# Aircraft Emissions at Airports

FETE
21st July 2011

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# Outline

- Context
- Engine emissions
- UK Airport emissions

# Context

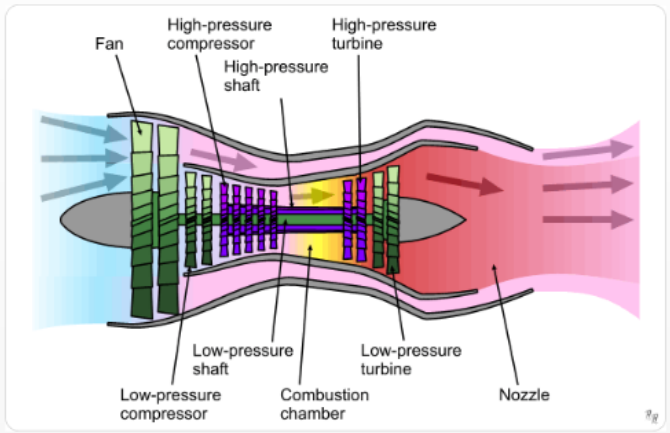
- Aviation affects the environment via the emission of pollutants from aircraft and airport infrastructure.[1]
- Impacting upon:
  - Human health
  - Climate
- Expected 5% growth p.a. up to 2025. [2]
- 30% UK CO2-eq by 2050.[3]

"We will cancel the third runway at Heathrow... [and] refuse permissions for additional runways at Gatwick and Stansted"

[Coalition Government Agreement, May 2010]

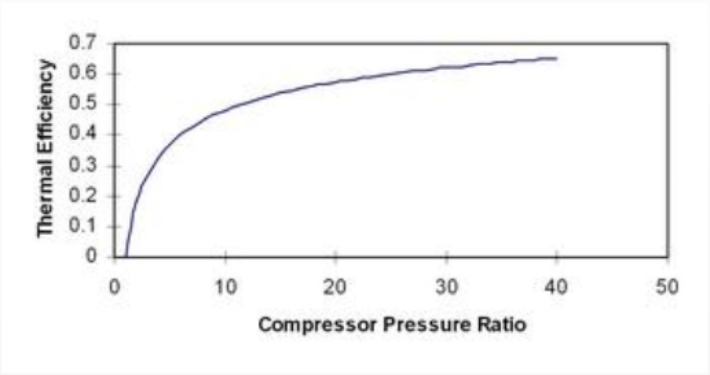
1 - Lee et al. (2009)
2 - Airbus (2007)
3 - CCC (2009)

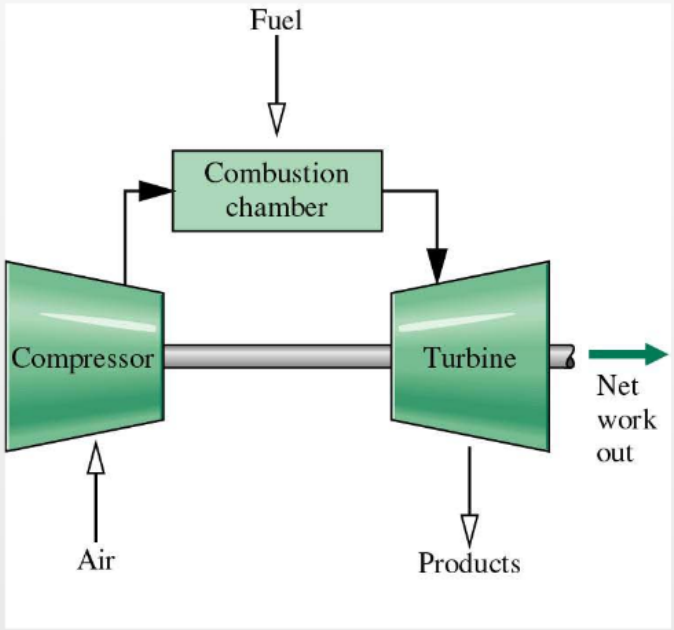
# Overview: Aircraft Engines

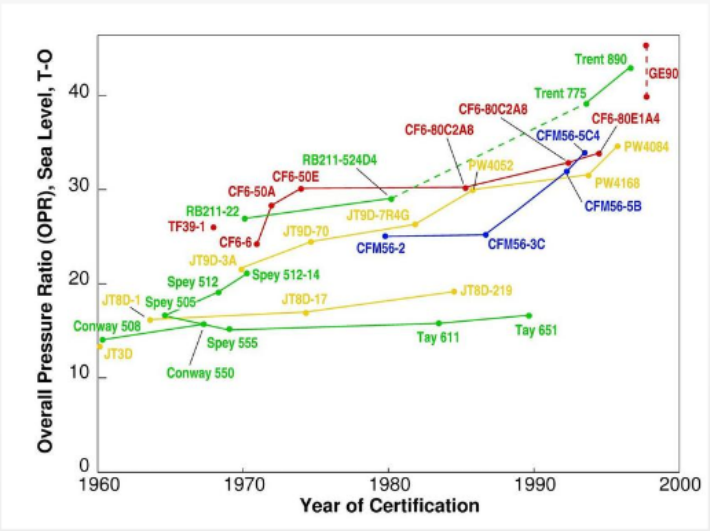



$$\eta_B = 1 - \frac{1}{TR} = 1 - \frac{1}{PR^{(\gamma-1)/\gamma}}$$

PR = Pressure Ratio
gamma = heat capacity ratio

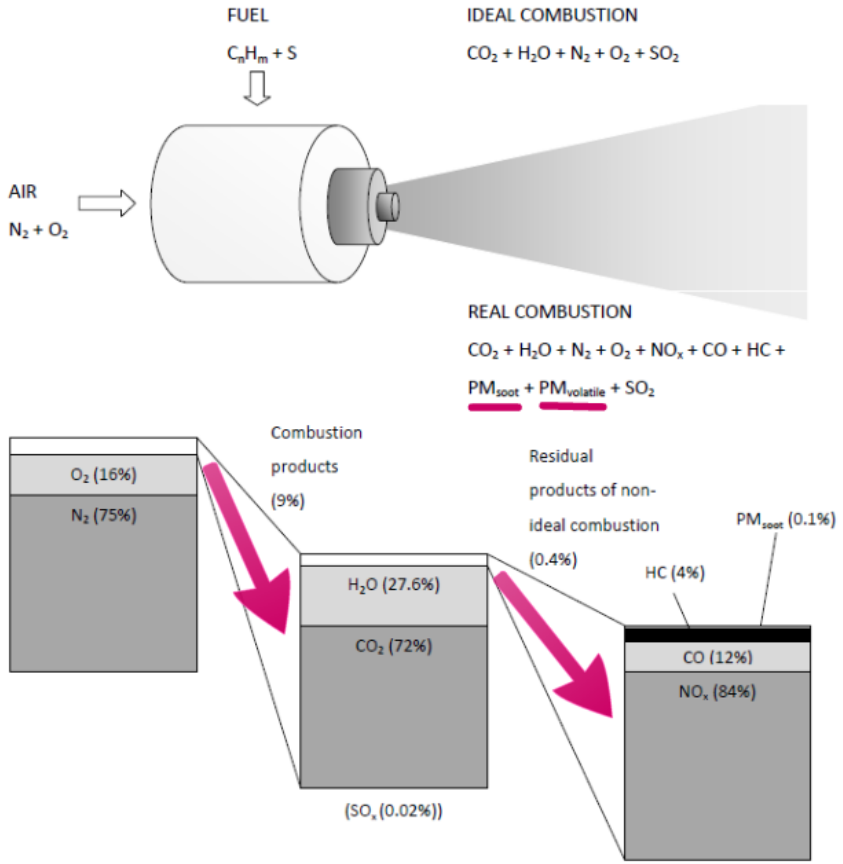


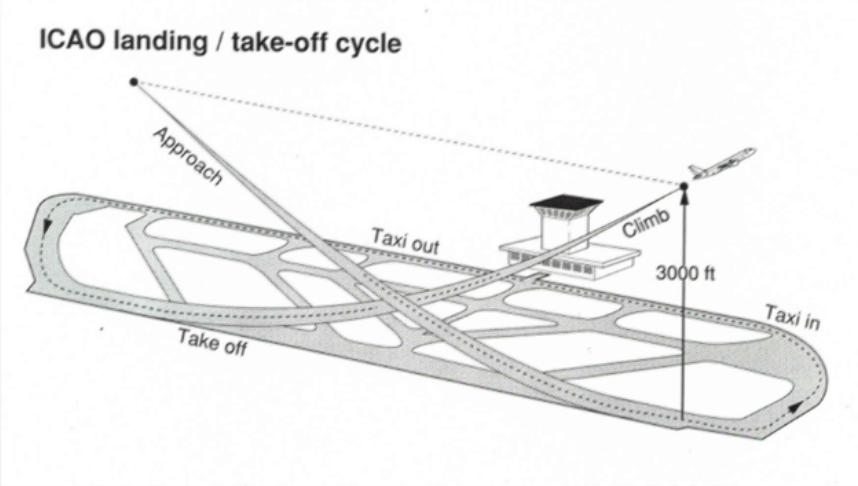
# Engine Emissions

Regulated:
NOx
Smoke
CO
HC
SOx



## Emissions Regulations

- International Civil Aviation Organization (ICAO)
- Only LTO, not cruise
- Maximum amount over 'standard' LTO cycle, accounting for engine size (maximum output)



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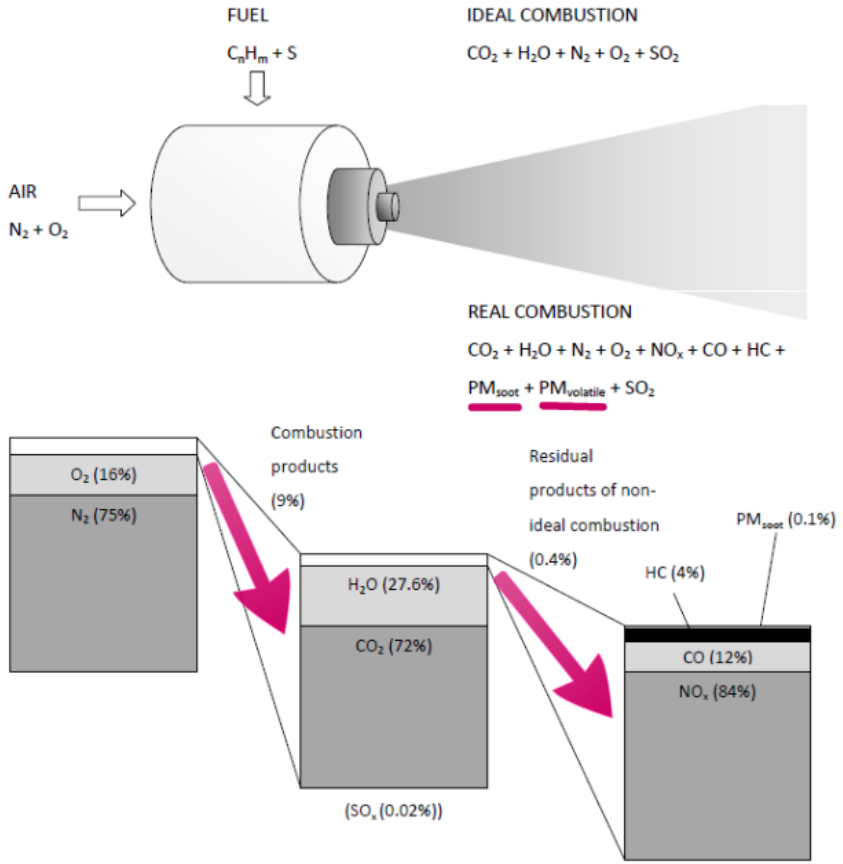


# NOx

## Thermal NOx

$$O_2 \rightleftarrows O + O$$

$$O + N_2 \rightleftarrows N + NO$$

$$O_2 + N \rightleftarrows O + NO$$

$$N + OH \rightleftarrows NO + H$$

- T > 1500K
- Production is temperature and time dependent

# NOx Regulation

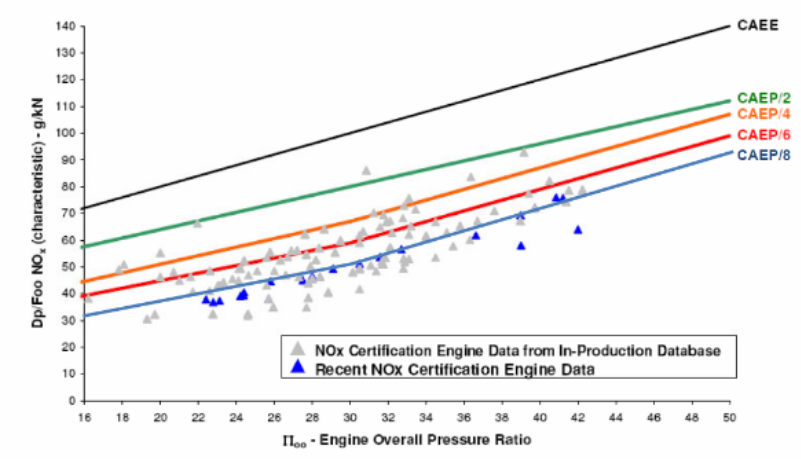
Higher pressure ratio = higher combustion temp

↓

More difficult to reduce NOx for higher pressure ratios

↓

Regulation accounts for engine pressure ratio




↓

NOx regulation:

- Reduces NOx
- Limits fuel efficiency (CO2)
- Induces manufacturers to increase pressure ratio to limit reduction on efficiency

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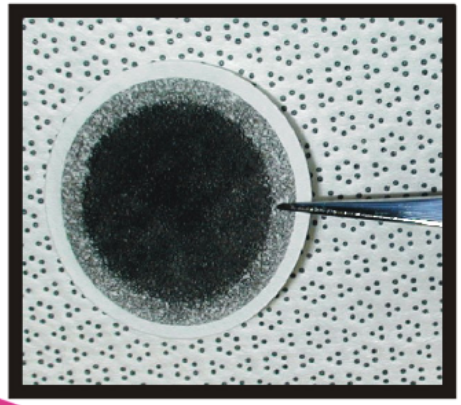
# Smoke



Regulation concerned with visibility

# PM2.5

Volatile

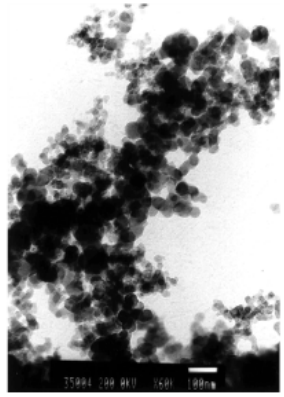
Non-volatile

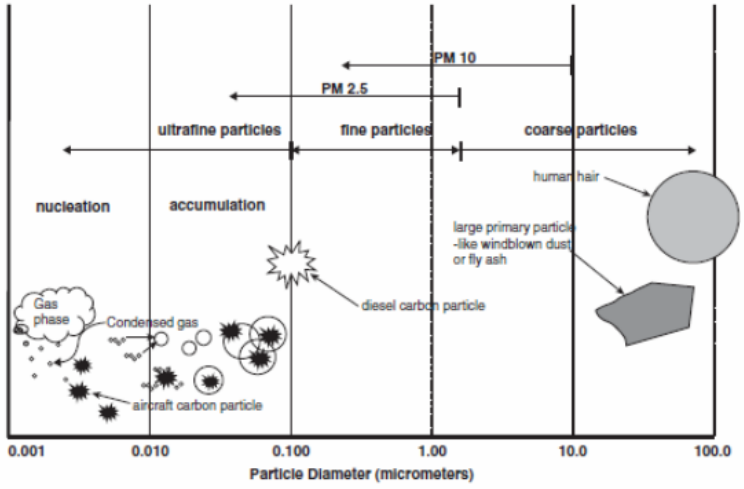
Organics

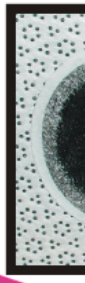
Sulfates

Soot

Form in exhaust plume, condense onto soot particles.



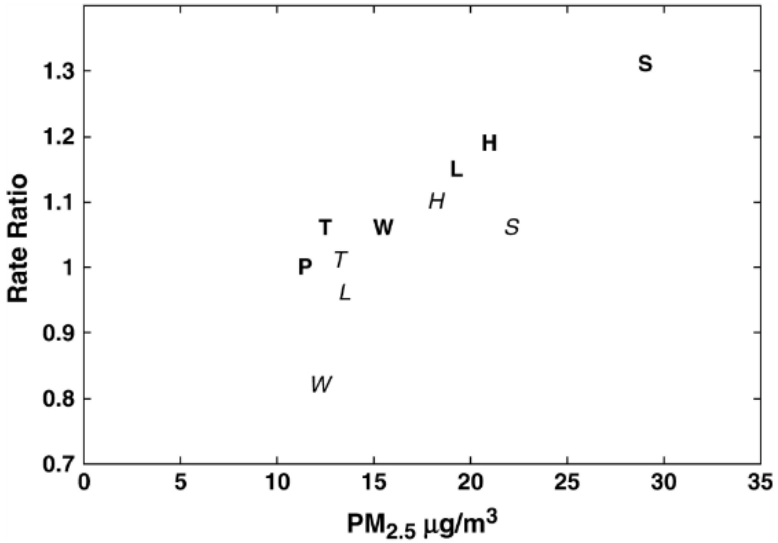


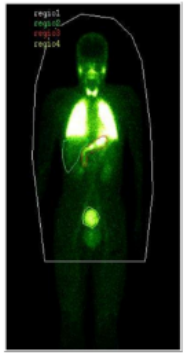
fraction

# Health Impacts

## Clear epidemiological evidence for PM2.5:[4]



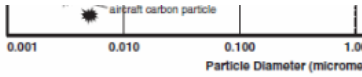

Six cities study:
P = Portage, WI (reference)
T = Topeka, KS
W = Watertown, MA
L = St Louis, MO
H = Harriman, TN
S = Steubenville, OH



1-2% increase in risk of premature mortality per 1ug/m concentration increase.

Growing evidence to suggest different PM fractions (species and size) have different toxicity.

4 - Laden et al. (2006)

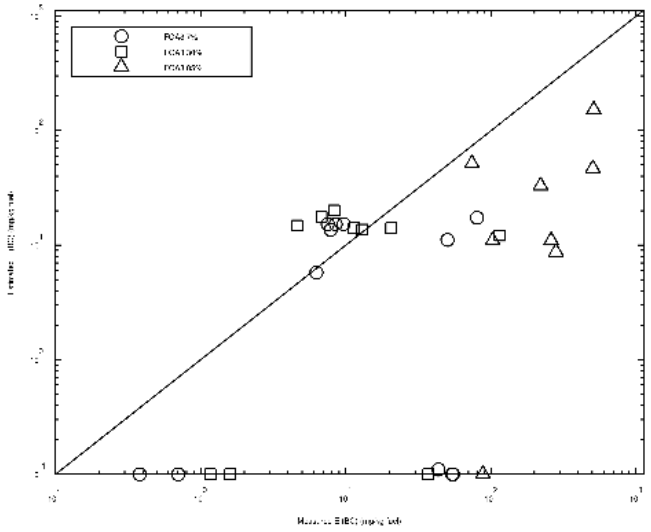



# Estimate soot fraction

Aircraft soot not directly regualted, only a few engines have been measured.

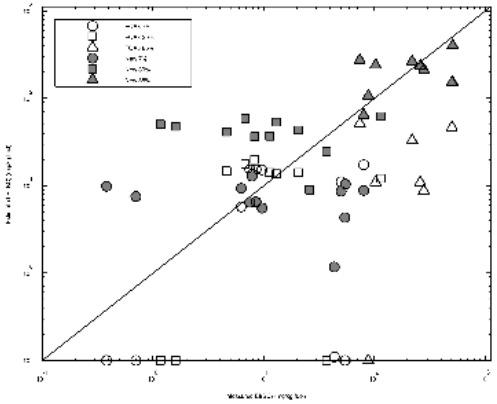
Current method to estimate soot emissions:

- First Order Approximation (FOA3)
- Significant discrepancies when compared to measurement data - order of magnitude error in 40% of cases



# Proposed method

$$EI(BC)\,[mg/kg\,fuel] = 4.57.\left(\frac{EI(NO_x)}{EI(NO_x)_{ref}}\right)^{-1.27}.\left(\frac{EI(CO)}{EI(CO)_{ref}}\right)^{-0.4}.\left(\frac{SN_{MAX}}{SN_{MAX,ref}}\right)^{0.2}.\left(PR.\frac{F}{F_{00}}\right)^{1.25}$$



FOA3:

- $R^2$ = -0.02

Proposed model:

- $R^2$ = 0.58

Factor 8 increase in soot emissions estimates.

## Soot-NOx Trade-off

| Controlling Factor | NOx | Soot |
|---|---|---|
| Temperature | ↑ | ↓ |
| Residence time | ↑ | ↓ |
| Air/fuel ratio | ↑ | ↓ |

## Hypothesis:

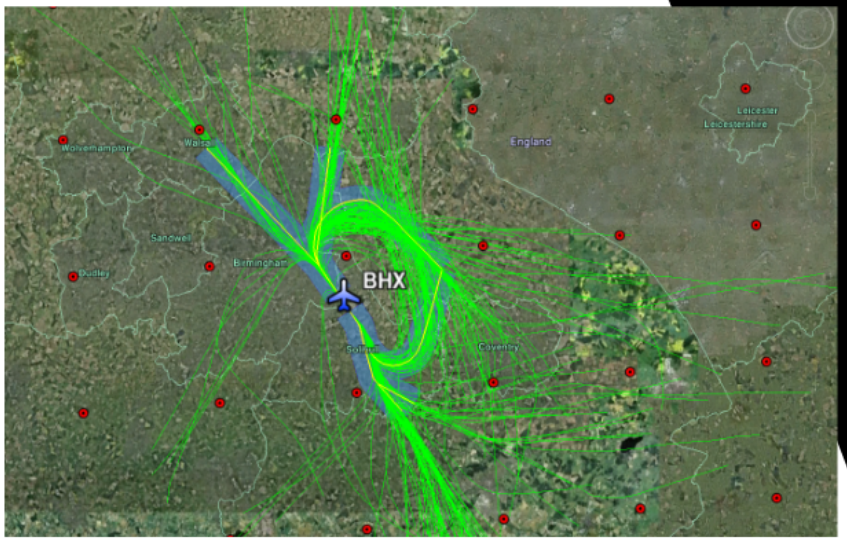
NOx regulations have led to increased soot emissions by:

- Increasing pressure ratios
- Reducing residence times
- Not picked up by smoke measurement (smaller size = more dangerous to health)

# Outline

- Context
- Engine emissions
- UK Airport emissions

# UK Airports Emissions

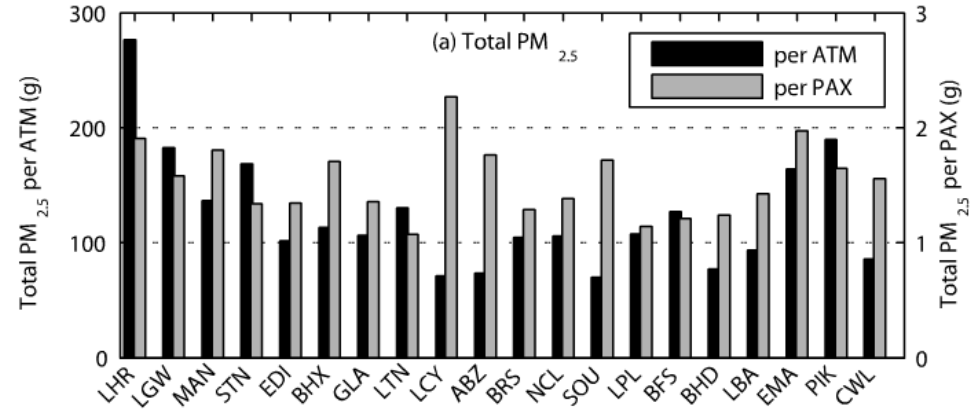

- Busiest 20 UK airports, real 2005 schedule

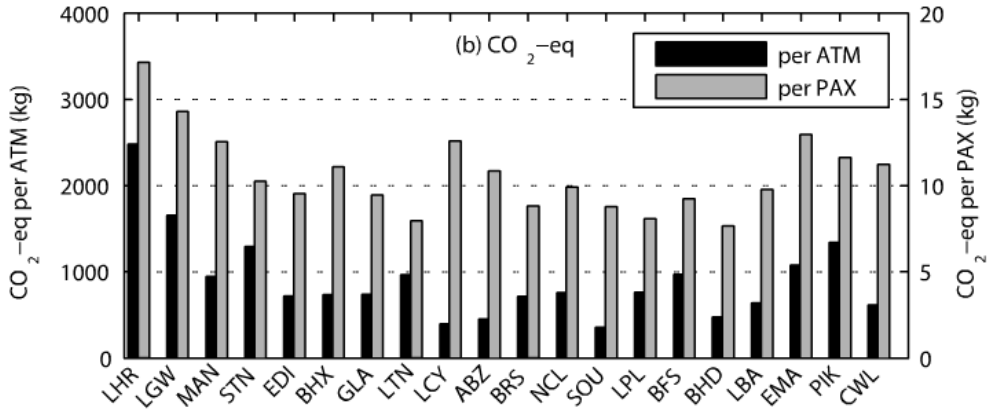
Stettler et al. (2011) Air quality and public health impacts of UK airports. Part I: Emissions. Atmospheric Environment.

# Results: Airport Performance

Per service unit:

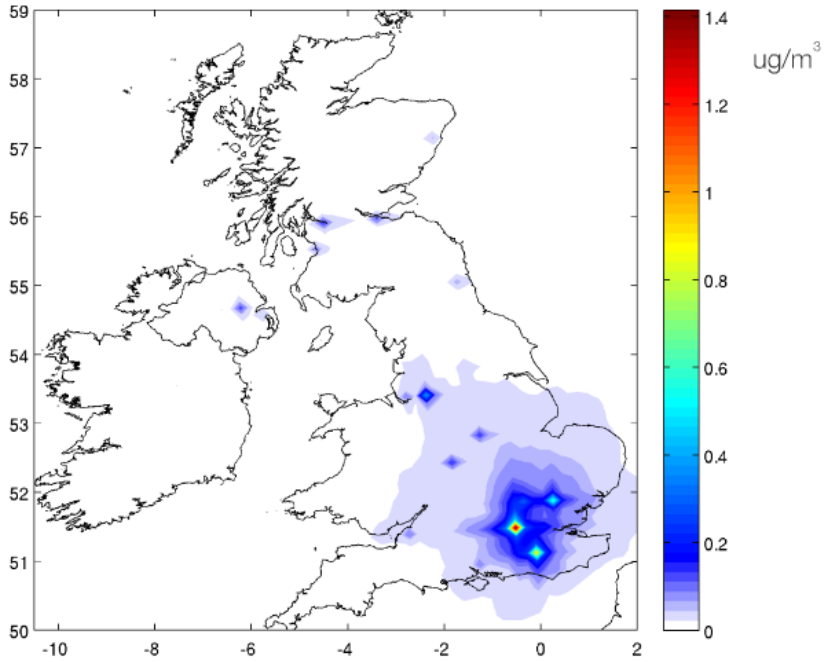
- ATM
- Passenger



# Impacts Modelling

Concentration attributable to aviation



# Summary

- Current PM estimation method underestimates by factor 8
- Soot-NOx trade-off
- Health impacts of UK airports...