Direct greenhouse gases and VOCs emissions totals from UK moorland burning

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I. Introduction

- Heather (*Calluna vulgaris*) heathlands occur Europe-wide, but are in decline.
- Management using prescribed burning is increasing, particularly in the UK (Fig. 1).
- ~200 km^2 of heather moorlands burnt in Scotland, with a further ~120 km^2 burnt in England (Fig. 2).
- Burning of the moorland ("muirburn") accounts for almost all emissions from biomass burning in the UK.
- Currently, there are no data concerning the emission factors from muirburn.
- Consequently, estimates of emissions from muirburn, such as those used in the UK's *National Atmospheric Emission Inventory* (NAEI), often rely on emission factors from other vegetation types (e.g. Dragosits *et al.*, 2009).
- Trace gases have important localised impact on health, directly, and through formation of ozone.
- This poster presents the first directly measured emission factors for heather dominated moorlands for eleven greenhouse gas and volatile ogrganic compound (VOC) species.
- These emission factors are then used with measurements of fuel load and combustion completeness, and recent estimates of UK burnt area to calculate total emissions (kilotonnes year^{-1}) for each gas species.

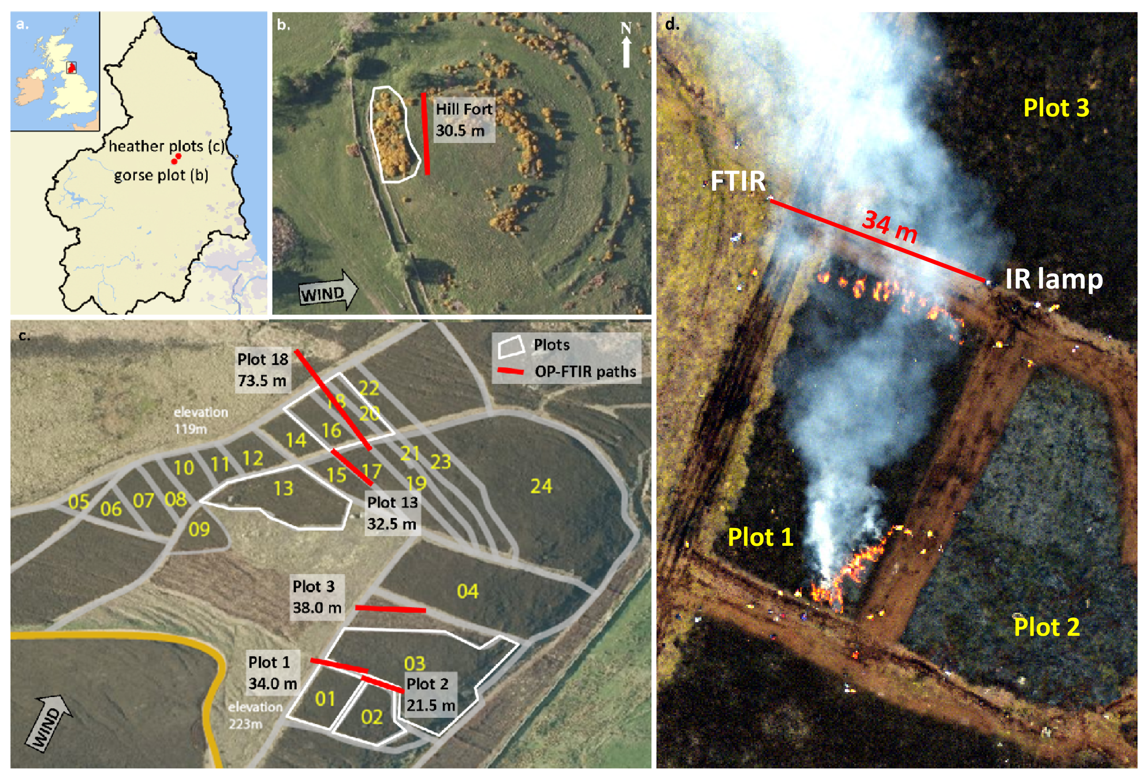
Figure 1. Typical prescribed muirburn on New Moor, Northumberland. The heather is often burned in the UK for grouse nesting or sheep grazing.

Figure 2. Aerial photography of the Derwent area of the Peak District National Park. This patchwork pattern, caused by intensive prescribed burning, is typical of the majority of upland moors in the UK (Yallop et al., 2006).

II. Field sites and data sources

- The emission factor results presented here come from 5 fires measured on 22 March 2010 near Debdon, Northumberland (Fig. 3).
- Fuel load and combustion completeness data were also collected at these sites, however, a more comprehensive database of these variables was compiled from data collected at Howden Moor (Peak District National Park) and those published in Legg et al. (2010) from near Dalwhinnie, Cairngorms National Park, Scotland.

Figure 3. (a) Location of Northumberland field sites in the UK; (b & c) aerial photos of experimental gorse and heather plots, showing location of the OP-FTIR paths (see section III); (d) aerial photo of fire in progress on plot 2, also showing location of the OP-FTIR path downwind of the fire.



III. Emission factors: Methodology

- Smoke absorption of an infrared source is measured by open-path Fourier transform infrared (OP-FTIR) spectroscopy.
- An FTIR spectrometer and IR source are placed downwind of the fire and are separated by 20-50 m (Figs. 3 & 4).
- Amount of absorption by plume gases is used to identify and retrieve gas concentrations (Smith *et al.*, 2011) (Fig. 5).
- Ratios of concentrations of various gases to those of carbon dioxide are used in a carbon mass balance (detailed in Wooster *et al.*, 2011) to calculate emission factors (grams of gas species *x* released per kg of dry fuel combusted).

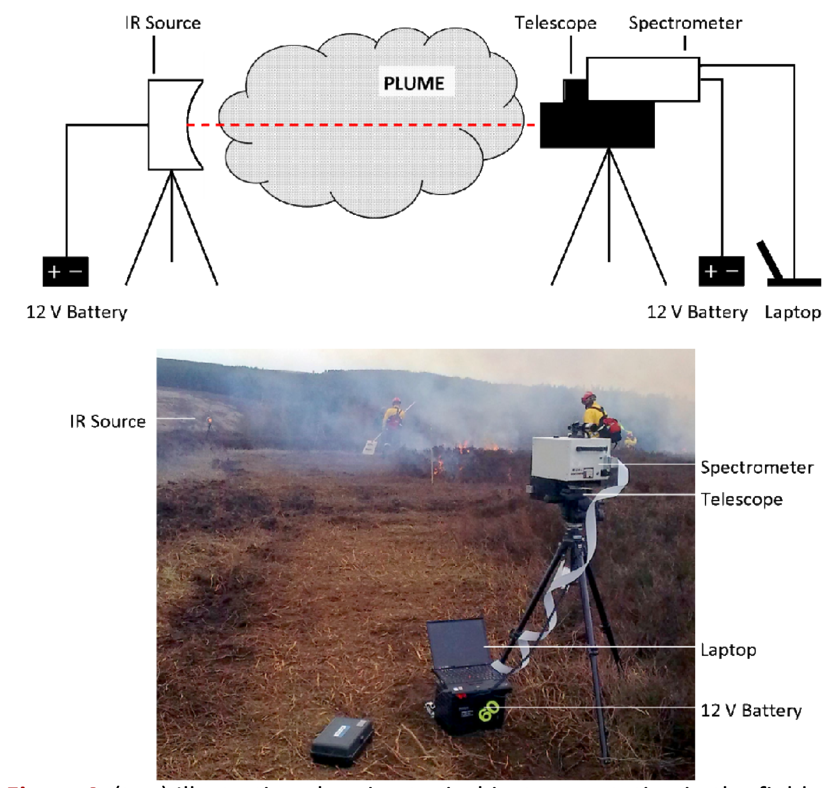


Figure 4. (top) Illustration showing typical instrumentation in the field. (bottom) Photograph of a typical field setup (pathlength = 21.5 m)

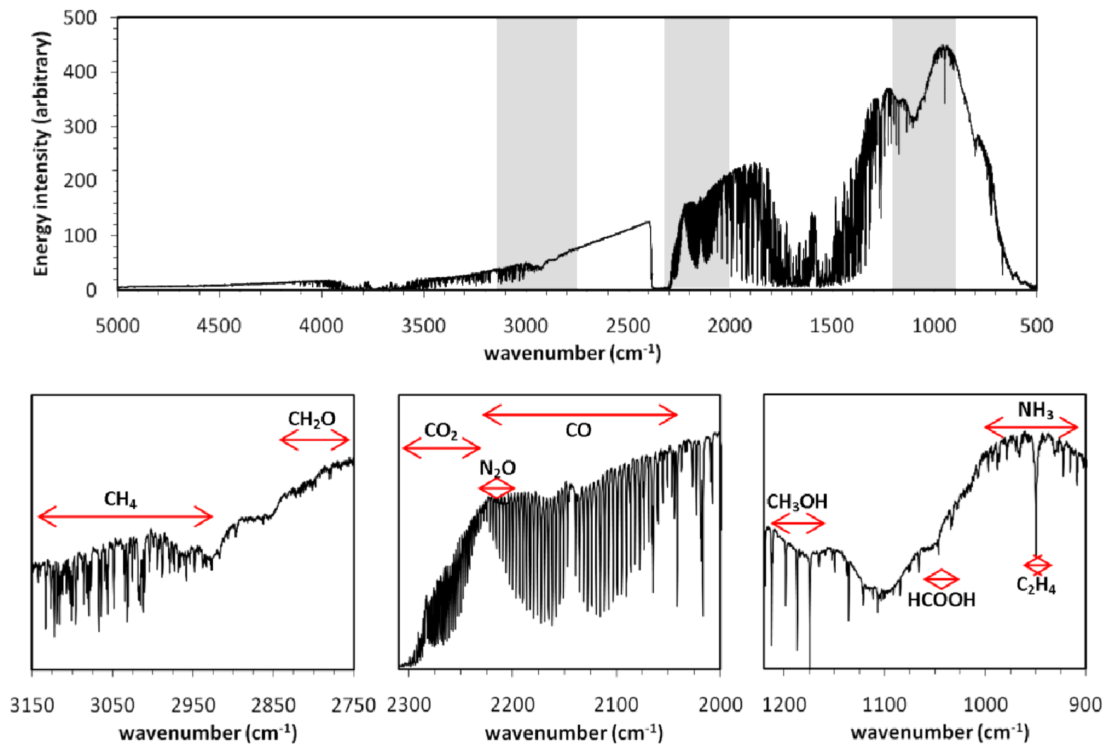


Figure 5. A typical infrared spectrum of a biomass burning plume (Plot 1, pathlength = 32 m). The grey boxes indicate the spectral location of the three subplots. The absorption bands of important biomass burning emissions are indicated by the red arrows.

IV. Emission factors: Results

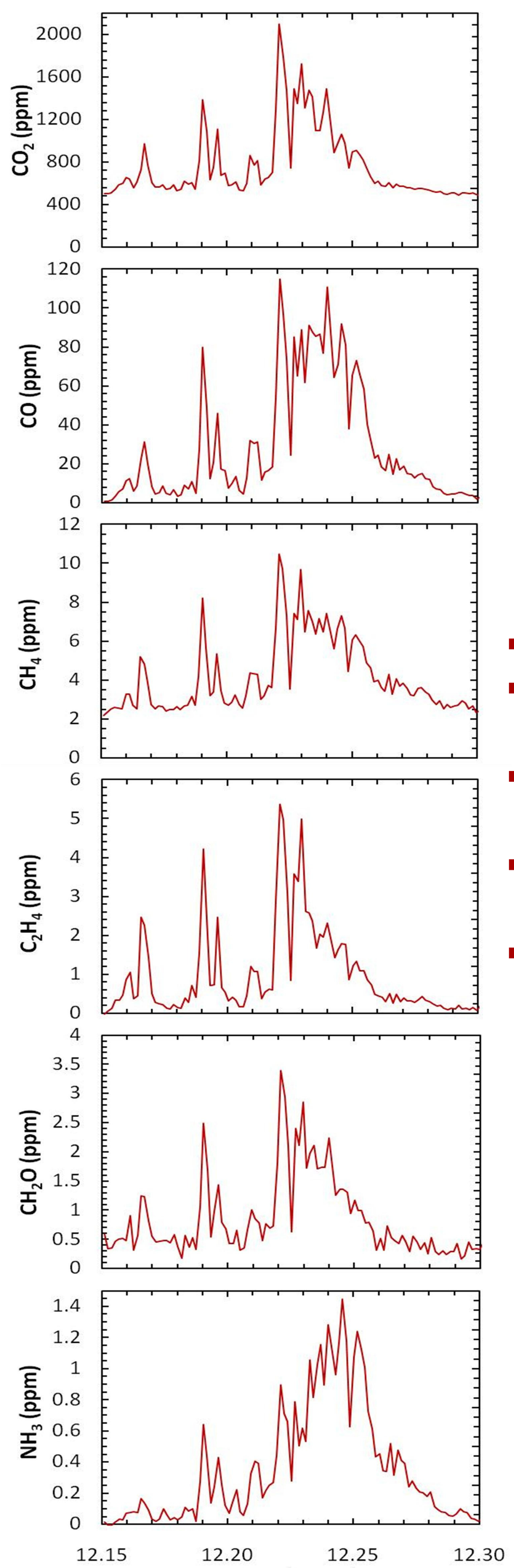


Figure 6. Time-series of path-averaged concentrations (ppm) for a selection of gas species for Plot 2. Notice the difference in peak concentrations between flaming products (e.g. CO_2) and smouldering products (e.g. CO, NH_3).

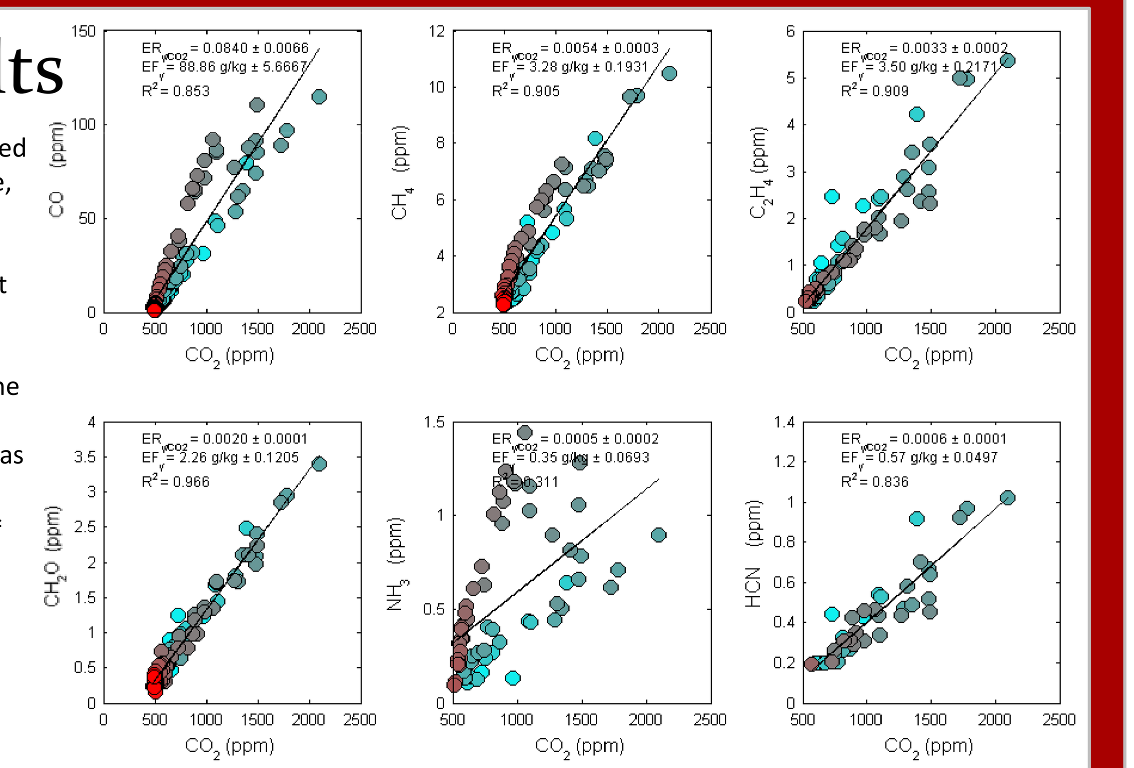


Figure 7 (right). Path-averaged concentrations for Plot 2 fire, plotted as a function of CO_2 concentration. The slope of the least-squares line of best fit (black) is taken as the emissions ratio ($ER_{y/CO2}$) between the two species. The colour indicates the time at which each measurement was taken during the fire (cyan = earlier during backfire; red = later during headfire).

- Emission factors are dissimilar to those from other ecosystems (Table 1)
- High emission factors for pyrolysis products (e.g. C_2H_4, C_2H_2, CH_2O), possibly due to windy conditions blowing gases away from flames before combustion takes place.
- Very low emission factor for NH_3, possibly due to the nitrogen-poor soils of upland moors and consequential low nitrogen content in the vegetation.
- Noticeable difference in emission factors between backfire and headfire for some gas species (particularly CH_3OH and NH_3).
- Since contact with pyrolysis products is more thorough in backing fires, emissions consist of a higher proportion of well-oxidised products, whereas in heading fires the emission of incomplete combustion products is higher.

Gas	Emission Factor (g kg^{-1} dry fuel)		Andreae and Merlet (2001)	
	Backfire	Headfire	Boreal forest	Savanna
CO_2	1679.40 ± 9.92	1597.97 ± 23.27	1569 ± 131	1613 ± 95
CO	80.50 ± 5.99	136.43 ± 11.26	107 ± 37	65 ± 20
CH_4	2.83 ± 0.10	3.37 ± 0.71	4.7 ± 1.9	2.3 ± 0.9
C_2H_2	1.09 ± 0.13	0.71 ± 0.06	0.27 ± 0.09	0.29 ± 0.27
C_2H_4	3.01 ± 0.25	2.21 ± 0.38	1.12 ± 0.55	0.79 ± 0.56
C_2H_6	0.24 ± 0.08	0.25 ± 0.07	0.60 ± 0.15	0.32 ± 0.16
HCOOH	0.27 ± 0.07	0.34 ± 0.09	2.9 ± 2.4	0.7
CH_3OH	0.37 ± 0.14	1.17 ± 0.19	2.0 ± 1.4	1.3
CH_2O	1.62 ± 0.35	2.15 ± 0.17	2.2 ± 0.5	0.35 ± 0.09
NH_3	0.23 ± 0.05	0.81 ± 0.28	1.4 ± 0.8	1.0 ± 0.5
HCN	0.62 ± 0.08	0.38 ± 0.08	0.15	0.028 ± 0.003

Table 1. Emission factors (EFs) of 11 gases released by heather moorland burning, stratified into backfire and headfires. Each EF is derived from mean of five separate fires (Fig. 3c), with uncertainty taken as the standard deviation. Typical EFs reported in Andreae and Merlet (2001) for other ecosystems are shown for comparison.

V. Estimating Annual Emissions

$$E_x = A \times B \times \alpha \times EF_x$$

Where E_x = emission of species *x* (g)
A = burnt area (m^2)
B = fuel load (kg m^{-2})
α = combustion completeness (%)
EF_x = emission factor for species x (g kg^{-1} fuel combusted)

A – Burnt Area

- Scotland: **200 km^2** (Scotland's Moorland Forum, 2002)
- England: **114 km^2** (Yallop et al., 2006)

B and α – Fuel load and combustion completeness (Fig. 8)

- Peak District National Park (Marrs, pers. com.)
- Debdon, Northumberland (this study)
- Cairngorms National Park (Legg *et al.*, 2010)
- Mean fuel loads of **1.15 kg m^{-2}** and **1.75 kg m^{-2}** are used here, for late building and mature heather, respectively.
- Mean combustion completeness of **71.5 %** and **67.4 %** are used here, for late building and mature heather.

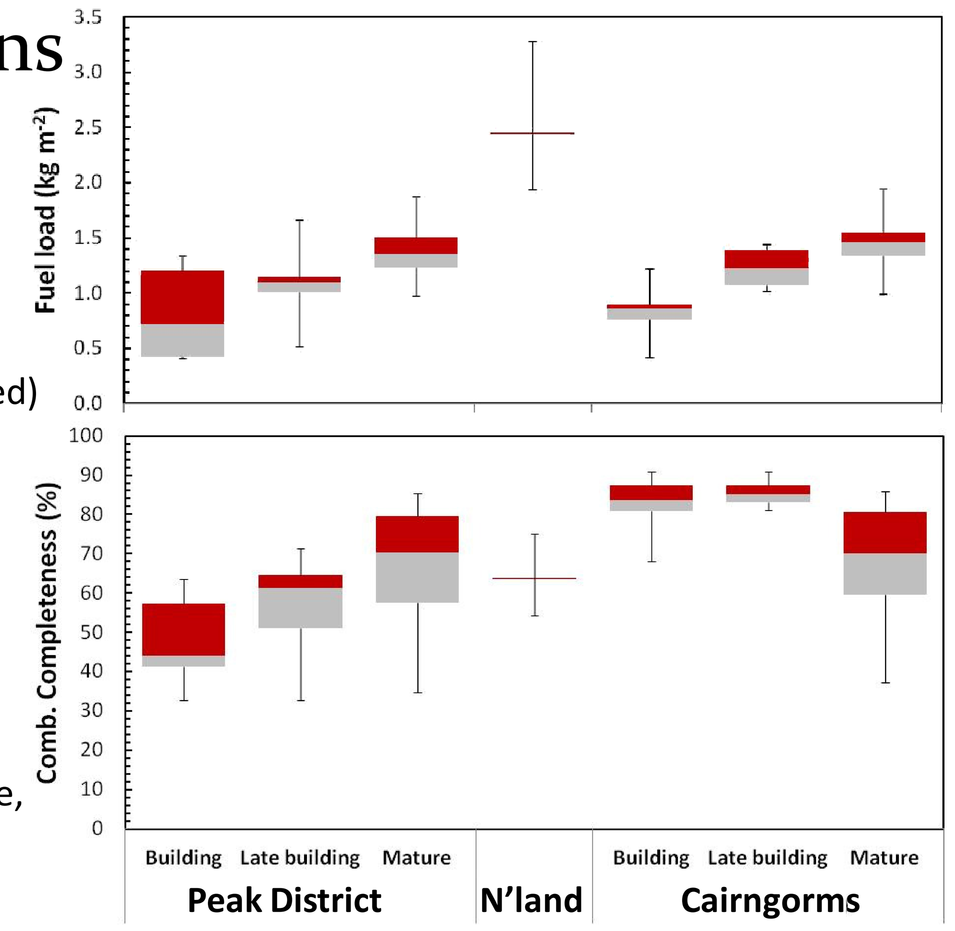


Figure 8. Fuel load and combustion completeness measured at Howden Moor, Peak District National Park (n = 30) and at the field sites in Northumberland (n = 5), along with measurements published in Legg *et al.* (2010) (n = 26) for Crubenmore Estate, near Dalwhinnie, Cairngorms National Park.

Emissions Scenarios

- 'Best estimate' total emissions are based upon the figures above, where the majority of burnt heather is mature (80%) and most of the fires are headfires (90%) (Table 2).
- Other scenarios based on higher frequency (i.e. Greater burnt area, but younger heather) and lower frequency (vice versa) burning are included for comparison as both of these scenarios are within the range of uncertainty associated with the variables.
- Table 3 presents final estimated emissions for each trace gas (in kilotonnes year^{-1})
- 0.26 kt NH_3 significantly less than previous estimates (Dragosits et al., 2009).

Table 2. Total emissions modelling scenarios. The burnt area, fuel load, combustion completeness and emission factors vary between different scenarios. The best estimate assumes a 16-year burn cycle, whereby 80% of the burnt heather is mature, and 90% of heather is burned with a head fire.

Scenario name & Code	Burnt Area (km^2)	Heather Age (%)		Burn Strategy (%)	
		L.B.	Mature	Back	Head
Best estimate (BE)	314	20	80	10	90
Higher frequency (HF)	382	50	50	10	90
Lower frequency (LF)	246	10	90	10	90
More backburning (BB)	314	20	80	50	50
Maximise NH_3 (MN)	314	0	100	0	100

Table 3. Estimates of total emissions (kt year^{-1}) of eleven trace gases from moorland burning in the UK under five different burning scenarios. These represent the first estimates based on direct measurements of emission factors from moorland fires. Notice how the largest emissions of different gases (e.g. NH_3 and CH_2O) can occur under different scenarios.

Scen.	Mass of gas species (kilotonnes year^{-1})										
	CO_2	CO	CH_4	C_2H_2	C_2H_4	C_2H_6	HCOOH	CH_3OH	CH_2O	NH_3	HCN
BE	**561.29**	**45.72**	**1.16**	**0.26**	**0.80**	**0.09**	**0.12**	**0.38**	**0.73**	**0.26**	**0.14**
HF	618.97	50.42	1.28	0.29	0.88	0.10	0.13	0.42	0.81	0.29	0.15
LF	453.07	36.91	0.94	0.21	0.65	0.07	0.09	0.31	0.59	0.21	0.11
BB	572.68	37.91	1.08	0.31	0.91	0.09	0.11	0.27	0.66	0.18	0.17
MN	592.06	50.55	1.25	0.26	0.82	0.09	0.13	0.44	0.80	0.30	0.14

VI. Conclusions

- First estimate of total emissions of individual gas species from UK moorland burning using direct measurements of emission factors, fuel load and combustion completeness, and published estimates of UK burnt area.
- Emission factors for some gas species are significantly different to those from other vegetation types, having a large effect on total emissions calculations (Fig. 9).
- For NH_3, the emission factor is only 20% of that used in the UK's NAEI estimates.
- Recent measurements in Northumberland (March 2011) at a further 16 fires will help reduce uncertainty in both emission factor and biomass variables

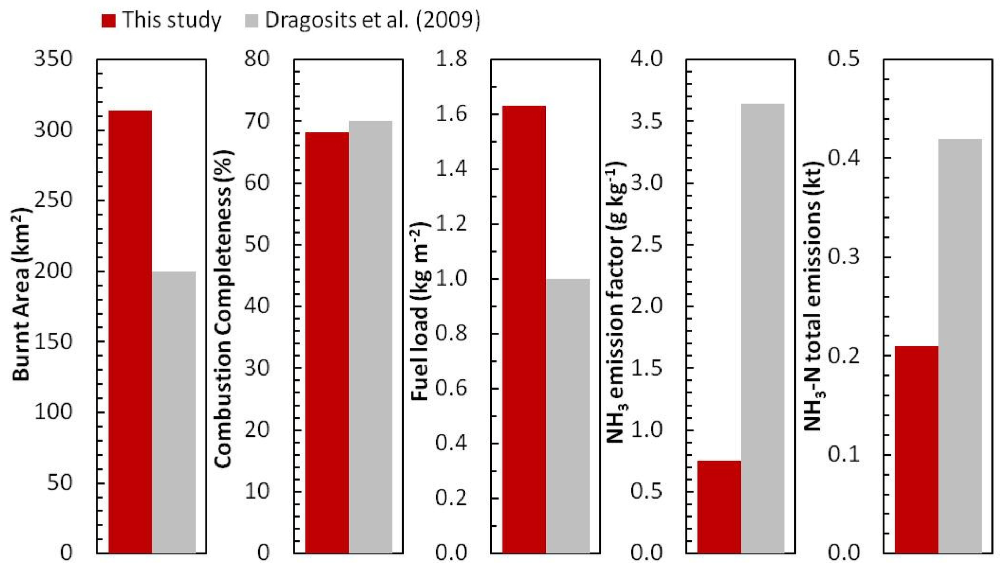


Figure 9. Comparison of total emissions modelling variable values used in this study with those used for the NAEI (Dragosits *et al.*, 2009) for NH_3. This figure shows the importance of having a measured emission factor for moorland burning.

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