Impact of maritime transport emissions on coastal air quality in Europe

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1. Impact of international shipping on European air quality
   • Tracers and physico-chemical characteristics
   • Impact on ambient PM and on gaseous pollutants

2. Mitigation strategies:
   • Environmental and health benefits from ECAs: case study

3. Conclusions
Rationale

Emissions from the marine transport sector contribute significantly to air pollution globally.

Increasing emission source:
- Globalization of manufacturing processes
- Increase of global-scale trade
- Relatively, large efforts to reduce other sources (industrial, power generation, etc.)
- More future growth expected

Human health

Climate

Ecosystems
How much of a problem?

- Different approaches used in different countries
- Not yet achieved the goals for protecting human health

Literature Review → Quantitative
Well-known **tracers** of combustion based on crude oil:
- V and Ni (>60 publications)
- Others: La, Th, Pb, Zn and SO$_4^{2-}$ (>18 publications)

<table>
<thead>
<tr>
<th>Where?</th>
<th>PMx</th>
<th>V/Ni</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>PM$_{10}$</td>
<td>3.2±0.8</td>
<td>Mazzei et al. (2008)</td>
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<tr>
<td></td>
<td>PM$_{2.5}$</td>
<td>3.2±0.8</td>
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</tr>
<tr>
<td>Ship engine</td>
<td>PM$_{2.5}$</td>
<td>2.3-4.5</td>
<td>Agrawal et al. (2008)</td>
</tr>
<tr>
<td>Spain</td>
<td>PM$_{10}$</td>
<td>4-5</td>
<td>Viana et al. (2009)</td>
</tr>
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<td>PM$_{2.5}$</td>
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<tr>
<td>Spain</td>
<td>PM$_{10}$</td>
<td>3</td>
<td>Pandolfi et al. (2011)</td>
</tr>
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<td></td>
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<td>Pandolfi et al. (2011)</td>
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<tr>
<td>Europe</td>
<td>PM$_{10}$</td>
<td>3-4</td>
<td>Viana et al. (2014)</td>
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<td>Europe</td>
<td>PM$_{10}$</td>
<td>2.3-2.5</td>
<td>Alastuey et al. (2016)</td>
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</tbody>
</table>

**Tracers are available, BUT:**
changing fuels result in changing tracers
In Southern Europe:

Qinhuangdao (China) (Lang et al., 2017):
Primary = 51% of shipping PM2.5 vs. Secondary = 48%; large seasonal variability

Premature deaths/year in Europe:

due to primary particles (301,000/year)
due to secondary particles (245,000/year)

More efficient for health to decrease primary PM emissions?

Andersson et al. (2009); Hammingh et al. (2012); Tian et al. (2013); Lang et al. (2017)
Comparability?

13-17% PM\(_{2.5}\) in China
Shanghai; Pearl River Delta
Zhao et al. (2013); Tao et al. (2017)

10-70% PM\(_{2.5}\) in Western USA, Seattle
Hadley (2017)

References:
- Genoa (Italy): Mazzei et al. (2008)
- Melilla (Spain): Viana et al. (2009)
- Cork (Ireland): Hellebust et al. (2010)
- Algeciras (Spain): Pandolfi et al. (2011)
- Lampedusa (Italy): Becagli et al. (2012)
- Barcelona (Spain): Amato et al. (2009)
- Netherlands, UK, Belgium, Denmark, France, Germany, Sweden, Norway, Luxembourg, Switzerland: Hammingh et al. (2012)
- UK: Hadley et al. (2016)
Contributions to gases (NO, NO$_2$, SO$_2$) > PM, N

Hotelling: contribution to SO$_2$ < NO & NO$_2$ due to low-S fuels at berth

Contribution to NO >> NO$_2$ and provoked local-scale depletion of O$_3$

Merico et al. (2016)
Mitigation strategies

Technological measures:
- low sulphur fuels
- sulphur scrubbers
- NOx mitigation measures
- liquid natural gas (LNG)
- slow steaming
- soot particle filters…

IMO (UN), MARPOL, SECAs, NECAs

EU Directive 2005/33/EC on sulphur emissions from ships

National regulations
**Directive 2005/33/EC:**
- SO$_2$ concentrations in 3 out of 4 harbours decreased (>2010)
- No decrease was observed in Tunis
- Average decrease $\text{SO}_2 = 66\%$ (daily)
- No significant changes for NOx & BC

*Schembari et al. (2012)*
Case study: ECA in the Marmara Sea

Philadelphia Strait

Marmara Sea
50,000 vessels/year

23 million inhabitants (and growing)
Environmental benefits

**PM$_{2.5}$ before ECA**
- Total PM$_{2.5}$: 5%
- Ship-sourced PM$_{2.5}$: 46%

**SO$_2$ before ECA**
- Total SO$_2$: 46%
- Ship-sourced SO$_2$: 4.6%

**PM$_{2.5}$ after ECA**
- Total PM$_{2.5}$: 1.7%

**SO$_2$ after ECA**
- Total SO$_2$: 4.6%
# Health benefits

<table>
<thead>
<tr>
<th>Health outcome</th>
<th>Scenario</th>
<th>PM\textsubscript{10}</th>
<th>PM\textsubscript{2.5}</th>
<th>SO\textsubscript{2}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hospital admissions for respiratory diseases (ICD-10 J00-J99)</td>
<td>Baseline (total burden)</td>
<td>13,000 (4,900 to 20,000)</td>
<td>18,000 (6,800 to 20,000)</td>
<td>1,200 (-830 to 3,200)</td>
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<td></td>
<td>Policy scenario (number avoided)</td>
<td>150 (57 to 230)</td>
<td>330 (125 to 370)</td>
<td>180 (108 to 460)</td>
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<td>% Change</td>
<td>-1%</td>
<td>-2%</td>
<td>-14%</td>
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<tr>
<td>Hospital admissions for circulatory system diseases (ICD-10 I00-I90)</td>
<td>Baseline (total burden)</td>
<td>4,300 (770 to 7,800)</td>
<td>6,000 (1,900 to 9,700)</td>
<td>1,700 (770 to 2,500)</td>
</tr>
<tr>
<td></td>
<td>Policy scenario (number avoided)</td>
<td>45 (8.1 to 82)</td>
<td>97 (30 to 160)</td>
<td>190 (90 to 290)</td>
</tr>
<tr>
<td></td>
<td>% Change</td>
<td>-1%</td>
<td>-2%</td>
<td>-12%</td>
</tr>
<tr>
<td>All-cause mortality (ICD-10 A00-R99)</td>
<td>Baseline (total burden)</td>
<td>120 (50 to 190)</td>
<td>670 (140 to 1,000)</td>
<td>17 (15 to 19)</td>
</tr>
<tr>
<td></td>
<td>Policy scenario (number avoided)</td>
<td>1 (0.4 to 1.6)</td>
<td>13 (2.7 to 19)</td>
<td>2 (1.7 to 2.2)</td>
</tr>
<tr>
<td></td>
<td>% Change</td>
<td>-1%</td>
<td>-2%</td>
<td>-10%</td>
</tr>
</tbody>
</table>

Viana et al. (2015)
Figure 45 Reduction in PM$_{2.5}$ mortality (premature deaths) - overall ECAMED domain
Conclusions & knowledge gaps

• What we know:
  o Nr. studies not large, but increasing
  o Contribution to PMx: 1-20% PMx, with large spatial variability

• What we don’t know (so well):
  o Is it more efficient to reduce primary or secondary emissions?
  o Impact of harbour operations & how to mitigate them

• Mitigation strategies:
  • Efficient: 50-66% SO$_2$ reduction, and 2$^{ary}$ PM

• Environmental and health benefits:
  • Effective reduction of ship-sourced SO$_2$ (46% to 5%, Istanbul)
  • Effective health benefits (12-14% decreased hospital admissions due to SO$_2$ and 10% reduced mortality due to SO$_2$, Istanbul)
  • Similar results for Mediterranean ECA
Thank you for your attention

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