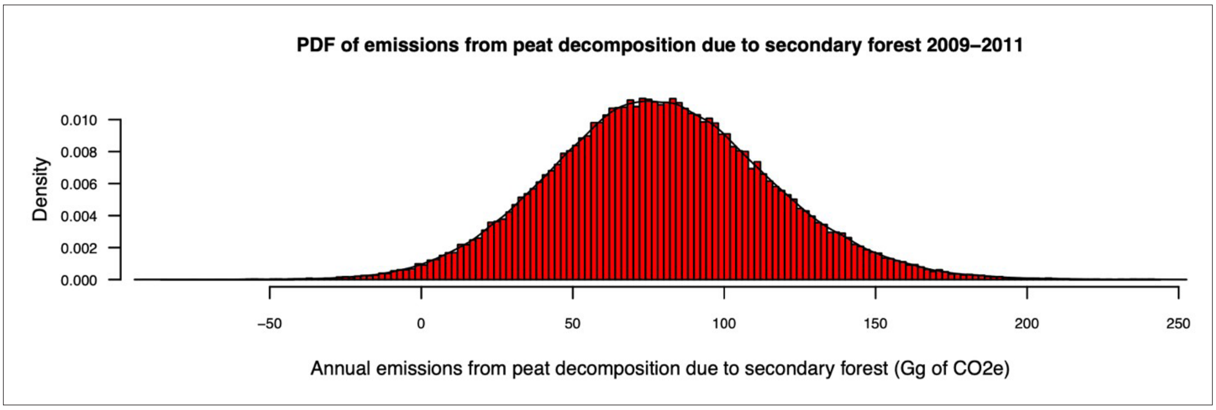
(c)


PDF of emissions from peat decomposition due to secondary forest 2003–2006
Density
0.000
0.002
0.004
0.006
0.008
−100
0
100
200
300
Annual emissions from peat decomposition due to secondary forest (Gg of CO2e)

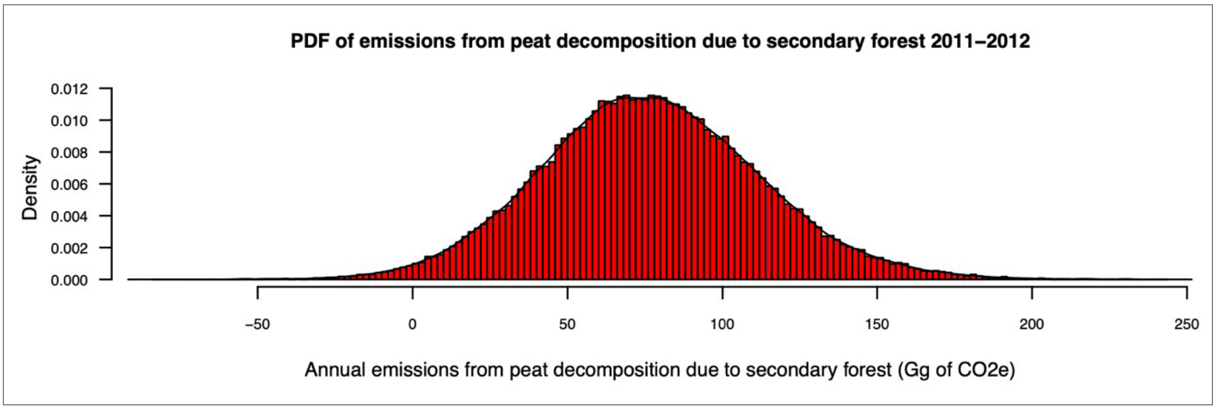
(d)


PDF of emissions from peat decomposition due to secondary forest 2006–2009
Density
0.000
0.002
0.004
0.006
0.008
0.010
−50
0
50
100
150
200
250
Annual emissions from peat decomposition due to secondary forest (Gg of CO2e)

(e)


PDF of emissions from peat decomposition due to secondary forest 2009–2011
Density
0.000
0.002
0.004
0.006
0.008
0.010
−50
0
50
100
150
200
250
Annual emissions from peat decomposition due to secondary forest (Gg of CO2e)

(f)



(g)

Figure 15. Density function of emissions from peat decomposition due to secondary forest per period: (a) 1990–1996 (b) 1996–2000, (c) 2000–2003, (d) 2003–2006, (e) 2006–2009, (f) 2009–2011, and (g) 2011–2012

6 Analysis of results

The following sections present comparative analyses of emissions and associated uncertainties obtained in FREL–2016 versus the Improved uncertainties analysis of FREL–2016. They cover **deforestation** (section 6.1), **degradation** (section 6.2), **peat decomposition** (section 6.3) and **total emissions** (section 6.4).

This comparative analysis assesses the impact of improvements in the uncertainties combination through implementation of the MCS.

6.1 Comparative analysis of emissions from deforestation and associated uncertainties

Table 15 and Figure 16 show the emissions from deforestation and associated uncertainties (estimated using IPCC Approach 1: PEA) reported in FREL–2016 per period and at the island level. This information was taken from tables in Annexes 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, and 8.7 of Indonesia's submitted FREL–2016 (MoEF 2016). As presented in Table 15 and Figure 16, in most periods and islands, the uncertainties of the emissions from deforestation have values of around 14%.

Table 15. Emissions from deforestation and associated uncertainties (estimated using IPCC Approach 1: PEA) reported in Indonesia's FREL–2016 at island level

Island	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)
Java	2	14.42	17,250	14.42	1,126	14.42	4,437	14.42	1,425	14.42	9096	14.42	381	14.42
Kalimantan	137,900	13.00	182,554	13.00	67,984	13.00	105,419	13.00	112,239	13.00	75,467	13.00	99,114	13.00
Maluku			37,918	18.44	3,335	18.44	3,649	18.44	3,332	18.44	4,792	18.44	2,581	18.44
Nusa	73	14.42	16,832	14.42	996	14.42	3,234	14.42	469	14.42	538	14.42	16,007	14.42
Papua	34	14.42	99,313	14.42	7,926	14.42	25,991	14.42	12,295	14.42	5,671	14.42	13,903	14.42
Sulawesi	1,542	18.44	96,412	18.44	25,275	18.44	32,989	18.44	16,347	18.44	14,418	18.44	7,141	18.44
Sumatera	59,362	13.42	286,727	13.42	36,309	13.42	88,644	13.42	140,294	13.42	72,096	13.42	109,811	13.42

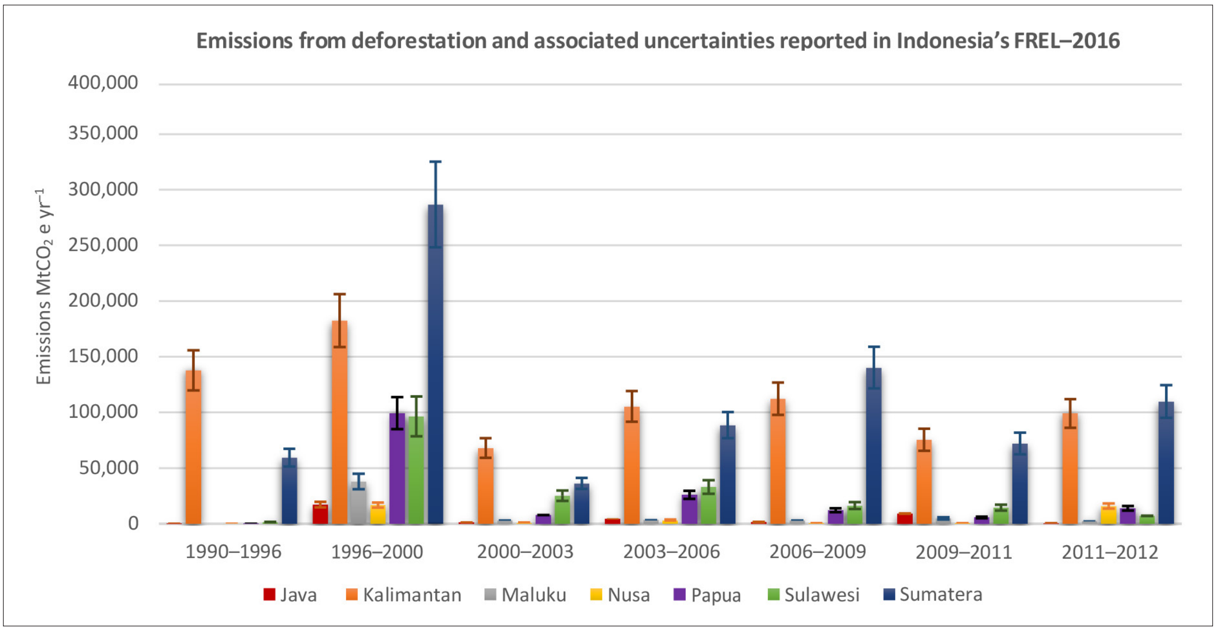


Figure 16. Emissions from deforestation and associated uncertainties reported in Indonesia's FREL–2016

Source: MoEF 2016

Table 16 and Figure 17 show the emissions from deforestation and associated uncertainties (estimated using IPCC Approach 2: MCS) for the Improved uncertainties analysis of FREL–2016 per period and at island level. This information was generated through MCS using data of the Improved uncertainties analysis of FREL–2016. As presented in Table 16 and Figure 17, in most periods and islands, the uncertainties of the emissions from deforestation have values between 20% and 30%.

Table 16. Emissions from deforestation and associated uncertainties (estimated using IPCC Approach 2: MCS) reported in the Improved uncertainties analysis of Indonesia's FREL–2016

Island	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)	Emission $MtCO_2e$ yr^{-1}	U (%)
Java	2	(24, 24.1)	11,871	(33.2, 33.3)	1,091	(30, 30)	3,916	(30, 30)	622	(28.1, 28)	926	(24.9, 25.1)	372	(28.1, 28.1)
Kalimantan	137,816	(16.1, 16.3)	182,598	24, 24)	74,143	(20.9, 20.8)	106,801	(20.6, 20.7)	114,427	(20.1, 20)	47,330	(23.8, 24.5)	99,855	(20.9, 21.1)
Maluku	-	(24.9, 25.7)	36,306	(29.2, 29.8)	3,334	(30.3, 31.5)	3,647	(30.5, 31.2)	3,332	(28, 29.1)	4,659	(23.5, 24.3)	2,572	(28.1, 29)
Nusa	73	(26.6, 28.7)	16,770	(27.3, 29)	996	(22.7, 23.5)	3,216	(30.3, 32.4)	468	(28.4, 30.3)	537	(23.1, 24.8)	15,968	(27.7, 29.5)
Papua	34	(19.3, 20.4)	99,130	(17.2, 17.6)	7,925	(22.7, 24.8)	27,919	(20.7, 21.5)	12,306	(19.2, 20.3)	5,669	(16.2, 16.4)	13,895	(18.3, 19)
Sulawesi	1,541	(20.8, 21.4)	96,163	(25.2, 25.7)	25,292	(29, 29.3)	33,545	(27.8, 28.3)	16,369	(25.2, 25.5)	14,443	(19, 19.3)	7,249	(24.6, 25.3)
Sumatera	59,355	(17.5, 17.9)	286,454	(22.9, 23.2)	36,358	(20.9, 21.1)	89,249	(21.9, 22.4)	156,001	(18.4, 18.8)	72,682	(17.2, 17.5)	109,875	(19.3, 19.6)

Source: MoEF 2016

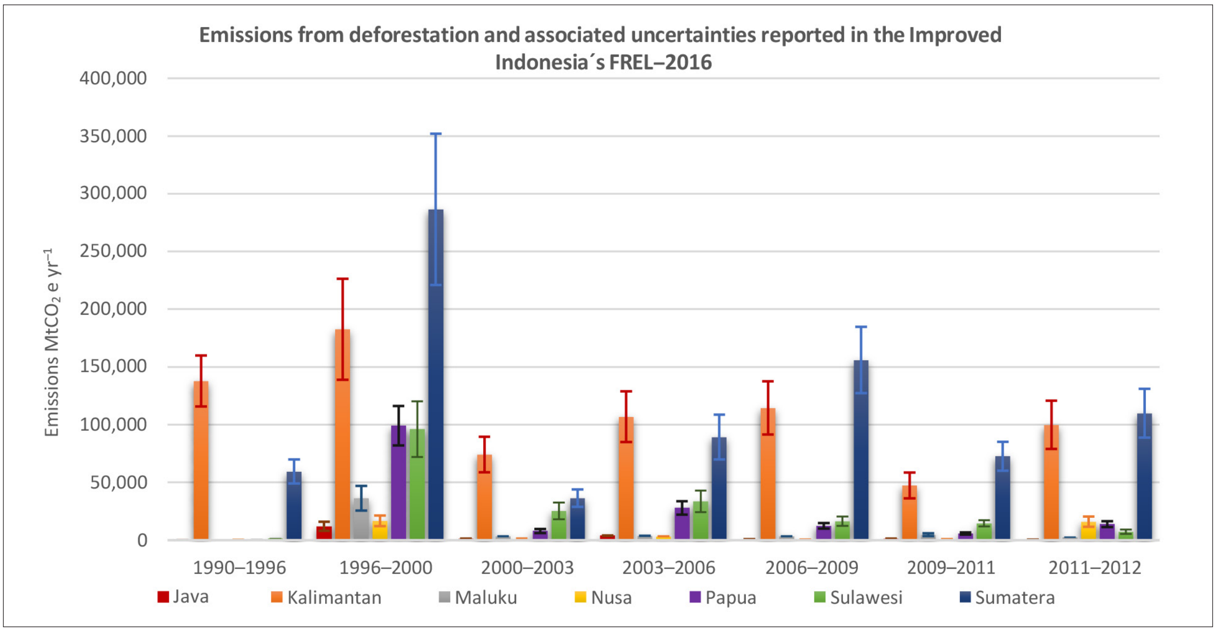


Figure 17. Emissions from deforestation and associated uncertainties reported in the Improved uncertainties analysis of Indonesia's FREL–2016

By comparing results of Table 15/Figure 16 versus Table 16/Figure 17, uncertainties of emissions from deforestation reported in FREL–2016 were underestimated by around 1.5 to 2 times. This underestimation of the uncertainties in general was present in all periods and islands.

6.2 Comparative analysis of emissions from degradation and associated uncertainties

Table 17 and Figure 18 show the emissions from degradation and associated uncertainties (estimated using IPCC Approach 1: PEA) reported in FREL–2016 per period and at island level. This information was taken from Annexes 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, and 8.7 of FREL–2016. As presented in Table 17 and Figure 18, in most periods and islands, the uncertainties of the emissions from degradation have values between 15% and 20%.

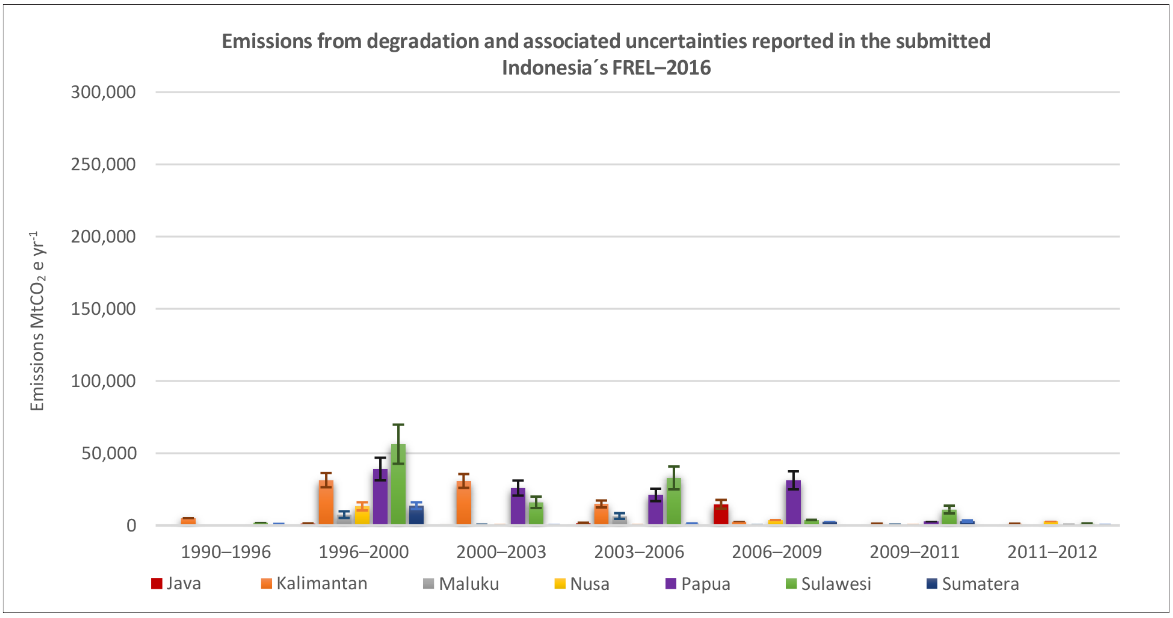


Figure 18. Emissions from degradation and associated uncertainties reported in Indonesia's FREL–2016

Source: MoEF 2016

Table 17. Emissions from degradation and associated uncertainties (estimated using the IPCC Approach 1: PEA) reported in FREL–2016

Island	1990–1996		1996–2000		2000-2003		2003-2006		2006–2009		2009–2011		2011–2012	
	Emission $MtCO_2e\ yr^{-1}$	U (%)	Emission $MtCO_2e\ yr^{-1}$	U (%)	Emission $MtCO_2e\ yr^{-1}$	U (%)	Emission $MtCO_2e\ yr^{-1}$	U (%)	Emission $MtCO_2e\ yr^{-1}$	U (%)	Emission $MtCO_2e\ yr^{-1}$	U (%)	Emission $MtCO_2e\ yr^{-1}$	U (%)
Java			1,179	20.81	42	20.81	1,553	20.81	14,668	20.81				
Kalimantan	5,089	15.62	31,345	15.62	30,854	15.62	14,911	15.62	2,696	15.62	1,037	15.62	1,164	15.62
Maluku			7,496	30.46	540	30.46	6,552	30.46	189	30.46	509	30.46		
Nusa			13,247	20.81	221	20.81	216	20.81	3,820	20.81	203	20.81	2,839	20.81
Papua			39,089	20.00	25,835	20.00	21,189	20.00	31,279	20.00	2,633	20.00	397	20.00
Sulawesi	1,944	24.19	56,265	24.19	16,045	24.19	32,855	24.19	3,848	24.19	11,067	24.19	1,240	24.19
Sumatera	644	53.85	13,774	16.97	154	16.97	1,320	16.97	2,727	16.97	3,062	16.97	282	16.97

Table 18 and Figure 19 show the emissions from degradation and associated uncertainties (estimated using IPCC Approach 2: MCS) for the Improved uncertainties analysis of FREL–2016 per period and at island level. This information was generated through the implementation of MCS using data of the improved uncertainties analysis of FREL–2016. As presented in Table 18 and Figure 19, in most periods and islands, the uncertainties of the emissions from degradation have values between 20% and 50%.

Table 18. Emissions from degradation and associated uncertainties (estimated using IPCC Approach 2: MCS) reported in the Improved uncertainties analysis of Indonesia's FREL–2016

Island	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
	Emission MtCO2e yr^{-1}	U (%)	Emission MtCO2e yr^{-1}	U (%)	Emission MtCO2e yr^{-1}	U (%)	Emission MtCO2e yr^{-1}	U (%)	Emission MtCO2e yr^{-1}	U (%)	Emission MtCO2e yr^{-1}	U (%)	Emission MtCO2e yr^{-1}	U (%)
Java			−2,098	(24, 24.1)	−70	(22, 22)	−2,772	(24, 24)	-26,072	(21, 20.9)				
Kalimantan	4,926	(23.4, 25.6)	31,209	(28.7, 32.1)	30,885	(27.7, 31.4)	14,930	(28.1, 31.5)	2,699	(26.3, 29.2)	1,029	(26.3, 29.1)	1,164	(29.6, 32.7)
Maluku			7,472	(106.1, 113.8)	539	(104.7, 111.2)	4,562	(124.3, 131.9)	784	(27.9, 31.1)	524	(100.8, 107.3)	0	(19.8, 19.9)
Nusa	6	(26.8, 29.5)	13,146	(37.6, 42.9)	250	(30.8, 35.1)	216	(37, 42)	3,820	(35.4, 40)	203	(35, 39.2)	3,052	(33.3, 38.6)
Papua			39,085	(45.2, 51.8)	22,834	(48.3, 53.8)	16,485	(56.2, 61.7)	26,675	(49.7, 54.8)	1,520	(85.4, 87.8)	-102	(421.8, 411)
Sulawesi	1,951	(30, 33.6)	55,682	(33.8, 38.8)	16,169	(31.5, 35.5)	32,957	(32.7, 37.4)	3,918	(30.2, 34.1)	11,072	(30.8, 34.6)	1,240	(32.9, 37.6)
Sumatera	489	(88, 90)	14,049	(33.3, 37.9)	57	(221.3, 225.4)	769	(95.2, 97.7)	2,414	(69.7, 71.8)	2,288	(50.6, 52)	80	(312.1, 322.8)

Source: MoEF 2016

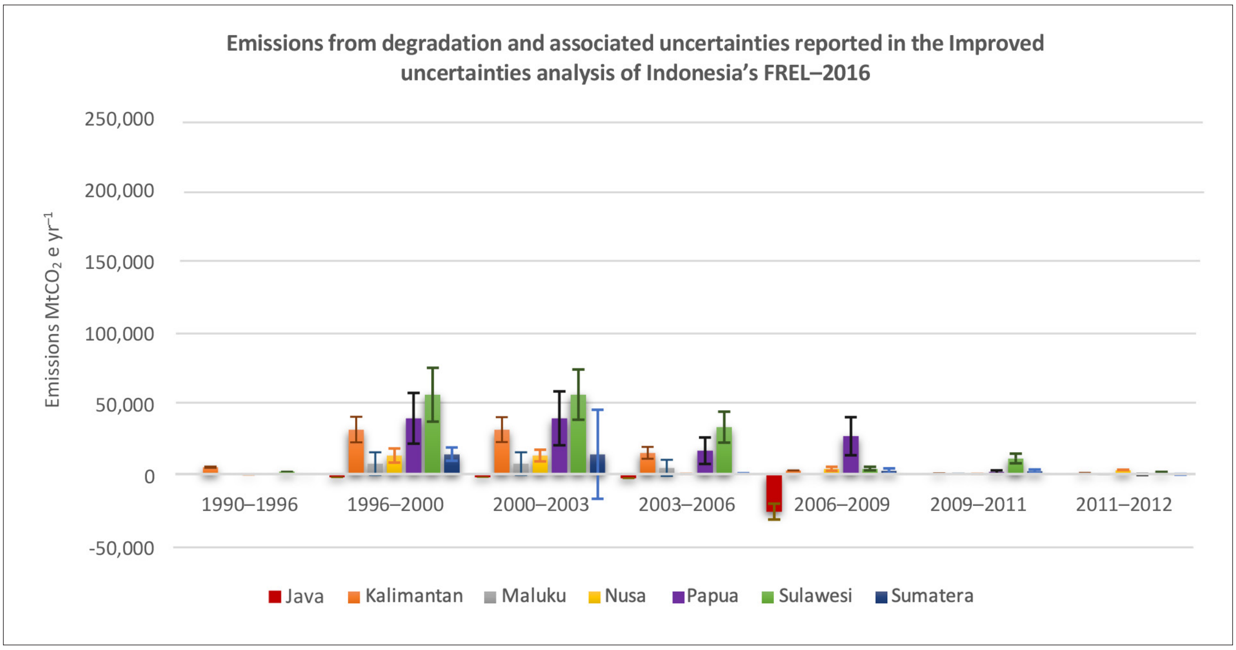


Figure 19. Emissions from degradation and associated uncertainties reported in the Improved uncertainties analysis of Indonesia's FREL–2016

Source: MoEF 2016

By comparing results of Table 17/Figure 18 with those of Table 18/Figure 19, uncertainties of emissions from degradation reported in Indonesia's submitted FREL–2016 were underestimated at least 2 times. This underestimation of the uncertainties in general was presented in all periods and islands.

6.3 Comparative analysis of emissions from peat decomposition and associated uncertainties

Table 19 shows the emissions from peat decomposition and associated uncertainties (estimated using IPCC Approach 1: PEA) reported in Indonesia's submitted FREL–2016 per period and at island level. This information was taken from tables in Annexes 8.1, 8.2, 8.3, 8.4, 8.5, 8.6 and 8.7 of the submitted FREL–2016 (MoEF 2016). The uncertainties presented in Table 19 were combined (using IPCC Approach 1) to obtain uncertainties of emissions from peat decomposition per period as they were not reported in Indonesia's submitted FREL–2016. The results of uncertainties of emissions from peat decomposition per period are shown in Table 19 and Table 20.

Table 19. Emissions from peat decomposition and associated uncertainties (estimated using the IPCC Approach 1: PEA) reported in Indonesia's FREL–2016

Island	1990–1996		1996–2000		2000–2003		2003–2006		2006–2009		2009–2011		2011–2012	
	Emission $MtCO_{2e}$ yr^{-1}	U (%)	Emission $MtCO_{2e}$ yr^{-1}	U (%)	Emission $MtCO_{2e}$ yr^{-1}	U (%)	Emission $MtCO_{2e}$ yr^{-1}	U (%)	Emission $MtCO_{2e}$ yr^{-1}	U (%)	Emission $MtCO_{2e}$ yr^{-1}	U (%)	Emission $MtCO_{2e}$ yr^{-1}	U (%)
Java														
Kalimantan	72,477	53.85	73,015	53.85	73,795	53.85	75,194	53.85	77,735	53.85	80,499	53.85	82,194	53.85
Maluku														
Nusa														
Papua	7,347	53.85	8,808	53.85	10,574	53.85	11,510	53.85	12,602	53.85	13,136	53.85	13,249	53.85
Sulawesi														
Sumatera	71,989	53.85	82,993	53.85	90,388	53.85	97,530	53.85	109,782	53.85	122,214	53.85	130,725	53.85
Total	151,783	36.32	164,816	36.23	174,757	36.10	184,235	36.15	200,119	36.36	215,799	36.23	226,168	31.28

Source: MoEF 2016

Table 20 and Figure 20 show the emissions from peat decomposition and associated uncertainties reported in Indonesia's submitted FREL–2016 and in the Improved uncertainties analysis. Uncertainties of emissions from peat decomposition per period for Indonesia's submitted FREL–2016 were obtained according to the process described previously. Uncertainties of emissions from peat decomposition for the Improved uncertainties analysis of FREL–2016 were obtained by the MCS.

In Table 20 and Figure 20, by comparing uncertainties of emissions from peat decomposition reported in Indonesia´s submitted FREL–2016 to the improved uncertainties analysis of FREL–2016, there are important underestimations of uncertainties reported in the former. The underestimation is emphasized in the first four periods and is reduced in the last three periods. In the case of uncertainties of emissions from peat decomposition reported in the improved uncertainties analysis of FREL–2016, this decreases over time because of the accumulative effect of emissions from peat decomposition.

Table 20. Emissions from peat decomposition and associated uncertainties reported in Indonesia's FREL–2016 and in the Improved uncertainties analysis ofIndonesia's FREL–2016

Period	Indonesia's submitted FREL–2016 (MoEF 2016)		Improved uncertainties analysis of Indonesia's FREL–2016	
	Emissions Mt CO_2 e yr^{-1}	Uncertainties	Emissions Mt CO_2 e yr^{-1}	Uncertainties
1990-1996	151,783	36.33	155,089	(77.5, 82.6)
1996-2000	164,816	36.23	161,611	(58.7, 61.9)
2000-2003	174,757	36.10	167,420	(55.7, 61.9)
2003-2006	184,235	36.15	175,129	(49, 52.6)
2006-2009	200,119	36.36	183,761	(40.8, 43.4)
2009-2011	215,799	36.23	189,338	(37.7, 40.1)
2011-2012	226,168	31.28	196,635	(35.2, 37.8)

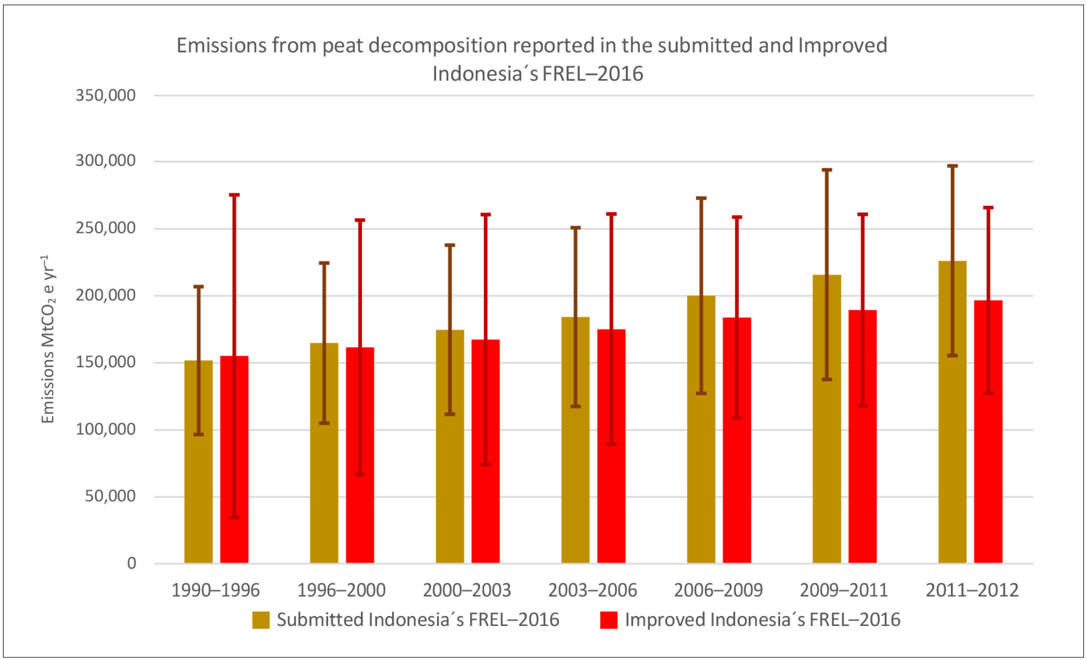


Figure 20. Emissions from peat decomposition reported in Indonesia's FREL–2016 and in the Improved uncertainties analysis of Indonesia's FREL–2016

6.4 Comparative analyses of total emissions and associated uncertainties

Table 21 and Figure 21 show total emissions and associated uncertainties reported in Indonesia's submitted FREL–2016 and in the Improved uncertainties analysis of FREL–2016. Uncertainties of total emissions for Indonesia´s submitted FREL–2016 were obtained from Table 5 and tables in Annexes 8.1, 8.2, 8.3, 8.4, 8.5, 8.6, and 8.7 of the submitted FREL–2016 (MoEF 2016). Uncertainties of total emissions for the Improved uncertainties analysis of FREL–2016 were obtained through the implementation of MCS.

In Table 21 and Figure 21, by comparing uncertainties of total emissions reported in Indonesia's submitted FREL–2016 with the Improved uncertainties analysis of FREL–2016, it is possible to identify an underestimation of uncertainties reported in the submitted FREL–2016 for the first four periods. This underestimation is reduced in the last three periods.

Table 21. Total emissions, and associated uncertainties reported in Indonesia's FREL–2016 and in the Improved uncertainties analysis of Indonesia's FREL–2016

Period	Indonesia's submitted FREL–2016 (MoEF 2016)		Improved uncertainties analysis of Indonesia's FREL–2016	
	Emissions Mt CO_2 e yr^{-1}	Uncertainties	Emissions Mt CO_2 e yr^{-1}	Uncertainties
1990–1996	358,372	16.33	361,281	(34.1, 36.0)
1996–2000	1,064,218	7.56	1,049,447	(12.6, 12.9)
2000–2003	391,399	16.50	387,225	(24.9, 26.4)
2003–2006	527,194	13.29	510,569	(18.3, 19.3)
2006–2009	545,747	21.48	501,524	(17.0, 17.8)
2009–2011	408,202	19.70	352,219	(21.0, 22.1)
2011–2012	481,026	17.84	451,854	(16.8, 17.7)

Source: MoEF 2016

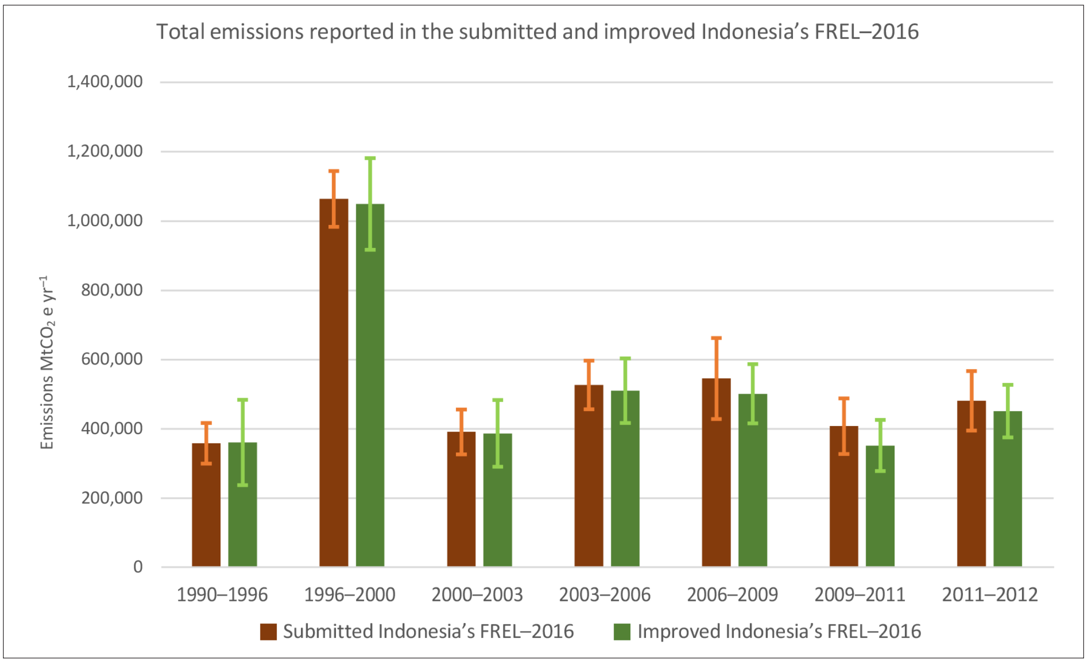


Figure 21. Total emissions reported in Indonesia's FREL–2016 and in the Improved uncertainties analysis of Indonesia's FREL–2016

There are several cases where: (i) uncertainties of annual emissions from peat decomposition (mainly due to degradation and secondary forest) at transition level are large and distributions are non-normal, and (ii) distributions of annual emissions from degradation at transition level are non-normal. Therefore, it is more appropriate to combine the uncertainties of the Improved uncertainties analysis of FREL–2016 using numerical statistical techniques, particularly the Monte Carlo technique, instead of using Approach 1.

7 Improved baseline FREL uncertainty

7.1 Uncertainties of baseline

Using the total emissions simulated per period, the uncertainties of average total emissions were estimated using MCS. Table 22 shows the baseline 1990–2012, quantile 2.5%, quantile 97.5%, and lower and upper uncertainties of this baseline. These uncertainties were obtained from the PDF shown in Figure 22.

Table 22. Baseline (1990–2012) and associated uncertainties of the Improved uncertainties analysis of Indonesia's FREL–2016

Period	Baseline $MtCO_2e\ yr^{-1}$	Quantile 2.5	Quantile 97.5	Lower Uncertainties (%)	Upper Uncertainties (%)
1990–2012	532,714.6	484,294.5	582,421.2	9.1	9.3

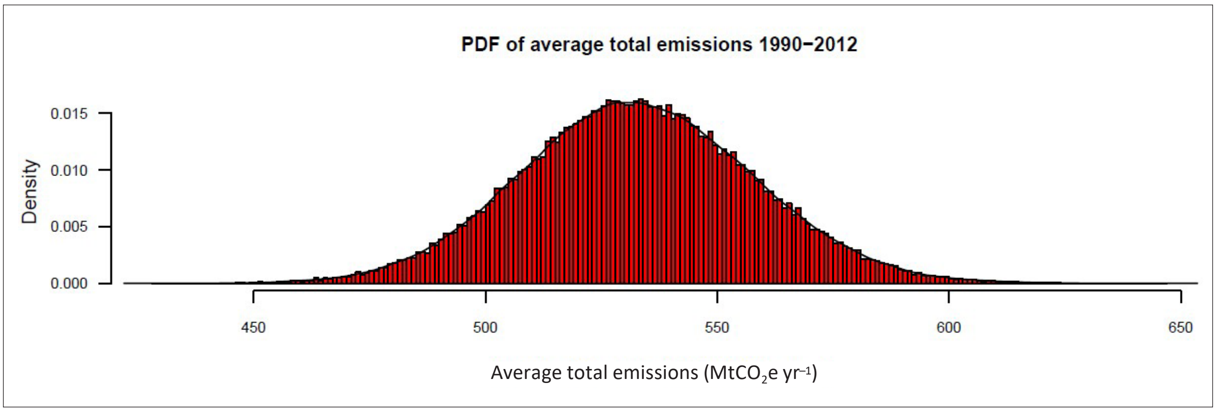


Figure 22. Density function of average total emissions 1990–2012

7.2 Analysis of uncertainties of baseline

7.2.1 Uncertainties of baseline of submitted Indonesia's FREL–2016

Table 23 and Figure 23 show per period the emissions from deforestation, forest degradation, peat decomposition and totals, and associated overall uncertainties reported in Indonesia's submitted FREL–2016. Overall uncertainties per period have values between 13% and 20%, and the 'average uncertainty' was estimated as a simple average of overall uncertainties per period. As the baseline is the result of the sum of emissions per period divided by a constant (number of years of the reference period), the appropriate method to combine uncertainties (using IPCC Approach 1) of an average is by using IPCC Equation 3.2.

When combining uncertainties of total emission (of Indonesia's submitted FREL–2016) per period using IPCC Equation 3.2, the uncertainty of the baseline has a value of 5.6%, which differs from the 16% reported in Indonesia's submitted FREL–2016.

Table 23. Emissions, emissions overall uncertainties, baseline and baseline uncertainties of Indonesia's submitted FREL–2016

Emissions source	Emissions in each period (CO_2e)						
	1990–1996	1996–2000	2000–2003	2003–2006	2006–2009	2009–2011	2011–2012
Deforestation	198,912,693	737,006,187	142,951,619	264,363,082	286,400,629	173,891,040	248,937,119
Forest degradation	7,676,560	162,396,173	73,690,805	78,596,482	59,226,954	18,511,560	5,920,802
Peat decomposition	151,782,943	164,815,980	174,757,024	184,235,616	200,118,642	215,799,004	226,167,756
Total	358,372,196	1,064,218,341	391,339,448	527,194,180	545,746,225	408,201,603	481,025,677
% Uncertainty	16	8	17	13	22	20	18
Emission average (baseline)	539,442,524						
Average uncertainty (%)	16.10						
Correct average uncertainty (%)	5.6						

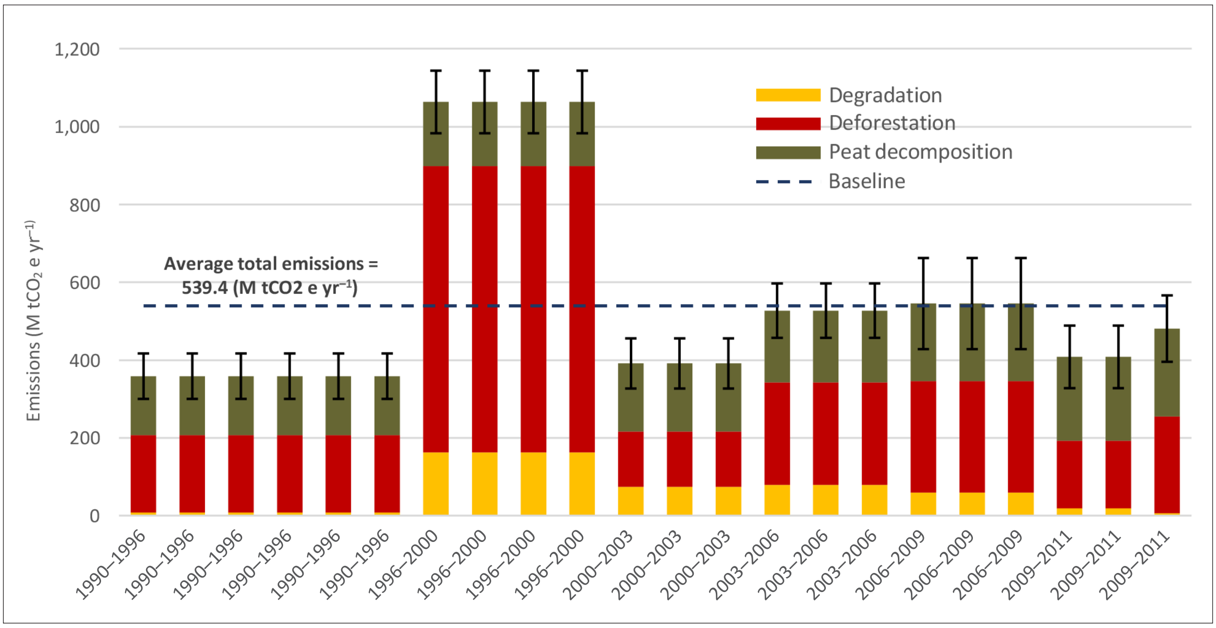


Figure 23. Annual and average annual historical emissions (and associated uncertainties) from deforestation, forest degradation, and the associated peat decomposition (in $MtCO_2$) in Indonesia from 1990 to 2012

Source: Indonesia's submitted FREL–2016 (MoEF 2016)

7.2.2 Uncertainties of baseline of the Improved uncertainties analysis of Indonesia's FREL–2016

Table 24 and Figure 24 show per period the emissions from deforestation, forest degradation, peat decomposition, and totals, and associated overall uncertainties of the Improved uncertainties analysis of FREL–2016. Overall uncertainties per period have values between 17% and 34%, and baseline uncertainty has values of –9.1% and +9.3%, which were obtained using MCS.

The current baseline uncertainties (–9.1, +9.3) are smaller than the uncertainty (16%) reported in Indonesia's submitted FREL–2016. This is because 'average uncertainty' reported in the submitted FREL–2016 was estimated as a simple average of overall uncertainties per period. This implied an overestimation of the baseline uncertainty reported in Indonesia's submitted FREL–2016.

Table 24. Emissions, emissions overall uncertainties, baseline, and baseline uncertainties of the Improved uncertainties analysis of Indonesia's FREL–2016

Emissions source	Emissions in each period (CO_2e)						
	1990–1996	1996–2000	2000–2003	2003–2006	2006–2009	2009–2011	2011–2012
Deforestation	198,820,107	729,291,626	149,140,085	268,293,601	303,524,280	146,245,646	249,784,946
Forest degradation	7,371,297	158,544,464	70,665,360	67,146,509	14,239,025	16,635,247	5,434,286
Peat decomposition	155,089,435	161,611,066	167,419,765	175,128,726	183,760,938	189,338,047	196,635,181
Total	361,280,839	1,049,447,156	387,225,210	510,568,836	501,524,243	352,218,940	451,854,413
% Uncertainty	34	13	25	18	17	21	17
Emission average (baseline)	516,302,805						
Average uncertainty (%)	(–9.1, +9.3)						

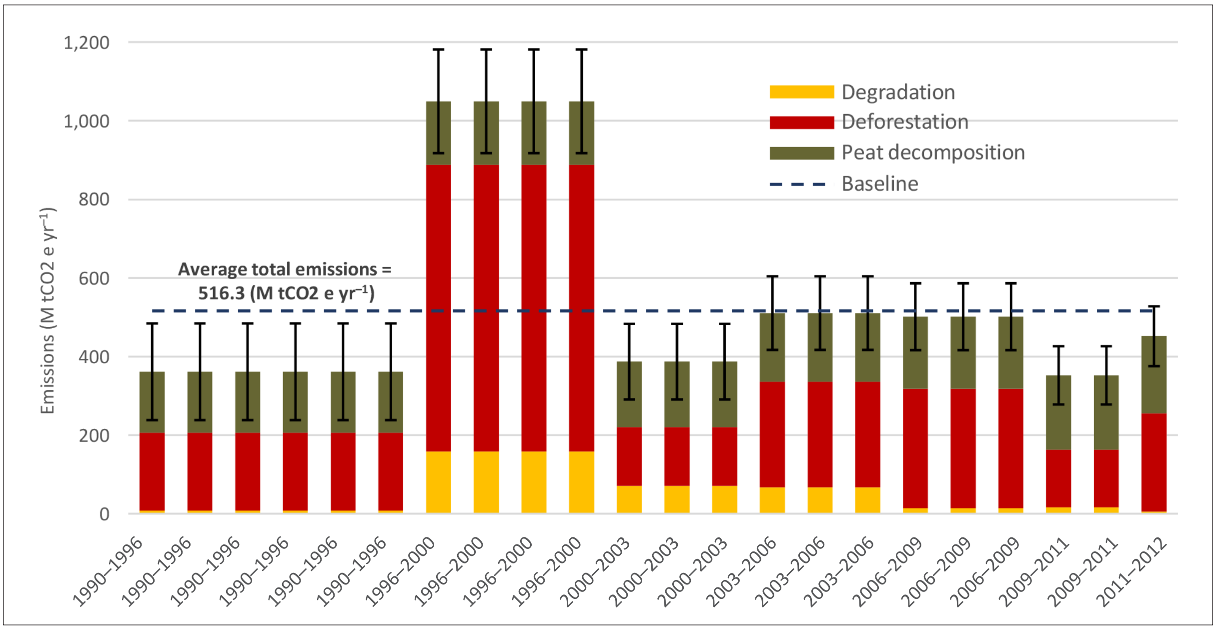


Figure 24. Annual and average annual historical emissions (and associated uncertainties) from deforestation, forest degradation, and the associated peat decomposition (in $MtCO_2$) in Indonesia from 1990 to 2012

Source: Improved uncertainties analysis of Indonesia's FREL–2016.

8 Conclusions

- Using the AD, EFs, and associated uncertainties provided by the Government of Indonesia, the Indonesian FREL–2016 uncertainty was recalculated by MCS following IPCC (2006).
- In the current "Improved uncertainties analysis of FREL–2016", uncertainties of emissions from deforestation, degradation, peat decomposition, and totals were estimated with IPCC Approach 1 (PEA) and Approach 2 (MCS). Uncertainties estimated with Approach 1 were close to uncertainties estimated with Approach 2. This is an important result as it was expected that Approach 1 would provide indicative estimations of uncertainties.
- As uncertainties of EFs from degradation and peat decomposition are large, it is more appropriate to combine the uncertainties of the Improved uncertainties analysis of FREL–2016 using MCS instead of Approach 1.
- Uncertainties of emissions from deforestation at island level have values between 20% and 30% when MCS was used, which are higher than the 14% value reported in FREL–2016. This means an underestimation of 1.5 to 2 times.
- Uncertainties of emissions from degradation at island level have values between 20% and 50% when MCS was used, which are higher than the 15% to 20% values reported in FREL–2016. This means an underestimation of at least 2 times.
- Uncertainties of emissions from peat decomposition have values between 35% and 83% with a median of 50% when MCS was used, which are higher than the 31% to 36% (with a median of 36%) values reported in FREL–2016. This means an underestimation of at least 1.5 times in the first four periods (1990–1996, 1996–2000, 2000–2003, and 2003–2006).
- MCS uncertainties of emissions due to deforestation, degradation, and peat decomposition at forest type, island, and/or period and overall are larger than those values reported in Indonesia's FREL–2016. This is mainly because an appropriate process to combine uncertainties was implemented in the current analysis and the use of MCS (the PEA was incorrectly applied in the submitted FREL–2016 to combine uncertainties).
- Uncertainties (obtained with MCS) of total emissions are reducing over time because uncertainties of emissions from peat decomposition (PD) have reduced over time. In particular, this is because, the proportion "emissions due to PD–deforestation"/ "emissions due to PD–total" increased from 14% in 1990–1996 to 59% in 2011–2012 (see Table 13). On the other hand, the proportion of "emissions due to PD–secondary forest"/ "emissions due to PD–total" has decreased from 86% in 1990–1996 to 39% in 2011–2012. As uncertainties of emissions due to PD–deforestation are smaller than uncertainties of emissions due to PD–secondary forest, the weight of uncertainties of emissions due to PD–deforestation increases as the proportion of "emissions due to PD–deforestation"/ "emissions due to PD–total" increases.
- The baseline uncertainty estimated for the Improved uncertainties analysis of FREL–2016 using MCS has values (–9.1, +9.3) smaller than the uncertainty reported in the submitted FREL–2016 (16.1%). Nevertheless, according to data in Table 5 of the submitted FREL–2016, baseline uncertainty was overestimated because uncertainties were incorrectly combined using Approach 1.
- Considering the values of AD, EFs and associated uncertainties provided by the Indonesian government to Improved uncertainties analysis of FREL–2016, it is possible to ensure that baseline uncertainties (estimated with MCS) have values of –9.1 and +9.3. These results were verified with the results of IPCC Approach 1. Nevertheless, considering that reliable estimators of unbiased AD and associated uncertainties will need to be incorporated in future, baseline uncertainties will need to be re-estimated using these new inputs. Furthermore, uncertainties of unbiased AD may well be larger than the ones currently reported. Therefore, baseline uncertainties of the Improved uncertainties analysis of FREL–2016 could be significantly underestimated.

9 Recommendations

- The uncertainty analysis of AD should be improved, as suggested in paragraph 26 of the "Report on the technical assessment of the proposed forest reference emission level of Indonesia submitted in 2016" (UNFCCC 2016). To that end, adjusted areas and associated uncertainties could be estimated following Oloffsson (2013, 2014, 2020). The use of adjusted areas as AD will guarantee the use of unbiased estimators of deforestation rates in updates of Indonesia's FREL. This will address the 'accuracy' requirement of the Annex to decision 12 / CP.17 (UNFCCC 2012).
- A reliable and unbiased estimator of AD will possibly address larger uncertainties of AD. In case uncertainties of AD are larger in the future, it will make sense to combine the uncertainties of Indonesia's updated FREL using the Monte Carlo technique.
- In several cases, uncertainties of EFs seem to be too small compared with the sample size used to obtain them. Therefore, uncertainties of EFs should be reviewed and re-estimated.
- In future, when AD will be obtained from unbiased estimators following Oloffsson (2013, 2014, 2020), domains of AD and EFs will differ. In that case, AD and EFs could be combined following Birigazzi (2018).
- When AD is obtained from unbiased estimators and AD and EFs are correctly combined, the uncertainty analysis of the Improved uncertainties analysis of FREL–2016 could be re-run using MCS.

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Under its Nationally Determined Contribution (NDC), Indonesia has continued to reduce greenhouse gas (GHG) emissions. Reducing emissions from deforestation and forest degradation, the sustainable management of forests, and the conservation and enhancement of forest carbon stocks (REDD+) is a key component of the NDC target from the land sector.

Indonesia submitted its 1st FREL in January 2016 (FREL–2016) covered emissions from deforestation, forest degradation, and peat decomposition. As part of the FREL–2016 improvement, the next FREL should consider land-use change dynamics and emissions/removal in biomass and soil. This improvement needs to reduce the uncertainty of emission factors (EFs) and activity data (AD) including non-CO_2 GHGs and reinforce sink monitoring.

Analysis in this working paper aims to improve and re-run the uncertainty in Indonesia's FREL–2016 by using Monte Carlo simulation (MCS). This working paper is expected to provide recommendations for Indonesia and other wetland-rich countries to meet their conditional land use emission reduction targets through improving the accuracy in their wetlands GHG accounting.

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