Biomass Burning – Emissions Calculation Methodology

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Emissions from vegetation fires

- The general expression reported in the literature is as follows:
- Emissions from biomass burning:
  - $E = M \times EF$
    - E: total emission of the gaseous species considered
    - M: mass of dry matter burned
    - EF: species and source specific emission factor
- In the literature various methods are reported to determine the amount of biomass burned (M). These methods depend on the type of biomass burned considered.

Forest and crop residues

- Major types of biomass considered:
  - Forest including:
    - Dry evergreen forest
    - Dry dipterocarp forest
    - Moist evergreen forest
    - Hill evergreen forest
    - Mangrove forest
  - Agricultural residues including:
    - Rice straw, rice stubble,
    - sugarcane Topd/leaves
    - Maize stalk, maize husk

Amount of forest biomass burned

- Various studies have been published dealing with amount of biomass burned from various sources mainly in tropical regions (Seiler and Crutzen, 1980, Hao and Liu 1994, Streets *et al*., 2003, etc.).
- The calculation methodology described in those studies is based from the one developed by Seiler and Crutzen (1980). It is as follows:
- Amount of biomass burned:
  - $M = A \times B \times \beta$
    - M: amount of above ground biomass burned
    - A: area of land burned
    - B: above ground biomass load (dry matter density)
    - β: fraction of biomass burned also termed burning efficiency

Parameters required to calculate amount of forest biomass burned

Biomass load range (kg/m^2)
5 -55[a]; 10[b] (7.5 – 22.5)
Burning efficiency
0.2[c]; 0.45[d]; 0.6[e]

[a]*Brown and Gaston (1996);*
[b]*IPPC (1996);* [c]*Levine (2000);*
[d]*Hao and Liu (1994);*
[e]*Streets et al., (2003);*

Vegetation Class	Biomass Density (g/m^2)	Burning efficiency
evergreen needleleaf forest	36700	0.25
evergreen broadleaf forest	23350	0.25
deciduous needleleaf forest	18900	0.25
deciduous broadleaf forest	20000	0.25
mixed forest	22250	0.25
woodland	10000	0.35
wooded grassland	3300	0.4
closed shrubland	7200	0.5
open shrubland	1600	0.85
grassland	1250	0.95
cropland	5100	0.6

Michel *et al.*, 2005

Amount of crops residues burned

- The determination of amount of agricultural residues burned using default values found in the literature is reported similarly in works of Hao and Liu 1994; Streets *et al*., 2003; or IPCC 1996.
- The general expression used is as follows:
- <u>Amount of crop residues burnt</u>
  - $M = P \times D \times f \times \beta$
  - M: amount of crop residues burned per year
  - P: annual production of crop
  - D: ratio of residue to crop product
  - f: fraction of residues being burned
  - β: Fraction of above ground biomass burned (burning efficiency)

Parameters required to calculate amount of crop residues burned

Crops	Residue-to-crop ratio	Dry matter fraction	Dry matter burned in field**	Dry matter burned in field***	Burning efficiency
Corn	2.0[e,f]	0.40[e,f,g]	25%[e,g]	17%[e,d]	92%[e]
Rice	1.76[f]	0.85[e,f,g]	25%[e,g]	17%[e,d]	89%[e]
Sugarcane	0.3[f]	0.71[e,f,g]	25%[e,g]	17%[e,d]	68%[e]

[e]*Streets et al., (2003);* [f]*Koopmans and Koppejan (1997);* [g]*OEPP, Thailand (1990)*; **Data for South Asia ***Data for Rest of Asia

Emissions from vegetation fires - use of emission ratios

- Calculation of emissions from vegetation fires using emissions ratios either for forest fires or crop residues burning is reported in the literature and described in the IPCC revised guidelines 1996. The method is as follows:
- <u>Amount of carbon released to the atmosphere:</u>
  - $M(C) = M \times C$
    - M(C): Total mass of carbon released to the atmosphere
    - C: mass percentage of carbon in the biomass
    - M: amount of above ground biomass burned

Emissions from vegetation fires - use of emission ratios

- Amount of carbon released to the atmosphere as CO2:
  - $M(CO_2) = M(C) \times CE$
    - $M(C0_2)$: mass of carbon released as CO2 during the fire
    - M(C): Total mass of carbon released to the atmosphere
    - β: fraction of biomass oxidized also termed combustion efficiency
- Amount of species Xi released to the atmosphere:
  - $M(Xi) = ER(Xi) \times M(C0_2)$
    - M(Xi): amount species Xi produced by burning
    - ER(Xi): CO_2 normalized species emission ratio
    - $M(C0_2)$: mass of carbon released as CO_2 during the fire

Emission ratios

Emission Ratios		
Compound	Forest fires	Crop residues burning
CH_4	0.012 (0.009-0.015)	0.005 (0.003-0.007)
CO	0.06 (0.04-0.08)	0.06 (0.04-0.08)
N_2O	0.007 (0.005-0.009)	0.007 (0.005-0.009)
NOx	0.121 (0.094-0.148)	0.121 (0.094-0.148)

Ratios for carbon compounds are mass of carbon released as CH_4 or CO (in units of carbon) relative to mass of total carbon released from burning (in units of carbon); those for nitrogen compounds are expressed as the mass of nitrogen compounds released relative to the total mass of nitrogen released from the fuel (IPCC, 1996)

Emissions from vegetation fires - use of emission factors

- Calculation of emissions from vegetation fires using emissions factors is also widely reported in the literature including Hao and Liu 1994; USEPA, 2002; Streets *et al*., 2003. The expression used is as follows:
- <u>Emissions from biomass burning</u>
  - $E = M \times EF$
    - E: total emission of the gaseous species considered;
    - M: mass of dry matter burned
    - EF: species and source specific emission factor

Emission factors

	Tropical Forest	Crop residues
Compounds	Emission Factors (g/kg)[a]	
CO_2	1580 ± 90	1515 ± 177
CO	104 ± 20	92 ± 84
CH_4	6.8 ± 2.0	2.7
N_2O	0.20	0.07
NOx	1.6 ± 0.7	2.5 ± 1.0
PM2.5	9.1 ± 1.5	3.9
TPM	6.5-10.5; 20[b]	13; 10[b]
OC	5.2 ± 1.5	3.3
BC	0.66 ± 0.31	0.69 ± 0.13

[a]Andrea and Merlet (2001); [b]Levine (2000)

Uncertainties

- Burned areas:
  - Satellite retrieval of hotspot and burned areas recently available after 1995
    - Sensor limitations,
    - orbital drift,
    - cloud and smoke occurrence, etc.
  - Aerial observation by plane and forest services
    - Incomplete and varying coverage

Uncertainties

- Burning efficiency:
  - It corresponds to the amount of fuel that is actually combusted
    - Fuel load,
    - fuel moisture,
    - vegetation type,
    - rate of spreading of the fire
    - Human intervention

Emission Factors

- Emission Factors:
  - The amount of chemically active trace species and aerosols released from a fire depends on:
    - Fuel type
    - Fire characteristics
      - Flaming: complete combustion lead to a larger fraction of oxidized species e.g. CO2, NOx
      - Smoldering: incomplete combustion lead to a larger fraction of reduced species e.g. CO, NH3 and NMVOC species
  - Seasonal and regional variation

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