Category		Title
NFR	11.B	Forest fires
SNAP	1103 110301 110302	Forest and other vegetation fires Man-induced Other
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Contents

1 Overview

This chapter describes emissions from (naturally or man-induced) burning of non-managed and managed forests and other vegetation, excluding agricultural burning of stubble, etc. This includes domestic fires (fuel wood-, crop residue-, dung and charcoal burning) as well as open vegetation fires ([1]) (forest, shrub-, grass- and cropland burning). According to Barbosa (2006, personal communication), 95 % of the forest fires in the Mediterranean region are related to human impact (negligence, arson, etc.). For the boreal area, Molicone et al. (2006) estimate 87 % of forest fires to be caused by human influence. Only a small portion of open vegetation fires is caused by natural phenomena such as lightning (Koppman et al., 2005).

The relative contribution of (open and domestic) biomass burning emissions to the global annual emission for CO is ~ 25 %, for NO_x ~ 18 % and for non-methane volatile organic compounds (NMVOC) and CH_4 ~ 6 % (Intergovernmental Panel on Climate Change (IPCC), 2001). In Europe however, the contribution to total emissions is much lower, since the vast majority of fires occur in tropical regions.

Several studies on global emissions from open vegetation fires carried out by Van der Werf et al. (2006), Hoelzemann et al. (2004) ([2]) and Ito and Penner (2004) give emissions of 2 000 Tg C, 1 700 Tg C and 1 300 Tg C respectively for the year 2000 (cited in van der Werf et al., 2006). The inter-annual variation can be high. Van der Werf et al. (2006) calculated a minimum of 2 000 Tg C for the year 2000 and a maximum of 3 200 Tg C for 1998 within the eight-year period 1997–2004. Only a small part of these emissions 8–25 Tg C, with a minimum in 1998 and the maximum in the year 2000, take place in Europe.

According to the Corinair90 inventory, forest fires account for 0.2 % of European NO_x emissions, 0.5 % of NMVOC, 1.9 % of CO emissions and 0.1 % of NH_3 emissions. The contribution to the total emissions is small, but uncertainties are very large. Since fires occur over short periods of time, emissions may significantly contribute to ground-level concentrations during these events. According to the European Fire Information System (http://effis.jrc.it/), the CO_2 emissions during recent catastrophic fires in Greece was in the range of 4.5 Mt until end of August 2007, representing some 4 % of the total annual CO_2 emissions of this country. A similar share of fire emissions to total emissions of CO_2 were also observed in Portugal during heavy fire campaigns in 2003 and 2005 (Barbosa et al. 2006). For August 2003, the contribution of wildfire emissions in South Europe of observed particulate levels of $PM_{2.5}$ appeared to be comparable to anthropogenic emissions, with significant impact on radiative properties in large areas of Europe (Hodzic et al. 2007).

([1]) In literature also referred to as 'wildlife' if burning of agricultural land is excluded (e.g. Hoelzemann et al., 2004).
([2]) Wildfires only.

2 Description of sources

2.1 Process description

Forest fires have always been a feature of forest ecosystems. However, although 'natural' forest fires may be initiated by lightning, recent estimates indicate that on a global scale almost all biomass burning is human-initiated and is increasing with time (Andreae, 1991; Levine, 1994). Much of the global emission results from so-called slash-and-burn agriculture in the tropics, but such practices are much less common in Europe. Prescribed burning, a management practice common in North America, and upon which most emission-factor measurements are based, is also not common in Europe. Recent analysis of the available data in the European Forest Fire Information System (EFFIS) shows that over 95 % of the fires in Europe are human-induced. The split of causes shows that most of them are due to misuse of traditional practices of straw burning of shrub-burning to recover areas for cattle feeding.

The frequency and extent of fires in Europe is very variable from year to year, reflecting year-to-year climatological variability, with an average of about half a million hectares in the last 20 years, excluding the European part of Russia. On average, during the period 2000 to 2005, about 100 000 fires occurred annually in European countries, burning almost 600 000 hectares of forest land every year. However, figures have reached values over 700 000 ha in 2003 or nearly one million ha in 2007 (EFFIS).

Emissions from forest fires depend on (1) the duration and intensity of the fire, (2) the total area burnt by the fire, and (3) the type and amount of vegetation that is burnt. This latter term is often referred to as fuel load. Of those three terms, the one that is known with a fair level of accuracy is the total burnt area.

2.2 Techniques

The state of the art in calculating emissions from open vegetation fires follows the work of Seiler and Crutzen (1980) and is formulated as:

Ex = A * B * C* EF,

where

Ex = emission of compound x

A = burnt area (m2)

B = fuel load (g dry matter m-2)

C = burning efficiency

EF = emission factor (g g-1 dry matter burnt)

Each of the components of the fuel classes are attributed a specific burning efficiency and emission factor for gas-phase or aerosol compounds, dependant also on the fire flaming or smoldering which is related with the diameter of the fuel type (Lenhouts, 1998). Emission factors for CO, CH4, VOC, NOx, N2O and SOx are taken from literature. If no local data on aboveground fuel load is available, default values can be applied. Values of total biomass for five biomes (boreal forest, temperate forest, Mediterranean forest, shrub land, grassland/steppe) and factors for each biome allowing aboveground biomass and the assumed fraction of biomass burnt in a fire to be derived, are provided. Biomass is converted into carbon by the multiplication with 0.45. The burning efficiency depends on the meteorological conditions and determines the type of combustion which may lead to flaming or smouldering fires. Depending on the available data, the above factors can be computed with more or less detail.

Burnt areas may be available as a geographic layer or as a global value for a country or a region. In the case of geographic information, the type of vegetation burnt by the fire can eventually be divided according to fuel type, if this layer is available. If no local data on aboveground fuel load is available, default values can be applied.

In the case of available geographical information of the burnt areas, the pre-fire vegetation can be classified into fuel types and distinctive fuel loads can be used for estimating emissions. The most common fuel type system for the classification of vegetation into fuel loads is that of the NFDRS shown in Table 2-1. In most ecosystems, there is currently hardly any information on fuel load. In particular, the classification of fuel into compartments showing various susceptibilities in a fire event is lacking. The latter is essential in the determination of fuel consumption — being the fraction of fuel actually consumed in a fire — as well as the fuel load fractions burning under smoldering or flaming combustion conditions and thus determining the species composition of the emissions.

Table 2-1 Fuel loads (tons dry mass ha-1) for different vegetation classes based on the National Fire Rating System (NFDRS) fuel models (Burgan, 1988). The 'translation' of the NDFRS fuel models into the European vegetation classes is based on Barbosa, et al. 2009

Vegetation class	Vegetation type	NFDRS fuel model	Fuel class					
			Dead fine	Dead small	Dead large	Live	Duff	Total
			tons dry mass ha^{-1}					
Open pine stands with perennial grasses and	Forest	C	3.14	0	0	3.59	4.03	10.8
Shrubland understory and pine overstory	Forest	D	6.72	0	0	8.97	3.36	19.1
Sclerophylous oakwood vegetation	Forest	F	10.1	3.36	0	17.9	5.6	37
Short-needled conifers with sparse undergrowth and thin layer of ground fuels	Forest	H	5.6	4.48	4.48	2.24	4.48	21.3
Broadleaved forests of quercus ilex, rotundifolia, and suber	Forest	O	11.2	6.72	4.48	15.7	7.85	46
Coniferous forest with Iberian-atlantic oak-ash woods and Cantabrian beechwoods	Forest	P	4.48	1.12	0	2.24	2.24	10.1
Broadleaved forest	Forest	R	2.24	1.12	0	2.24	1.12	6.72
Grassland vegetated by annual grasses and forbs	Grassland/ agriculture	A	0.45	0	0	0.67	0.45	1.57
Grassland vegetated by perennial grasses	Grassland/ agriculture	L	0.56	0	0	1.12	0.56	2.24
Sparsely vegetated areas	Grassland/ Agriculture	S	2.24	1.12	1.12	2.24	3.36	10.1
Non-forest class	Grassland/ agriculture	X	0.45	0	0	0.67	0.45	1.57
Inland and coastland marshes	Shrubland	N	6.72	0	0	4.48	4.48	15.7
Transitional woodland shrub	Shrubland	T	3.36	0	0	6.72	2.24	12.3

Burning efficiency depends on the meteorological conditions during the fire. If available information on the time and duration is available for each fire, this can be directly calculated. However, this information is often not available and average conditions for the summer time, when most fires in Europe occur, are used to derive the combustion efficiency.

2.3 Emissions

The major products of biomass burning are CO_2 and water vapour. However, a large number of particulates (including BC) and trace gases are produced, including the products of incomplete combustion (CO, NMVOCs) and nitrogen and sulphur species, which indirectly influence the tropospheric ozone (O_3) budget (Koppmann et al., 2005). These arise partly from nitrogen and sulphur contained in the vegetation and organic matter in the surface soils. Additionally, emissions can arise from the re-volatilisation of substances which have been deposited (Hegg et al., 1987, 1990).

Some emissions are not considered further here as they have little relevance for tropospheric chemistry, but they are worth mentioning for their stratospheric impacts. These include H_2, COS and to a lesser extent CH_3Cl (Crutzen et al., 1979, Andreae, 1991).

A secondary effect of fires is that emissions from the land-area after burning can be significantly enhanced relative to unburned areas. Such effects are not considered here.

2.4 Controls

Many forest fires are set deliberately or accidentally as a result of human activities. For example, data from Russia suggests that 68 % of fires occur within 5 km of a road (Korovin, 1996), while 95 % of all the fires in the European Union are human-induced. The main control options, therefore, consist of improved fire-prevention and fire-extinction. However, extinction has proven not to be possible in cases of extreme weather conditions such as those in Portugal in 2003 and 2005, or those of south-eastern Europe in 2007. Despite all the aerial and human capacity for fire fighting fires, the forest fires in the regions were only controlled when the meteorological conditions improved.

National and international laws set limits to NO_x, $O_3$and fine particulate air concentrations to prevent adverse human health effects or damage to vegetation.

Little information appears to be available on methodologies to reduce emissions during controlled forest burns. However, in the agricultural sector, it is known that time of burning and meteorological conditions have important effects on both emissions and ground level concentrations.

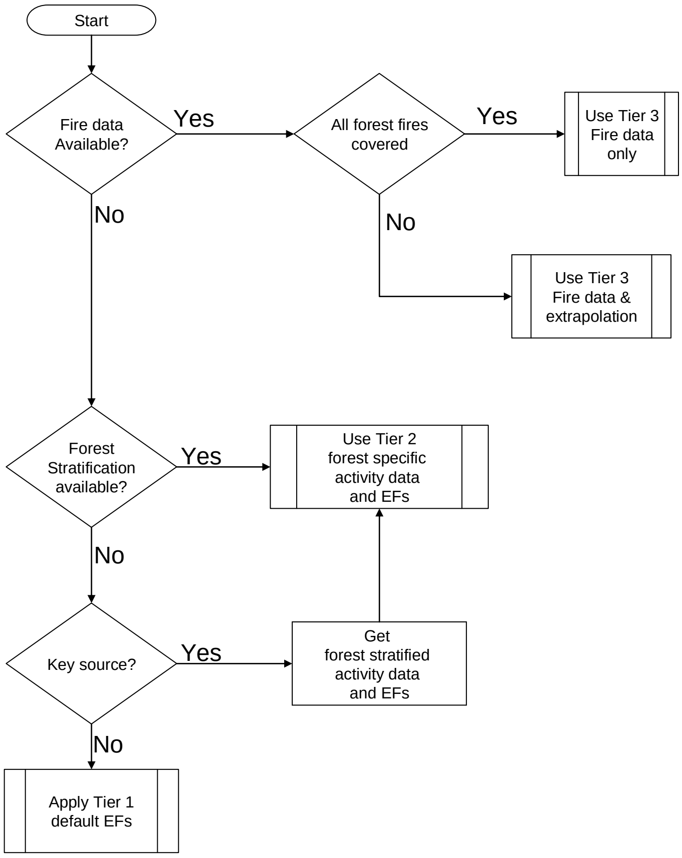
3 Methods

3.1 Choice of method

Figure 3-1 presents the procedure to select the methods for estimating process emissions from forest fires. The basic idea is:

- if detailed information is available, use it;
- if the source category is a key category, a Tier 2 or better method must be applied and detailed input data must be collected. The decision tree directs the user in such cases to the Tier 2 method, since it is expected that it is more easy to obtain the necessary input data for this approach than to collect specific fire data needed for a Tier 3 estimate;
- the alternative of applying a Tier 3 method, using detailed process modelling, is not explicitly included in this decision tree. However, detailed modelling will always be done at specific fire level and results of such modelling could be seen as ‘fire data’ in the decision tree.

Figure 3-1 Decision tree for source category 11.B Forest fires



3.2 Tier 1 default approach

3.2.1 Algorithm

The Tier 1 approach for emissions from forest fires uses the general equation:

$$E_{pollutant} = A_{burned} \times EF_{pollutant}, \qquad (1)$$

where

$E_{pollutant}$ is the emission of a certain pollutant,

A_{burned} is the total area that has been burned,

$EF_{pollutant}$ is the emission factor for this pollutant.

This equation is applied at the national level, using annual national statistics of area burnt.

In cases where specific abatement options are to be taken into account to reduce the forest fire emissions, a Tier 1 method is not applicable and a Tier 2 or Tier 3 approach must be used.

3.2.2 Default emission factors

The Tier 1 default emission factors are given in the table below. These are based upon the recommendations of Andreae (1991). The emission factor for NMVOC is based on the assumption that the average mass of NMVOC is 37 times the atomic mass unit.

The emission factors are derived from an assessment of the emission factors for the different biomes. Wide uncertainty ranges indicate that the emissions may vary significantly with the type of forest burnt. The biome-specific emission factors are given in Tier 2.

Particulate emission factors have been estimated by averaging the emission factors from the US Environmental Protection Agency (USEPA) methodology (see Tier 3 subsection), since no better information is available. If activity data are sufficiently available, however, it is good practice to use the Tier 3 methodology to estimate the particulate emissions.

Table 3-1 Tier 1 emission factors for source category 11.B Forest fires

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	11.B	Forest fires			
Fuel	NA				
Not applicable	PCB				
Not estimated	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	100	kg/ha area burned	4	600	EMEP/EEA (2006)
CO	3000	kg/ha area burned	100	16000	EMEP/EEA (2006)
NMVOC	300	kg/ha area burned	10	1500	EMEP/EEA (2006)
SOx	20	kg/ha area burned	1	110	EMEP/EEA (2006)
NH3	20	kg/ha area burned	1	130	EMEP/EEA (2006)
TSP	17	g/kg wood burned	4	100	averaged from US EPA (1996)
PM10	11	g/kg wood burned	2	80	averaged from US EPA (1996)
PM2.5	9	g/kg wood burned	2	80	averaged from US EPA (1996)
BC	9	% of $PM_{2.5}$	2	18	US EPA 2012*

* Using data from Regional Planning Organization inventories for 2002

3.2.3 Activity data

The activity data is the area of land burned.

3.3 Tier 2 technology-specific approach

3.3.1 Algorithm

In the Tier 2 approach, a split is made between different forests of land types. Emissions are estimated in a two-step process:

- estimate the emissions of carbon from the burned land;
- estimate the emissions of other trace gases using emission ratios with respect to carbon.

The basis calculation of the mass of carbon emitted M(C) follows the methodology of Seiler and Crutzen (1980):

$$M(C) = 0.45 \times A \times B \times \alpha \times \beta, \quad (2)$$

where:

0.45 = average fraction of carbon in fuel wood;

A = area burnt in m^2;

B = average total biomass of fuel material per unit area in kg/m^2;

α = fraction of above average above-ground biomass, relative to the total average biomass B;

β = burning efficiency (fraction burnt) of the above-ground biomass.

Values of these factors for the relevant biomes are given in the table below; these data are from Seiler and Crutzen (1980), with a new category 'Mediterranean forest' added to account for the low biomass density of this region. The 'α' and 'β' fractions assumed for this biome are derived from the Spanish Corinair 1990–1993 inventories; see also Rodriguez Murrilo (1994).

Table 3-2 Biome characteristics for forest-fire emission calculations

Biome	B = Biomass (kg/m^2)	α = Above ground fraction biomass	β = Burning efficiency
Boreal forest	25	0.75	0.2
Temperate forest	35	0.75	0.2
Mediterranean forest	15	0.75	0.25
Scrubland [1)]	7.5	0.64	0.5
Grassland (Steppe) [1)]	2	0.36	0.5

Note:
[1)] For the burning efficiency of Scrubland and Grassland, subjective estimates have been made in order to estimate the burning efficiency in Europe, which is assumed to be lower. Seiler and Crutzen (1980) estimate 0.8 for tropical biomes.

The emission of any particular species can then be obtained by multiplying the mass of carbon formed by the emission ratios (in g/kg C) in Table 3-3.

Table 3-3 Emission ratios for biomass fires, expressed relative to the carbon emitted as CO_2 (based upon recommendations of Andreae, 1991)

Species	**g X/kg C emitted as CO_2 'best guess'**
CO	230
CH_4	15
NMVOC	21
NO_x	8
NH_3	1.8
N_2O	0.4
SO_x	1.6

3.3.2 Technology-specific emission factors

The approach described in the previous section leads to the emission factors as they are expressed in the following Tier 2 emission factor tables.

Again, particulate emission factors have been estimated by averaging the emission factors from the USEPA methodology (see Tier 3 section) and are assumed to be the same for all types of forest. However, if the necessary activity statistics are available, it is good practice to use the Tier 3 methodology to estimate the particulate emissions.

Boreal forest

Table 3-4 Tier 2 emission factors for source category 11.B Forest fires, boreal forest

Tier 2 emission factors					
	Code	Name			
NFR Source Category	11.B	Forest fires			
Fuel	NA				
SNAP (if applicable)	1103	Forest and other vegetation fires			
Technologies/Practices	Boreal forest				
Region or regional conditions					
Abatement technologies					
Not applicable	PCB				
Not estimated	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	140	kg/ha area burned	50	400	EMEP/EEA (2006)
CO	3900	kg/ha area burned	1300	12000	EMEP/EEA (2006)
NMVOC	350	kg/ha area burned	120	1000	EMEP/EEA (2006)
SOx	27	kg/ha area burned	10	80	EMEP/EEA (2006)
NH3	30	kg/ha area burned	10	90	EMEP/EEA (2006)

TSP	17	g/kg wood burned	4	100	averaged from US EPA (1996)
PM10	11	g/kg wood burned	2	80	averaged from US EPA (1996)
PM2.5	9	g/kg wood burned	2	80	averaged from US EPA (1996)
BC	9	% of $PM_{2.5}$	2	18	US EPA 2012*

* Using data from Regional Planning Organization inventories for 2002

Temperate forest

Table 3-5 Tier 2 emission factors for source category 11.B Forest fires, temperate forest

Tier 2 emission factors					
	Code	Name			
NFR Source Category	11.B	Forest fires			
Fuel	NA				
SNAP (if applicable)	1103	Forest and other vegetation fires			
Technologies/Practices	Temperate forest				
Region or regional conditions					
Abatement technologies					
Not applicable	Aldrin, Chlordane, Chlordecone, Dieldrin, Endrin, Heptachlor, Heptabromo-biphenyl, Mirex, Toxaphene, HCH, DDT, PCB				
Not estimated	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, Total 4 PAHs, HCB, PCP, SCCP				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	190	kg/ha area burned	60	600	EMEP/EEA (2006)
CO	5400	kg/ha area burned	1800	16000	EMEP/EEA (2006)
NMVOC	500	kg/ha area burned	170	1500	EMEP/EEA (2006)
SOx	38	kg/ha area burned	10	110	EMEP/EEA (2006)
NH3	43	kg/ha area burned	10	130	EMEP/EEA (2006)
TSP	17	g/kg wood burned	4	100	averaged from US EPA (1996)
PM10	11	g/kg wood burned	2	80	averaged from US EPA (1996)
PM2.5	9	g/kg wood burned	2	80	averaged from US EPA (1996)
BC	9	% of $PM_{2.5}$	2	18	US EPA 2012*

* Using data from Regional Planning Organization inventories for 2002

Mediterranean forest

Table 3-6 Tier 2 emission factors for source category 11.B Forest fires, Mediterranean forest

Tier 2 emission factors					
	Code	Name			
NFR Source Category	11.B	Forest fires			
Fuel	NA				
SNAP (if applicable)	1103	Forest and other vegetation fires			
Technologies/Practices	Mediterranean forest				
Region or regional conditions					
Abatement technologies					
Not applicable	PCB				
Not estimated	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	190	kg/ha area burned	60	600	EMEP/EEA (2006)
CO	5400	kg/ha area burned	1800	16000	EMEP/EEA (2006)
NMVOC	500	kg/ha area burned	170	1500	EMEP/EEA (2006)
SOx	38	kg/ha area burned	10	110	EMEP/EEA (2006)
NH3	43	kg/ha area burned	10	130	EMEP/EEA (2006)
TSP	17	g/kg wood burned	4	100	averaged from US EPA (1996)
PM10	11	g/kg wood burned	2	80	averaged from US EPA (1996)
PM2.5	9	g/kg wood burned	2	80	averaged from US EPA (1996)
BC	9	% of $PM_{2.5}$	2	18	US EPA 2012*

* Using data from Regional Planning Organization inventories for 2002

Shrubland

Table 3-7 Tier 2 emission factors for source category 11.B Forest fires, shrubland

Tier 2 emission factors					
	Code	Name			
NFR Source Category	11.B	Forest fires			
Fuel	NA				
SNAP (if applicable)	1103	Forest and other vegetation fires			
Technologies/Practices	Shrubland				
Region or regional conditions					
Abatement technologies					
Not applicable	PCB				
Not estimated	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	86	kg/ha area burned	30	260	EMEP/EEA (2006)
CO	2500	kg/ha area burned	800	7500	EMEP/EEA (2006)
NMVOC	230	kg/ha area burned	80	680	EMEP/EEA (2006)
SOx	17	kg/ha area burned	5.67	50	EMEP/EEA (2006)
NH3	19	kg/ha area burned	6.33	60	EMEP/EEA (2006)
TSP	17	g/kg wood burned	4	100	averaged from US EPA (1996)
PM10	11	g/kg wood burned	2	80	averaged from US EPA (1996)
PM2.5	9	g/kg wood burned	2	80	averaged from US EPA (1996)
BC	9	% of $PM_{2.5}$	2	18	US EPA 2012*

* Using data from Regional Planning Organization inventories for 2002

Grass/steppe

Table 3-8 Tier 2 emission factors for source category 11.B Forest fires, grass/steppe

Tier 2 emission factors					
	Code	Name			
NFR Source Category	11.B	Forest fires			
Fuel	NA				
SNAP (if applicable)	1103	Forest and other vegetation fires			
Technologies/Practices	Grassland / Steppe				
Region or regional conditions					
Abatement technologies					
Not applicable	PCB				
Not estimated	Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn, PCDD/F, Benzo(a)pyrene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Indeno(1,2,3-cd)pyrene, HCB				
Pollutant	**Value**	**Unit**	**95% confidence interval**		**Reference**
			Lower	**Upper**	
NOx	13	kg/ha area burned	4	40	EMEP/EEA (2006)
CO	373	kg/ha area burned	120	1100	EMEP/EEA (2006)
NMVOC	34	kg/ha area burned	10	100	EMEP/EEA (2006)
SOx	3	kg/ha area burned	1	10	EMEP/EEA (2006)
NH3	3	kg/ha area burned	1	10	EMEP/EEA (2006)
TSP	17	g/kg wood burned	4	100	averaged from US EPA (1996)
PM10	11	g/kg wood burned	2	80	averaged from US EPA (1996)
PM2.5	9	g/kg wood burned	2	80	averaged from US EPA (1996)
BC	9	% of $PM_{2.5}$	2	18	US EPA 2012*

* Using data from Regional Planning Organization inventories for 2002

3.3.3 Abatement

Not available for this source category.

3.3.4 Activity data

The activity data is the area of land burned. If particulate emission factors are estimated using the emission factors presented in the tables above, the activity data for these factors is the total mass of biomass burned.

3.4 Tier 3 emission modelling and use of facility data

3.4.1 Algorithm

Tier 3 may be used for calculating particulate emissions using the emission factors given in the next section.

3.4.2 Tier 3 emission modelling and use of facility data

Particulate emission factors are taken from USEPA (1996) for forest and vegetation burning and shown in Table 3-9 below. It is good practice to use these factors in the absence of more appropriate data. Uncertainty ratings are explained in the General Guidance chapter 5, Uncertainties, in Part A, as well as in the original source (USEPA, 1996).

Table 3-9 Particulate emission factors for forest and vegetation burning (USEPA 1996)

		Emission Factor (g/kg)				
Fire/fuel configuration	**Phase[a]**	**$PM_{2.5}$**	**PM_{10}**	**TSP**	**Fuel mix (%)**	**Rating**
Broadcast logging slash						
Hardwood	F	6.0	7[b]	13.0	33.0	A
	S	13.0	14[b]	20.0	67.0	A
	Fire	11.0	12[b]	18.0		A
Conifer						
Short needle	F	7.0	8[c]	12.0	33.0	A
	S	14.0	15[c]	19.0	67.0	A
	Fire	12.0	13[c]	17.0		A
Long needle	F	6.0	6[d]	9.0	33.0	B
	S	16.0	17[d]	25.0	67.0	B
	Fire	13.0	13[d]	20.0		B
Logging slash debris						
Dozer piled conifer						
No mineral soil[d]	F	4.0	4.0	5.0	90.0	B
	S	6.0	7.0	14.0	10.0	B
	Fire	4.0	4.0	6.0		B
10 to 30 % mineral soil[e]	S	ND	ND	25.0	ND	D
25 % organic soil[e]	S	ND	ND	35.0	ND	D
Range fire						
Juniper slash	F	7.0	8.0	11.0	8.2	B

	S	12.0	13.0	18.0	15.6	B
	Fire[f]	9.0	10.0	14.0	12.5	B
Sagebrush	F	15.0	16.0	23.0		B
	S	13.0	15.0	23.0		B
	Fire[f]	13.0	15.0	23.0		B
Chaparral shrub						
communities	F	7.0	8.0	16.0		A
	S	12.0	13.0	23.0		A
	Fire	10.0	11.0	20.0		A
Line fire						
Conifer						
Long needle (pine)	Heading[g]	ND	40.0	50.0		D
	Backing	ND	20.0	20.0		D
Palmetto/gallberry[g]	Heading	ND	15.0	17.0		D
	Backing	ND	15.0	15.0		D
	Fire	ND	8-22	ND		D
Chaparralk	Heading	8.0	9.0	15.0		C
Grasslands[g]	Fire	ND	10.0	10.0		D

Notes:
a Unless otherwise noted, determined by field testing of fires of 1 acre size. F = flaming, S = smouldering. Fire = weighted average of F and S. ND = no data.
b For PM_{10}, emission factor rating is C.
c For PM_{10}, emission factor rating is D.
d For PM_{10}, emission factor rating is D.
e Determined using laboratory combustion hood.
f Fuel mix uncertain, because of short intense flaming phase. Use fire average for emission inventory purposes.
g Determined using laboratory combustion hood.

3.4.3 Activity data

The mass of vegetation burned is necessary to calculate particulate emission factors using the emission factors given in the Tier 3 section.

4 Data quality

4.1 Completeness

No specific issues.

4.2 Avoiding double counting with other sectors

No specific issues.

4.3 Verification

No specific issues.

4.4 Developing a consistent time series and recalculation

No specific issues.

4.5 Uncertainty assessment

Andreae (1991) suggests that the emissions of CO_2 are uncertain by about 50 % and a factor of 2 for the other trace gases. The fact that emission ratios so far determined seem to be consistent from Brazil to Canada (see Andreae, 1991, and references therein) lends some confidence to extrapolating results into Europe. However, one possible cause for concern lies in results reported by Hegg et al. (1987), which suggested that areas which had experienced substantial N-deposition emission ratios for NO_x could be an order of magnitude greater than those obtained in rural areas. Indeed, emissions of purely man-made species such as F12 are also observed from forest fires, again the result of resuspension of previously deposited pollutants (Hegg et al., 1990). Such re-suspension is very likely in many areas of Europe.

Moreover, the large uncertainty in the input data required for the calculations even increases the uncertainties in the emission estimates by an additional order magnitude, e.g. a comparison between three sources of information on burnt area in Russia for the year 2000 shows variations between 122 000 km^2 in the Global Burnt Area assessment, 4 600 km^2 derived by Bartalev et al. (2004) and the Russian official statistics of 20 000 km^2. The series of burnt area statistics from the European Forest Fire Information System (EFFIS) provide a consistent database from which good estimates can be derived; however these data do not include Russia, where most forest fires occur. The maps of burnt areas in EFFIS have been systematically produced since the year 2000 and have been contrasted with national statistics.

4.5.1 Emission factor uncertainties

Overall, a factor of 3 uncertainty would seem a reasonable first guess for emissions of gases such as NO_x from Europe.

4.5.2 Activity data uncertainties

No specific issues.

4.6 Inventory quality assurance/quality control QA/QC

No specific issues.

4.7 Gridding

No specific issues.

4.8 Reporting and documentation

No specific issues.

5 References

Andreae, M. O. (1991). 'Biomass burning. Its history, use, and distribution and its impact on environmental quality and global climate'. In J.S. Levine (ed.), *Global Biomass Burning: Atmospheric, Climatic, and Biospheric Implications*. MIT Press, Cambridge, Massachusetts, pp. 3–21.

Andreae, M.O., Browell, E.V., Garstang, M., Gregory, G.L., Harriss, R.C., Hill, G.F., Jacob, D.J., Pereira, M.C., Sachse, G.W., Setzer, A.W., Silva Dias, P.L., Talbot, R.W., Torres, A.L., and Wofsy, S.C. (1988). 'Biomass-burning emissions and associated haze layers over Amazonia', *Journal Geophysical Research*, 93, No D2, pp. 1509–1527.

Barbosa, P., Kucera, J., Strobl,P., Vogt, P., Camia,A., San-Miguel-Ayanz,J. (2006). European forest fire information system (EFFIS) — Rapid damage assessment: Appraisal of burnt area maps in Southern Europe using Modis data (2003 to 2005). Proceedings of the fifth International Conference on Forest Fire Research, 27–30 Figueira da Foz, Portugal, Elsevier Pub. ISSN 0378-1127.

Barbosa,, P., Camia, A., Kucera, J., Liberta, G., Palumbo, I., San-Miguel, J., and Schmuck, G. (2009). 'Assessment of Forest Fire Impacts and Emissions in the European Union Based on the European Forest Fire Information System'. In: *Developments in Environmental Science*, Volume 8 197, A. Bytnerowicz, M. Arbaugh, A. Riebau and C. Andersen (Editors), Elsevier B.V. ISSN: 1474-8177/DOI:10.1016/S1474-8177(08)00008-9.

Bartalev, S. A., V. G. Bondur, A. A. Gitelson, C. Justice, E. A. Loupian, D. Cline, V. I. Gorny, T. E. Khromova, P. W. Stackhouse, and S. V. Victorov. (2004). Remote sensing of the Northern Eurasia. Chapter 4 in NEESPI Science Plan.

Burgan, Robert E. (1988). Revisions to the 1978 National Fire-Danger Rating System. Res. Pap. SE-273. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 39pp.

Conard, S.G. and Davidenko, E.P. (1996). Fire in Siberian Boreal Forests — Implications for Global Climate and Air Quality 1. Presented at the International symposium on air pollution and change effects on forest ecosystems, 5–9.2.1996, Riverside, California.

Crutzen, P.J., Heidt, L.E., Krasnec, J.P., Pollock, W.H. and Seiler, W. (1979). 'Biomass burning as a source of atmospheric gases CO, H2, N2O,NO, CH3C and COS', *Nature*, Vol. 282, pp. 253–256.

EMEP/EEA (2006). EMEP/Corinair Emission Inventory Guidebook, version 4 (2006 edition), published by the European Environment Agency. Technical report No 11/2006. (https://www.eea.europa.eu/publications/EMEPCORINAIR4), accessed 23 July 2019.

Hegg, D.A., Radke, L. F., P. V. Hobbs, and Brock, C.A. (1987). 'Nitrogen and sulphur emissions from the burning of forest products near large urban areas', *Journal of Geophysical Research*, 92, No. D12, pp. 14701–14709.

Hegg, D.A., Radke, L. F., P. V. Hobbs, R.A. Rasmussen, and P. J. Riggan (1990). 'Emissions of some trace gases from biomass fires', *Journal of Geophysical Research*, 95, No D5, pp. 5669–5675.

Hodzic A., Madronich S., Bohn B., Massie S., Menut L., and Wiedinmyer C. (2007). 'Wildfire particulate matter in Europe during summer 2003: Meso-scale modeling of smoke emissions, transport and radiative effects', *Atmospheric Chemistry and Physics*, 7, pp. 4043–4064.

Hoelzemann, J., Schultz, M.G., Brasseur, G.P., Granier, C. and Simon, M. (2004). 'Global wildland fire emission model (GWEM): Evaluating the use of global area burnt satellite data', *Journal of Geophysical Research*, 109, D14S04, doi:10.1029/2003JD003666.

IPCC, Intergovernmental Panel on Climate Change (2001). Climate change 2001: The scientific basis. Third assessment report from working group 1. Edited by Houghton, J.T. et al., Cambridge University Press, UK.

Ito, A. and Penner, J.E. (2004). 'Global estimates of biomass burning emissions based on satellite imagery for the year 2000', *Journal of Geophysical Research*, 109, D14S05, doi:10.1029/2003JD004423.

Koppmann, R., von Czapiewski, K. and Reid, J.S. (2005). 'A review of biomass burning emissions, part I: gaseous emissions of carbon monoxide, methane, volatile organic compounds and nitrogen-containing compounds', Atmospheric Chemistry and Physics. Discuss., 5, pp. 10455–10516.

Korovin, G. N. (1996). 'Analysis of the distribution of forest fires in Russia'. In: Goldammer, J.G. and Furyaev, V.V., eds. *Fire in ecosystems of Boreal Eurasia*, pp. 112–128. Netherlands: Kluwer Academic Publishers.

Leenhouts, Bill. (1998. 'Assessment of biomass burning in the conterminous United States', *Conservation Ecology* [online] 2(1): 1. (www.consecol.org/vol2/iss1/art1) , accessed 23 July 2019.

Levine, J. S. (1994). 'Biomass burning and the production of greenhouse gases', *Climate Biosphere Interaction: Biogenic Emissions and Environmental Effects of Climate Change*, Ed. Righard G. Zepp, ISBN 0-471-58943-3. Copyright 1994 John Wiley and Sons, Inc.

Mollicone, D., Hugh, D.E. and Achard, F. (2006). 'Human role in Russian wild fires', *Nature*, Vol. 440, 23.3.2006.

Rodriguez Murillo, J.C. (1994). 'The carbon budget of the Spanish forests', *Biogeochemistry*, 25, pp. 197–217.

Seiler, W. and P. J. Crutzen (1980). 'Estimates of gross and net fluxes of arbon between the biosphere and the atmosphere from biomass burning', *Climatic Change* 2, pp. 207–247.

Stannars, D and Bourdeau, P. (eds.) (1995). *Europe's Environment. The Dobris Assessment*, European Environmental Agency, Copenhagen, Denmark.

USEPA (1996). Compilation of Air Pollutant Emission Factors Vol.1. Stationary, Point and Area Sources. Report AP-42 (fifth edition).

USEPA 2012: Report to Congress on Black Carbon, USEPA Report EPA-450/R-12-001, March 2012: (https://data.globalchange.gov/report/epa-450-r-12-001), accessed 23 July 2019.

Werf, G. van der, Randerson, J.T., Giglio, L., Collatz, G.J., Kasibhatla, P.S. and Arellano Jr., A.F. (2006). 'Interannual variability of global biomass burning emissions from 1997 to 2004', Atmospheric Chemistry and Physics. Discuss., 6, pp. 3175–3226.

6 Point of enquiry

Enquiries concerning this chapter should be directed to the relevant leader(s) of the Task Force on Emission Inventories and Projection's expert panel on Agriculture and Nature. Please refer to the TFEIP website (www.tfeip-secretariat.org/) for the contact details of the current expert panel leaders.