European characterization factors for damage to natural vegetation by ozone

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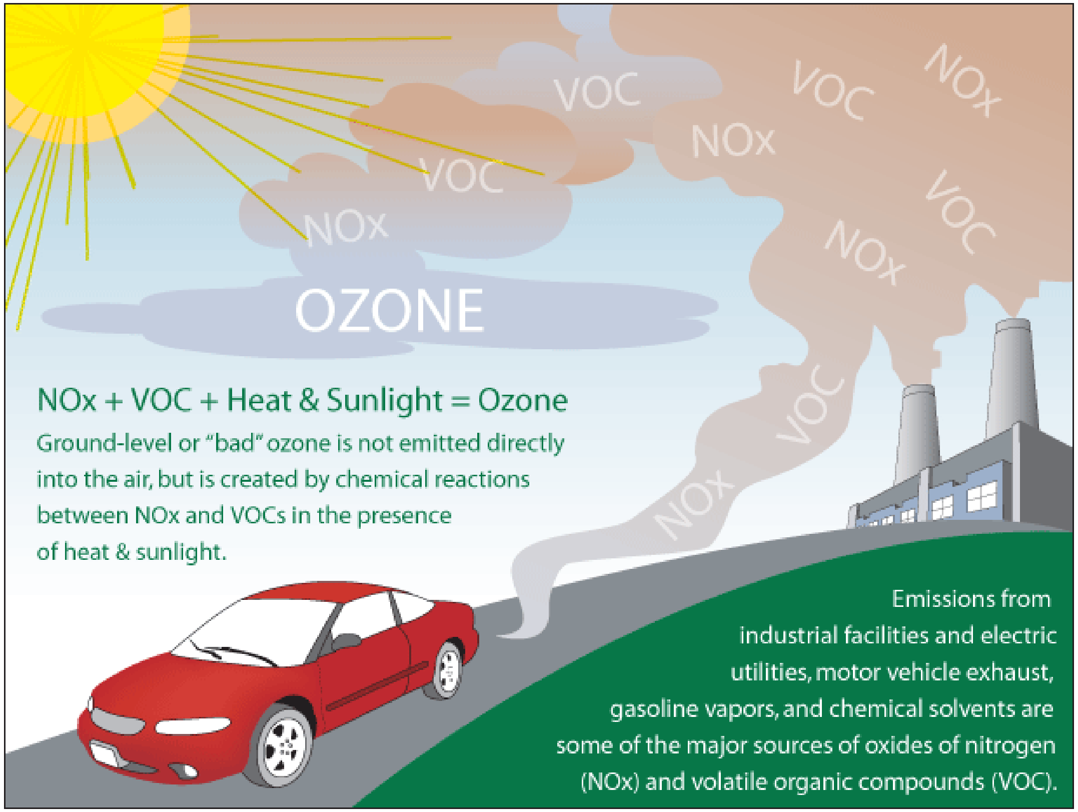
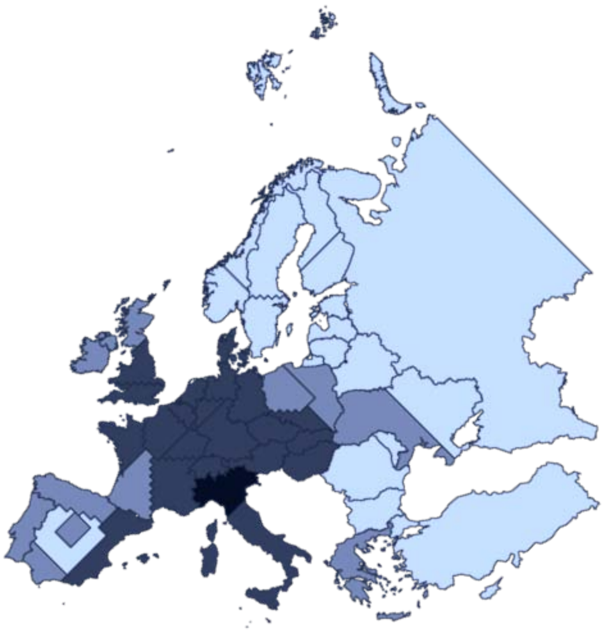
Ozone impact

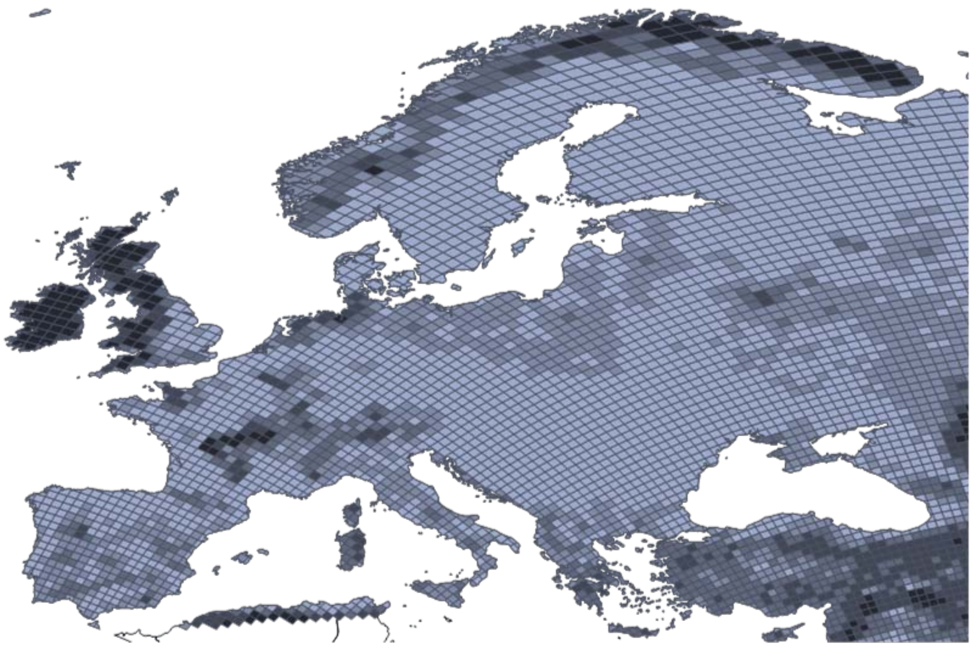
- Emissions of precursor substances, NOx and NMVOC
- Impacts on plants:
  - Yield loss
  - Biomass reduction
  - Leaf injury



From emission to impact



Emitting regions



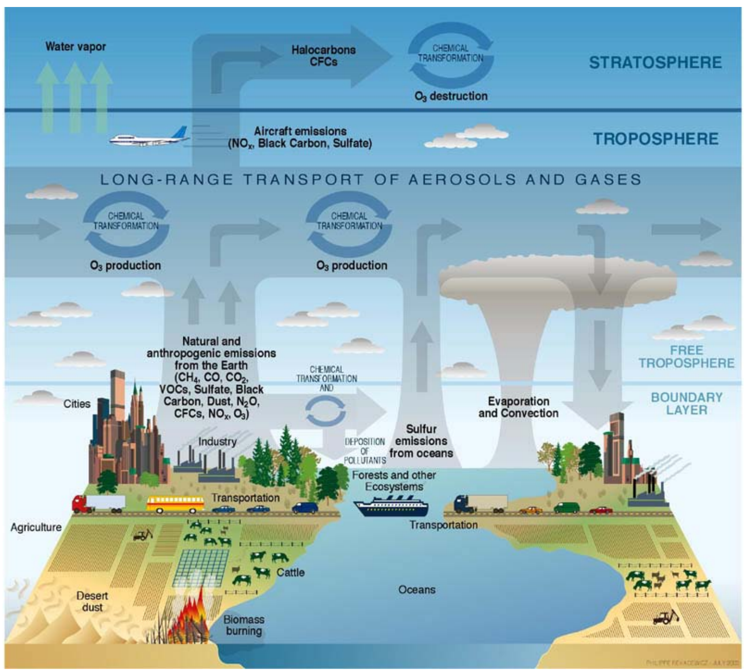
Receiving grids

Life Cycle Impact Assessment (LCIA)

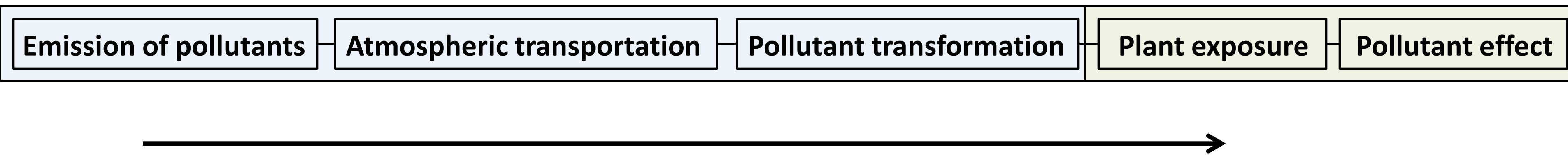
- The Characterization model consist of a fate and effect model

Emission of pollutants	Atmospheric transportation	Pollutant transformation	Plant exposure	Pollutant effect

fate model **effect model**



Life Cycle Impact Assessment (LCIA)



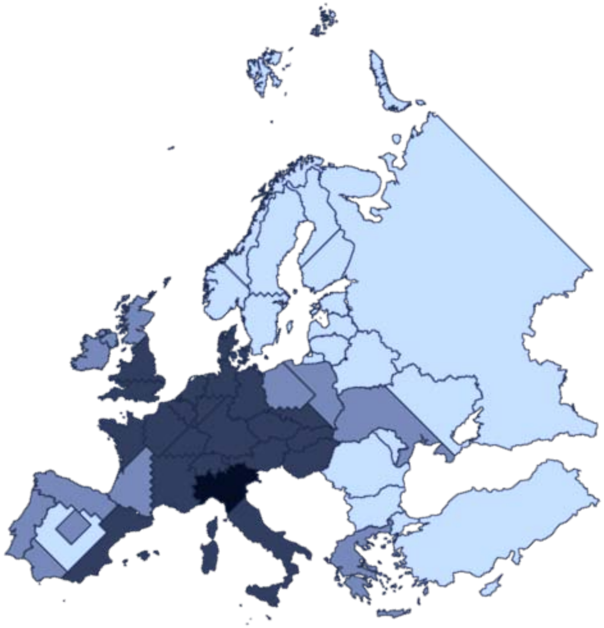
- Studies assessing ozone impacts to natural ecosystems have yet only included regionalized fate and exposure modeling

Characterization factors

$$CF_{x,i,e} = \sum_j \sum_e (FF_{x,i\rightarrow j} \cdot EF_{j,e})$$

Characterization factor (in $m^2 \cdot yr/kg$) :

- for substance x → NOx, NMVOC
- for vegetation type e → grassland, forest
- in region i → 65 european regions



Fate Factor

$$FF_{x,i \rightarrow j} = \frac{\Delta AOT40_j}{\Delta M_i}$$

Partial Fate Factor (in ppm.h·yr/kg):

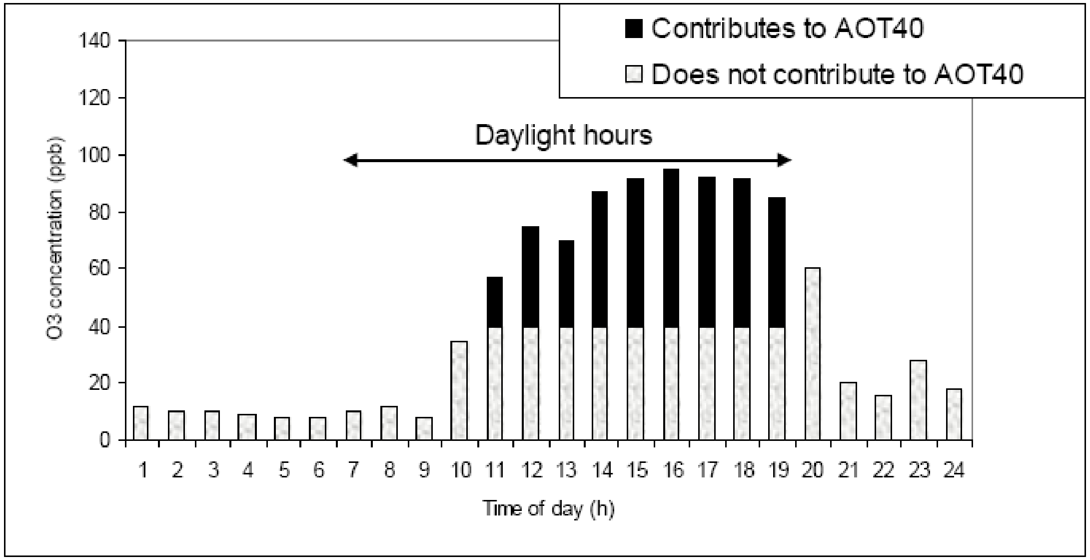
•represents the change in Accumulated Exposure Over a Threshold of 40 ppb ozone in a receiving compartment cell j (in ppm.h) due to a change of emission of precursor x in region i ([kg/yr])

•derived with the EMEP atmospheric fate model

•emissions were decreased by 15% compared to the baseline emission inventory

AOT40

- Measure of ozone exposure: Accumulated amount of Ozone over the Threshold value of 40 ppb (AOT40 in ppm.h)
- The exposure is taken over the relevant growing season and for daytime only

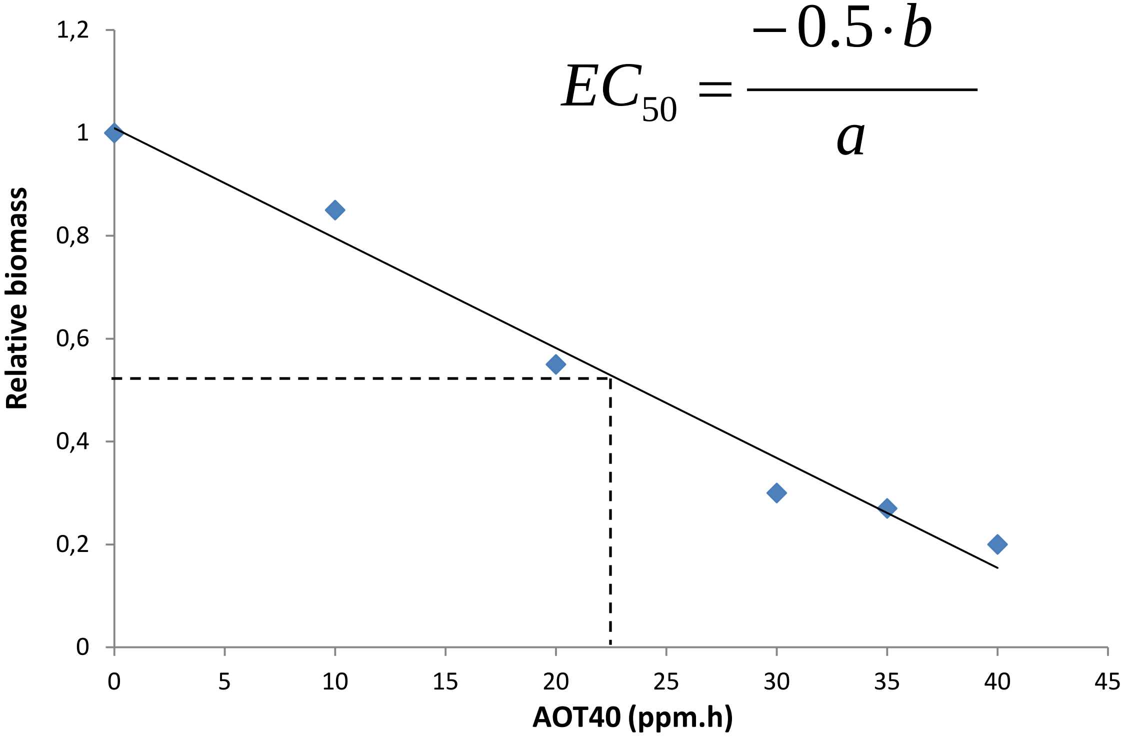


Effect Factor

Species-specific ozone dose-response functions were used to calculate Species Sensitivity Distributions (SSDs) by calculating an EC50 value for each species

- some species had no biomass decrease

$$EC_{50} = \frac{-0.5 \cdot b}{a}$$

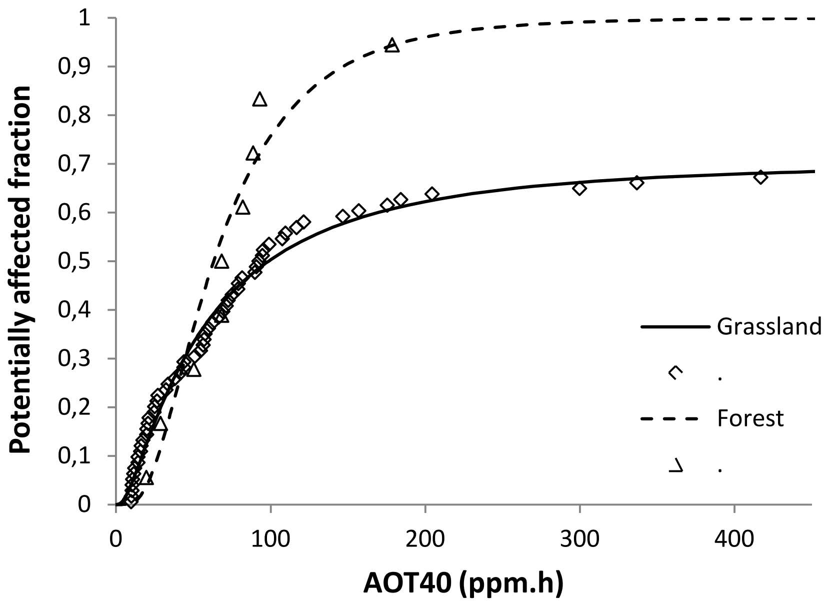


Effect factor

Species sensitivity distributions:

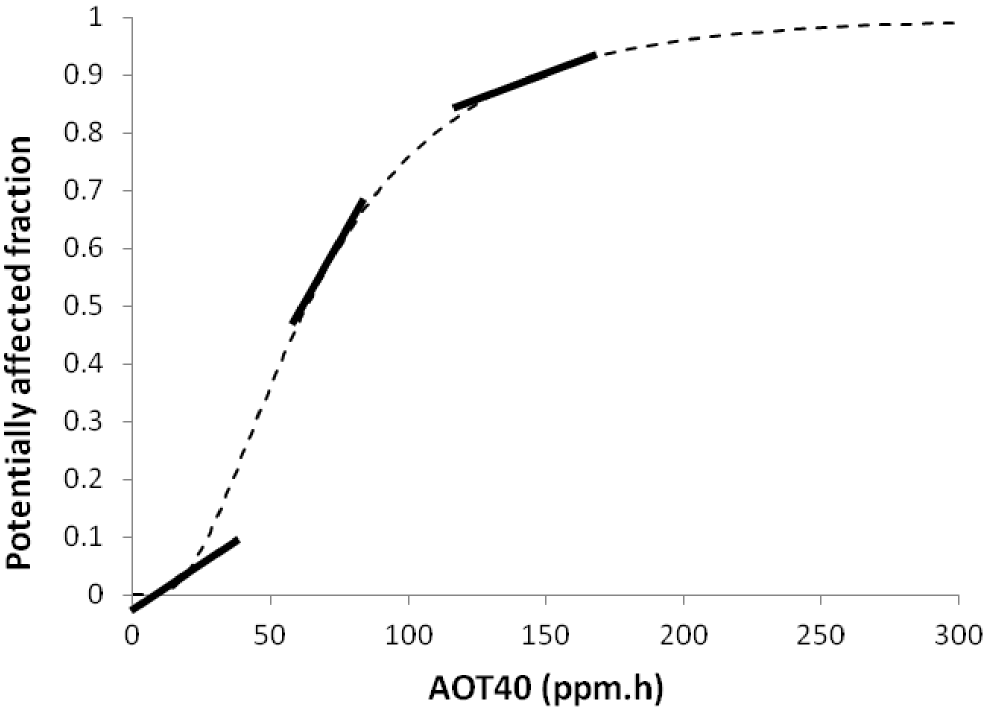
$$PAF_{j,e} = \frac{1 - f_{nbd}}{\sigma_e \cdot \sqrt{2 \cdot \pi} \cdot AOT40_{j,e} \cdot \ln 10} \cdot \int_0^{AOT40} \exp\left(-\frac{1}{2} \cdot \left(\frac{\log(AOT40_{j,e}) - \mu_e}{\sigma_e} \right)^2 \right)$$

- Potentially Affected Fraction (PAF)
- Including the fraction of species with no biomass decrease (F_{nbd})



Effect factor

- By taking the derivative of the PAF function, the <u>marginal</u> change in PAF due to the <u>marginal</u> change in ground level ozone exposure can be calculated (in ppm.h)



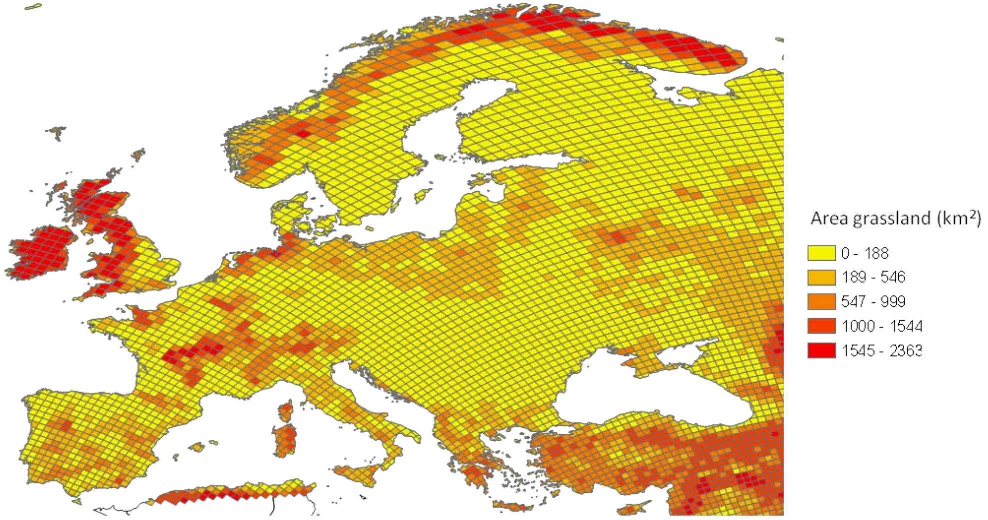
Effect Factor

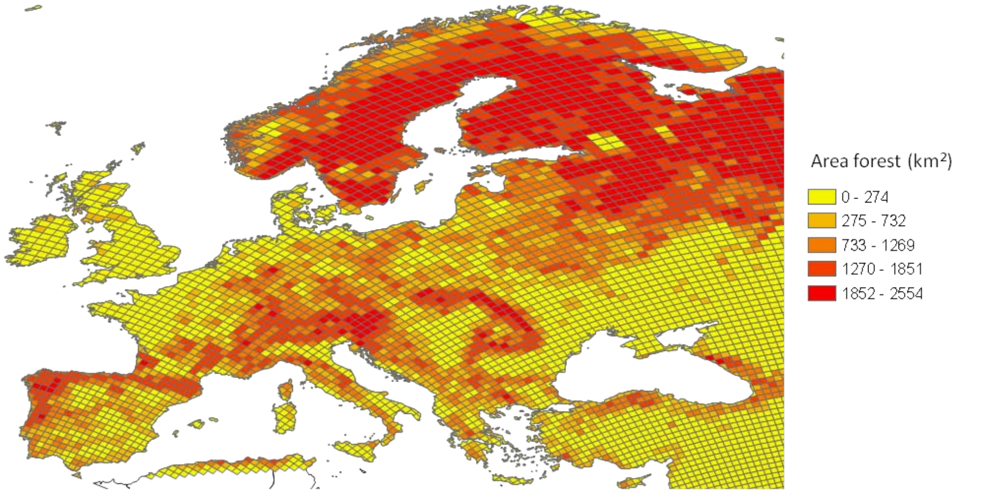
Finally the effect factor is defined as:

$$EF_{j,e} = \frac{\partial PAF_{j,e}}{\partial AOT40_j} \cdot A_{j,e}$$

•$A_{j,e}$ is the are occupied by vegetation type e in grid j (in km^2)

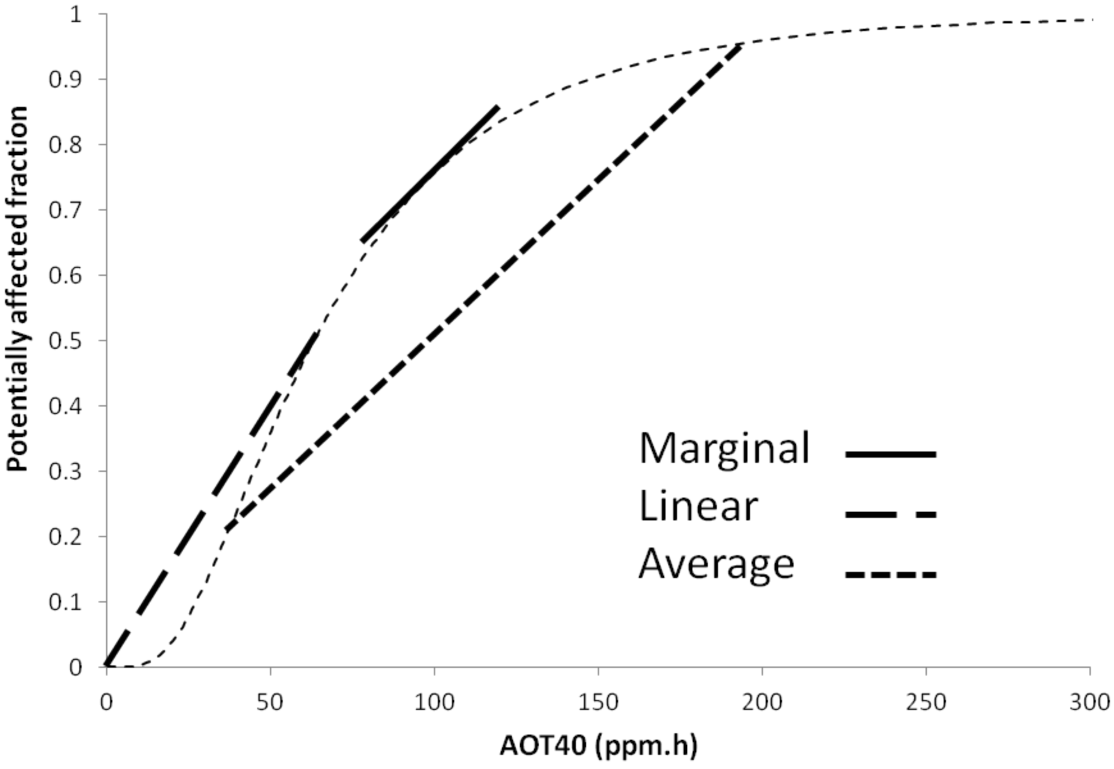
•the Global Land Cover 2000 database was used to calculate the grid-specific area occupied by each vegetation type



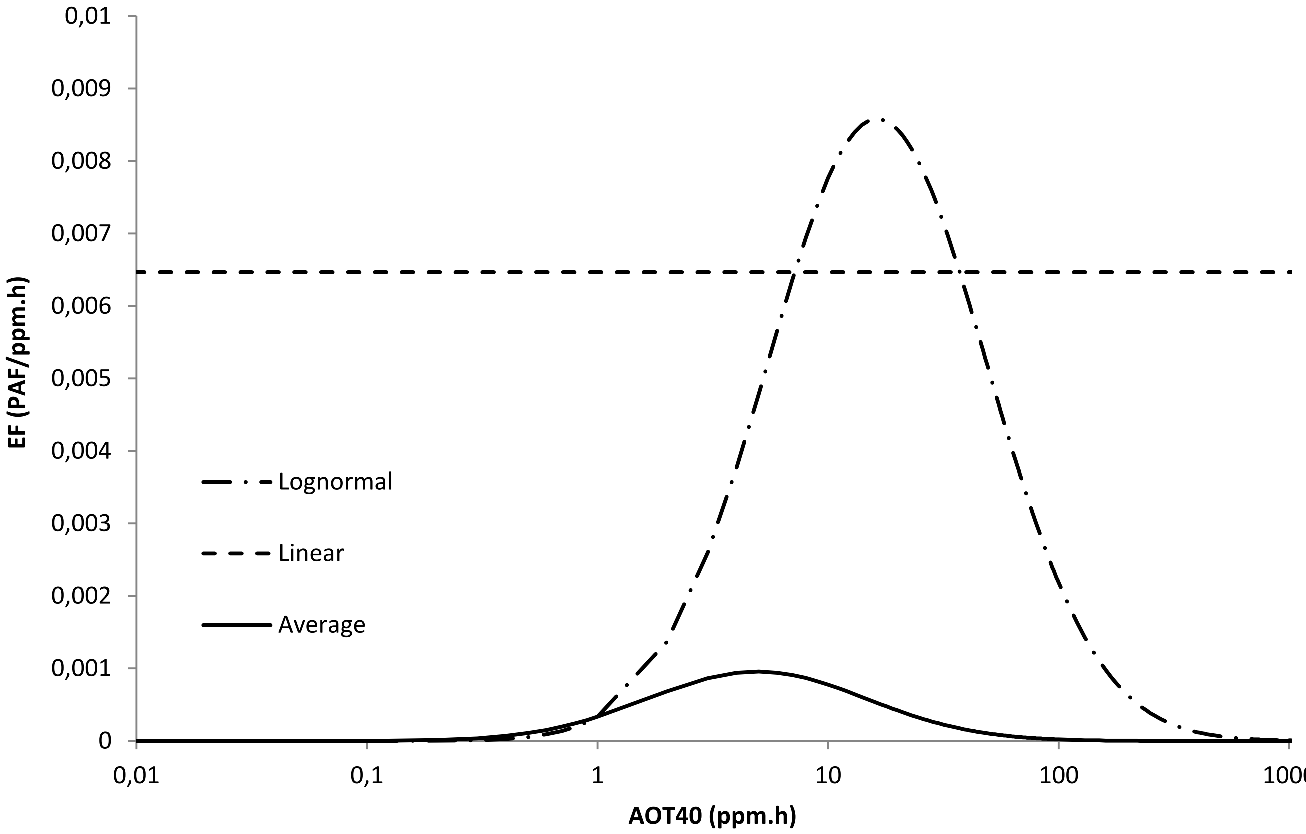


Alternative effect models

- Linear effect factor
- Average effect factor

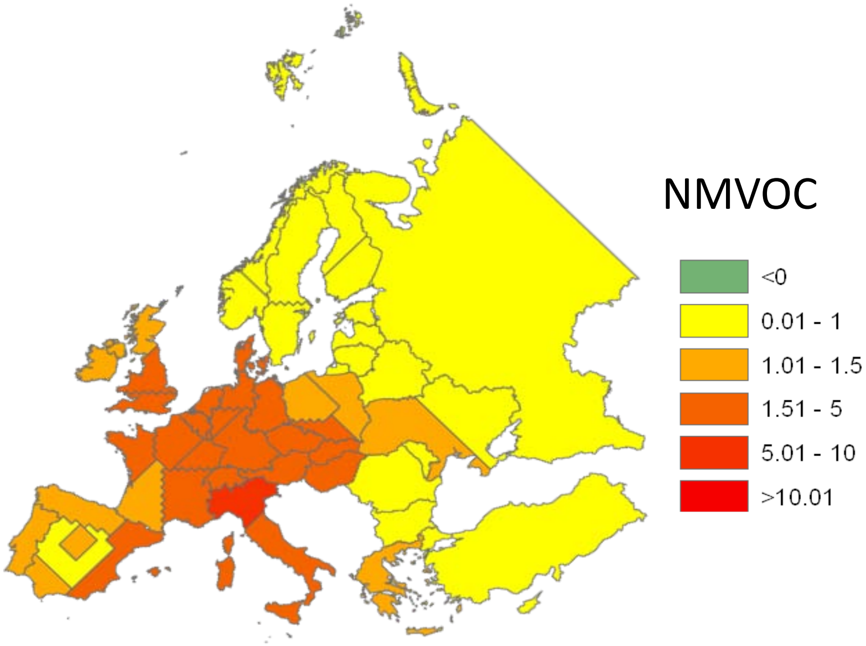


Alternative effect models



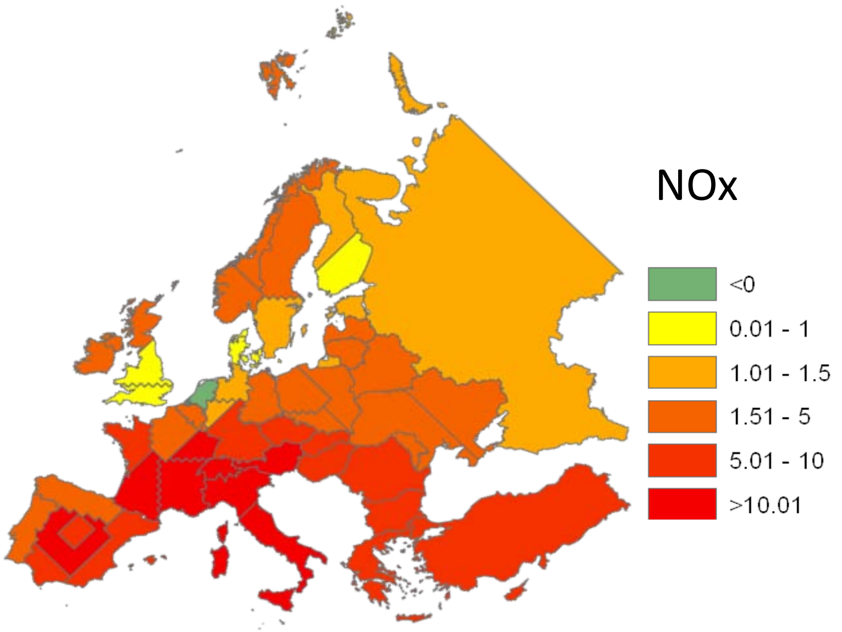
Analysis

- CFs are in the range of 0.2 – 5.0 PAF.m^2.yr/kg
- with lowest CFs for Finland and highest for Italy
- CFs are determined by a combination of FF and EF



Analysis

- CFs are in the range of -0.3 – 20.6 PAF.m^2.yr/kg
- with lowest CFs for the Netherlands and highest for Switzerland
- negative characterization factors for NOx indicate reduced ozone formation, due to titration effect



Normalization factor

The normalization factor equals the potentially affected fraction of natural plant species in Europe due to emissions of NOx and NMVOC per capita (in PAF.m^2/capita)

$$NF = \frac{\sum_x \sum_i (M_{x,i} \cdot CF_{x,i})}{\sum_i (N_{pop,i})}$$

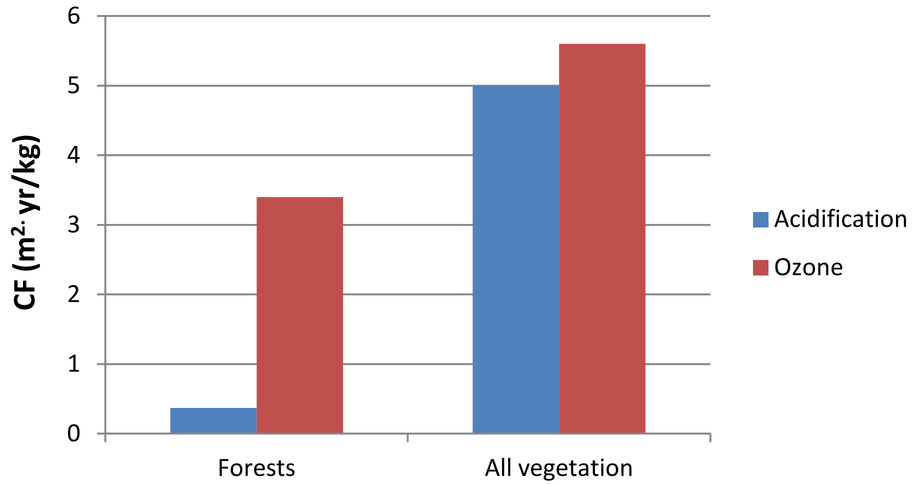
- NF is the normalization factor of the summation of all 65 regions
- $M_{x,i}$ is the emission of precursor x (NMVOC or NOx) in region i (in kg/yr) for 2010
- $CF_{x,i}$ is the characterization factor for substance x in region i
- $N_{pop,i}$ - is the number of inhabitants in region i

Normalization factor

- the normalization factor for ozone impact on natural vegetation due to emissions of NOx and NMVOC in 2010 is $1.4 \cdot 10^{-10}$ m^2 / capita.
- NOx contributed 80% and NMVOCs 20% to the normalization factor
- this implies that NOx is the main contributor to damage by ozone exposure in natural vegetation in Europe.

Comparison to other impact categories

The CFs for NOx can be compared with those for acidification by Van Zelm et al. (2007) and Roy et al. (2013)



- These results indicate a larger effect due to ozone damage by NOx emissions than that of acidification by NOx emissions, showing the importance of including ozone damage to natural vegetation in LCIA.

Uncertainties

- Fate factor
  - complex non-linear chemistry of photochemical ozone creation
  - different NMVOC substances have different potential to create ozone
  - receptor areas outside Europe are not taken into account in the fate factor calculations
- Effect factor
  - not all GLC2000 land cover classes corresponded in terms of species composition to the classification in vegetation types
  - sensitivity to ozone exposure can be overestimated at the community level due to a bias towards the use of sensitive species in fumigation experiments
  - region-specific SSDs are needed to show the distinctly different environmental conditions and species assemblages
  - large uncertainty in the tree SSD because it was based on 9 tree species compared to 61 species for grassland

Conclusions

- spatially explicit characterization factors for damage of tropospheric ozone by anthropogenic NOx and NMVOC emissions on natural vegetation in 65 European regions were derived for the first time
- NOx is the major contributor to damage caused by ozone
- effects caused by ozone exposure from NOx emissions are larger than that of acidification caused by NOx.