Beneficis mediambientals i socioeconòmics de la creació d'un Àrea de Control d'Emissions a la Mar Mediterrània
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Impact of maritime transport emissions on coastal air quality in Europe

Mar Viana
Institute of Environmental Assessment and Water Research
mar.viana@idaea.csic.es

Outline

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:
   - Overview
   - Case study: Marmara Sea (Turkey)

3. Conclusions

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(1)
# Impact of international shipping on European air quality

Rationale

Emissions from the marine transport sector
contribute **significantly** to air pollution globally
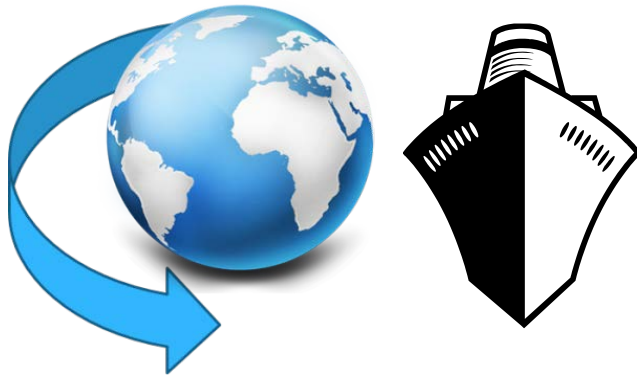
Increasing emission source:
- Globalization of manufacturing processes
- Increase of global-scale trade
- Relatively, large efforts to reduce other sources (industrial, power generation, etc.)
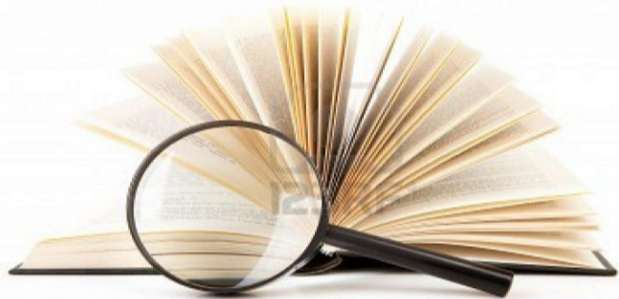- More future growth expected

Human health

Nose
Pharynx
Larynx
Cricoid cartilage
Trachea
Lungs
Bronchi
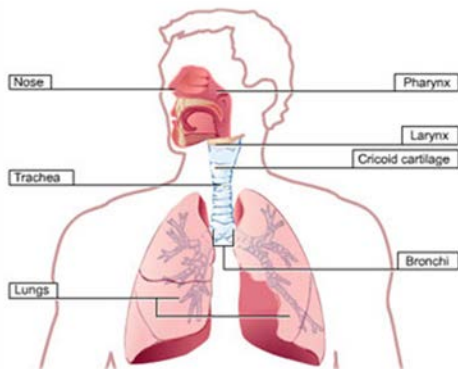
Climate

Ecosystems

How much of a problem?

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

Literature Review

Quantitative

Chemical tracers

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)

Where?	PMx	V/Ni	Reference
Italy	PM_{10}	3.2±0.8	Mazzei et al. (2008)
	$PM_{2.5}$	3.2±0.8	Mazzei et al. (2008)
	PM_{10}	3.2±0.8	Mazzei et al. (2008)
Ship engine		2.3-4.5	Agrawal et al. (2008)
Spain	$PM_{2.5}$	4-5	Viana et al. (2009)
	PM_{10}	4-5	Viana et al. (2009)
Spain	PM_{10}	3	Pandolfi et al. (2011)
	$PM_{2.5}$	3	Pandolfi et al. (2011)
Europe	PM_{10}	3-4	Viana et al. (2014)
Europe	$PM_{2.5}$	3-4	Viana et al. (2014)
Europe	PM_{10}	2.3-2.5	Alastuey et al. (2016)

Where?	PMx	Tracer	Value	Reference
Spain	PM_{10}	V/EC	<2	Viana et al. (2009)
	$PM_{2.5}$	V/EC	<2	Viana et al. (2009)
Spain	PM_{10}	La/Ce	0.6-0.8	Pandolfi et al. (2011)
	$PM_{2.5}$	La/Ce	0.6-0.8	Pandolfi et al. (2011)
Italy	PM_{10}	soluble V	80%	Becagli et al. (2012)
	PM_{10}	soluble V	>6 ng/m^3	Becagli et al. (2012)
	PM_{10}	soluble Ni	80%	Becagli et al. (2012)
	PM_{10}	non-ss SO_4^{2-}/V	200-400	Becagli et al. (2012)

Tracers are available, BUT:
changing fuels result in changing tracers

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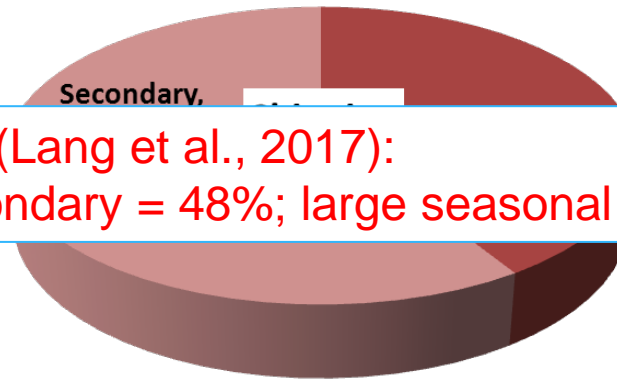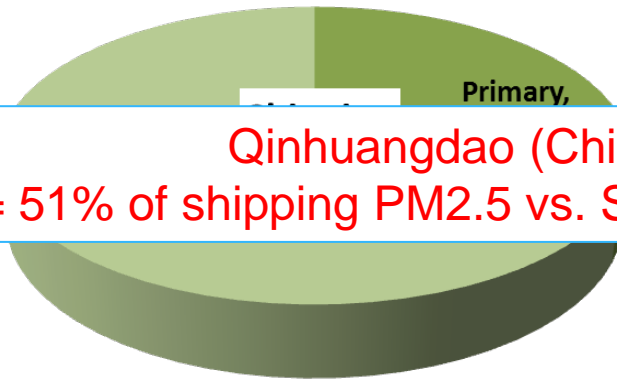
Other tracers

Shipping emissions correlate with:
- NO, NOx, SO_2 and VOCs
- Particle number concentration (N): nucleation episodes (SO_2) (Reche et al., 2011)
- Particle size distribution (80-500 nm; e,.g., Masiol et al., 2016)

Reche et al. (2011)
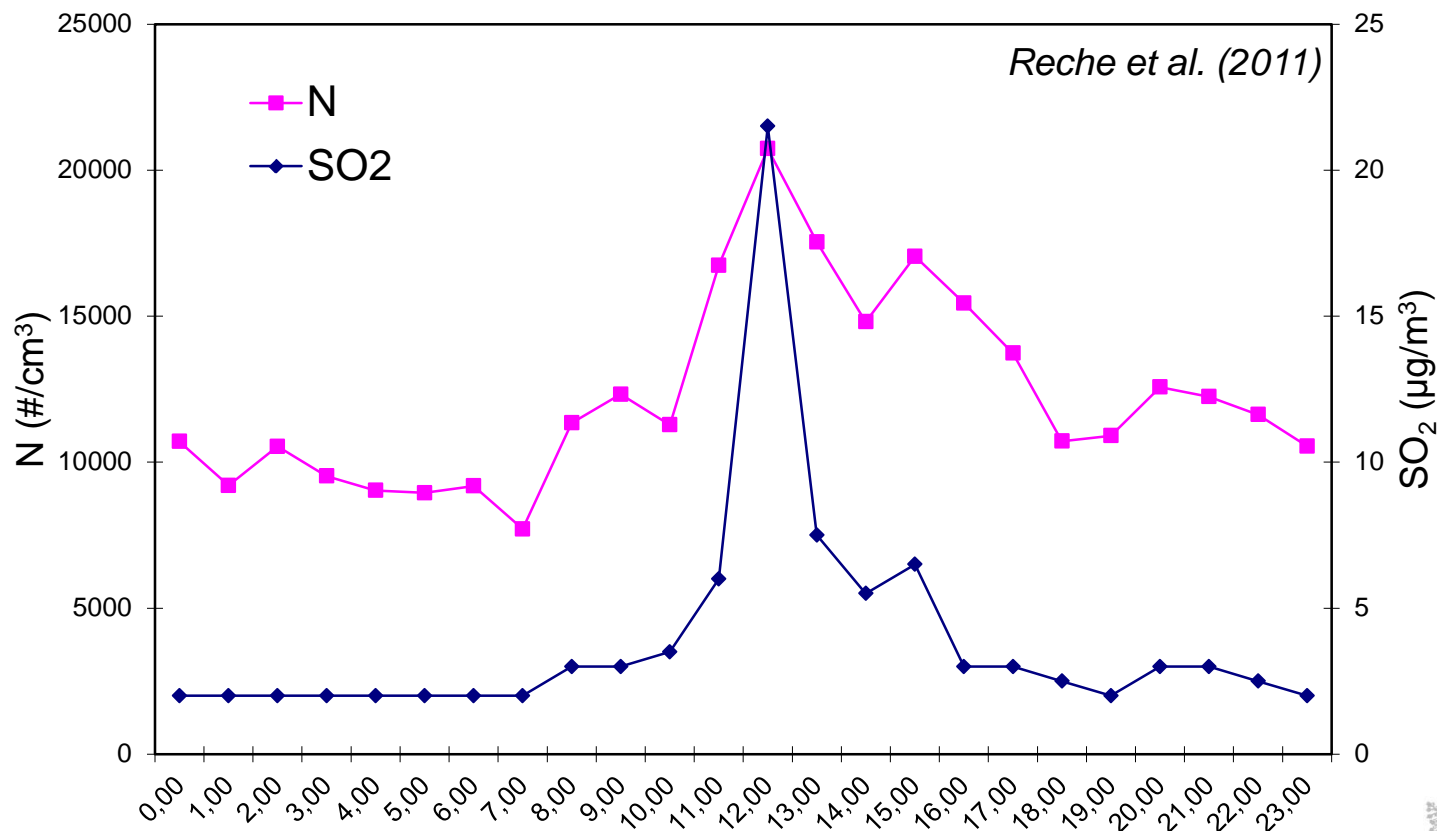
Primary *vs.* Secondary particles

In Southern-Europe:

Primary,

Secondary,

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

Viana et al. (2014)

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)

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)
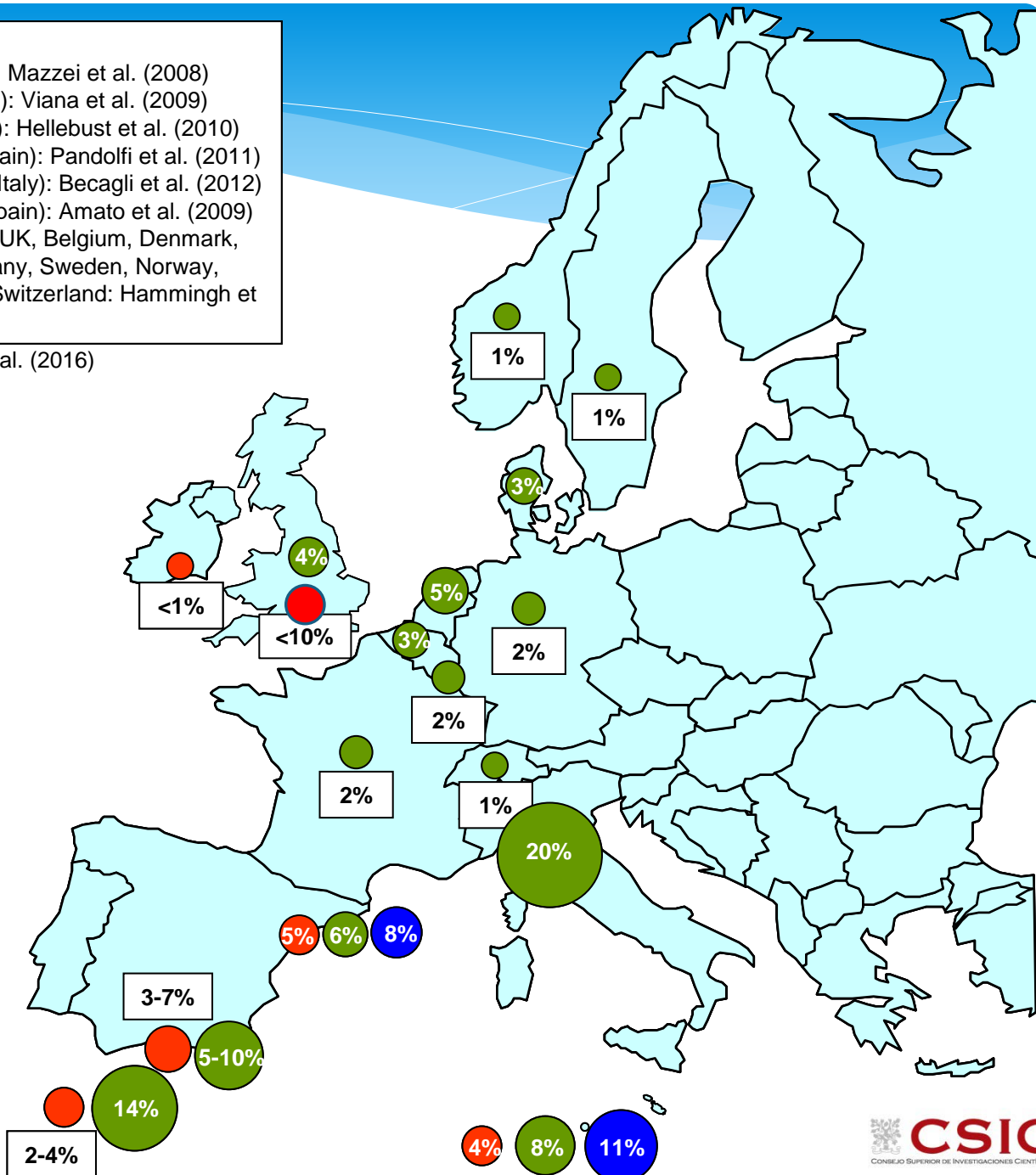- UK: Hadley et al. (2016)

PM$_{10}$

PM$_{2.5}$

PM$_1$

1-7% PM$_{10}$
1-20% PM$_{2.5}$
8-11% PM$_1$

Comparability?

13-17% PM$_{2.5}$ in China
Shanghai; Pearl River Delta
Zhao et al. (2013); Tao et al. (2017)
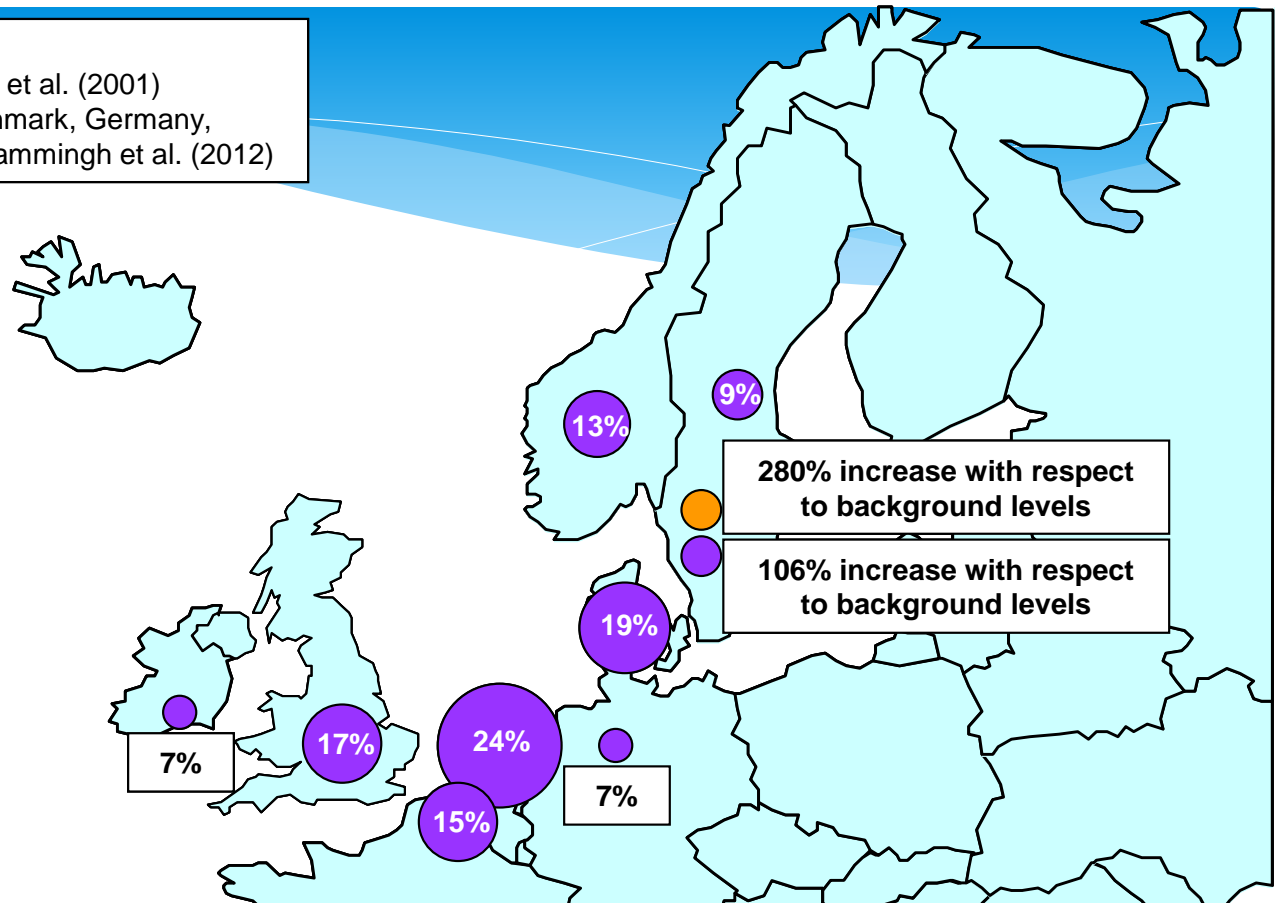
10-70% PM2.5 in Western USA, Seattle
Hadley (2017)

1%

1%

3%

4%

5%

<1%

<10%

3%

2%

2%

2%

1%

20%

5%   6%   8%

3-7%

5-10%

14%

2-4%

4%   8%   11%

References:
- Sweden: Isakson et al. (2001)
- Netherlands, Denmark, Germany, France, Ireland: Hammingh et al. (2012)

NO_2

SO_2

7-24% NO_2

Comparability?

13%

9%

280% increase with respect to background levels

106% increase with respect to background levels

19%

17%

24%

7%

15%

7%

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)

Impact of harbour operations

➢ Knowledge gap! Loading and unloading of vessels, fuelling, etc.

➢ Studies agree on the **relevance of this impact**:

- S-Europe: road dust = 26% PM_{10} in harbours; harbours = **9-12%** urban PM_{10} *(Pérez et al., 2016)*

- Los Angeles harbour: vehicular sources + road dust = **54%** of PMx, *vs*. shipping < 5% of $PM_{2.5}$ *(Minguillon et al., 2008)*

- Hotelling, manoeuvring *(Merico et al., 2016)*

(2)
Mitigation strategies

Mitigation strategies

IMO (UN), MARPOL, SECAs, NECAs

National regulations

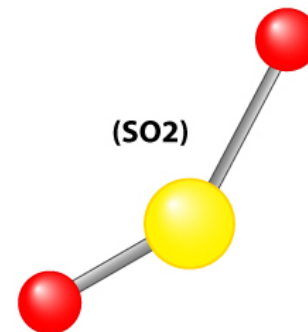**EU Directive 2005/33/EC on sulphur emissions from ships**

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

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Mitigation strategies

Velders et al. (2011)

(SO2)
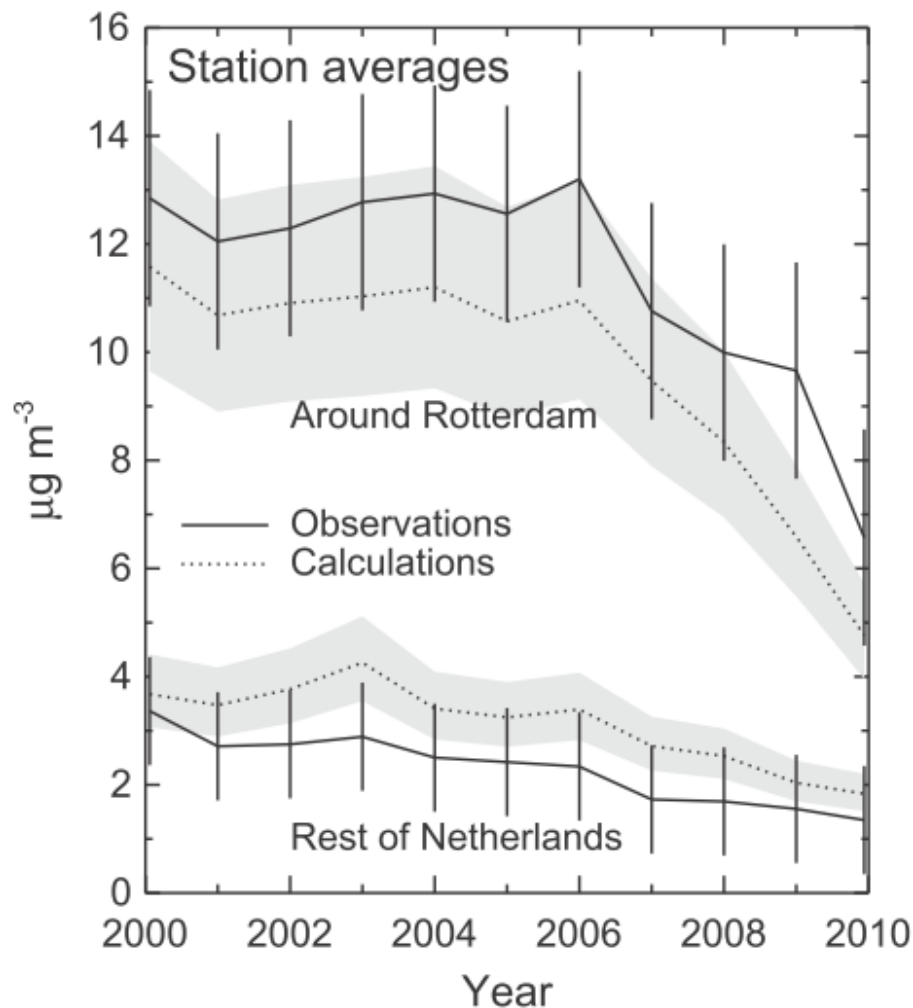
**Year 2010   <<   Years 2000-2006
(50%)**

SO$_2$ emissions reduction:
- >2006: use of low-S fuel due to the SECA regulations in the North Sea
- >2007: MARPOL convention
- >2010: EU directive 2005/33/EC

Mitigation strategies

Directive 2005/33/EC:

- SO_2 concentrations in 3 out of 4 harbours decreased (>2010)
- No decrease was observed in Tunis
- Average decrease SO_2 = 66% (daily)
- No significant changes for NOx & BC

Schembari et al. (2012)
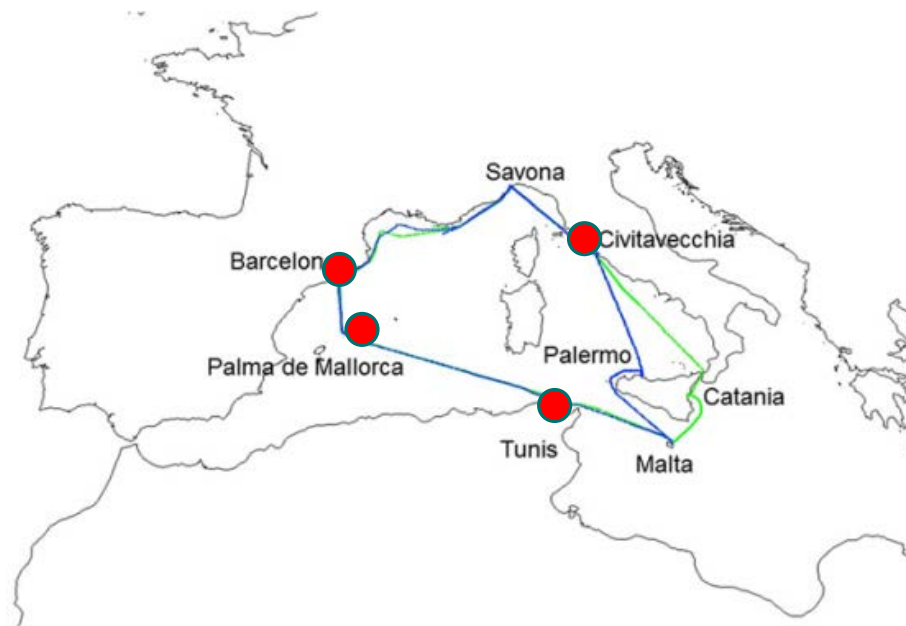
Sulphur reduction policy in the Baltic Sea SECA (2015):

- for the Baltic Sea only, the latest sulphur regulation is not cost-effective
- Expected annual cost = 465 M€
- Monetized benefit = 105 M€
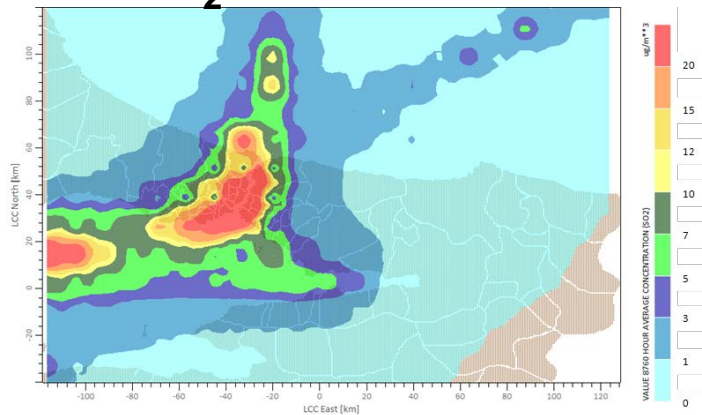
Annturi et al. (2016)

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Case study: ECA in the Marmara Sea

23 million inhabitants
(and growing)

Istanbul Strait

Marmara Sea

50.000 vessels/year

Canakkale Strait

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Challenges using BenMAP

Pollutant data: modelled SO_2, PM_{10}, $PM_{2.5}$ with CALPUFF

SO_2 before ECA

SO_2 after ECA
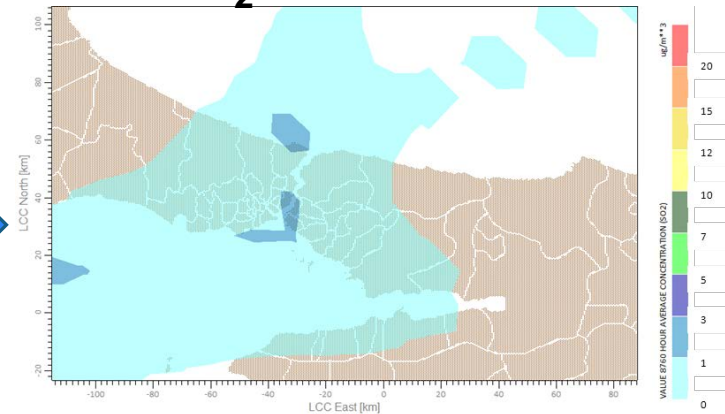
PM_{10} before ECA
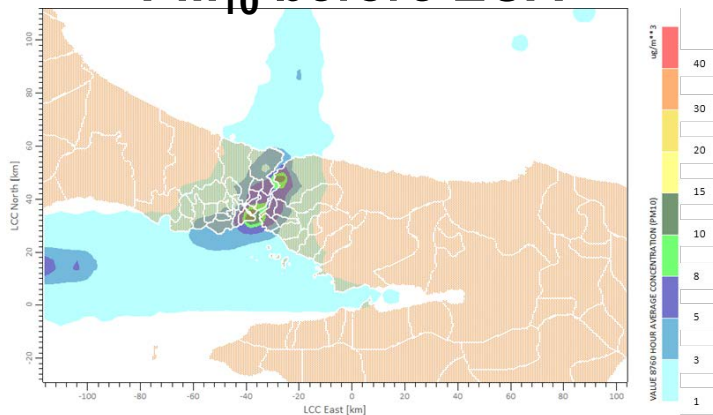
PM_{10} after ECA
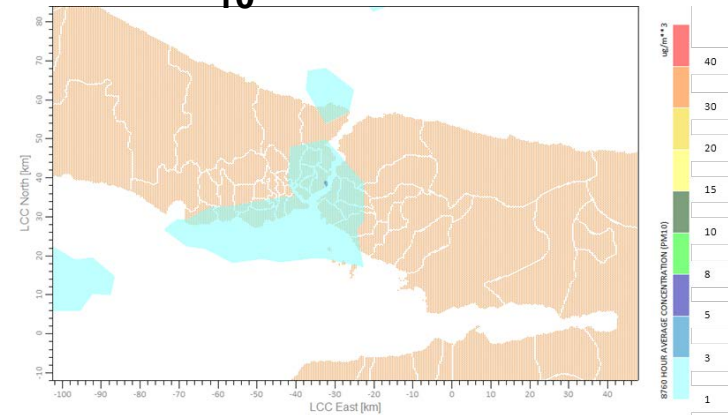
Highly spatially-resolved data

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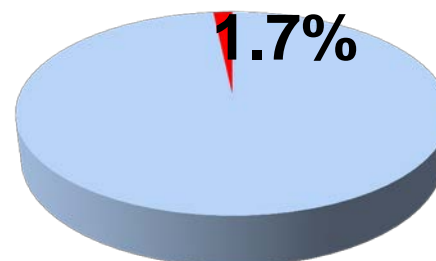
Results: Environmental benefits

Istanbul: Air quality improvement

$PM_{2.5}$ before ECA — 5%
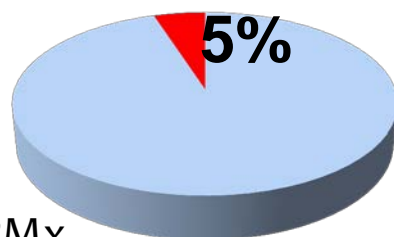
$PM_{2.5}$ after ECA — 1.7%

- Total PMx
- Ship-sourced PMx

SO_2 before ECA — 46%
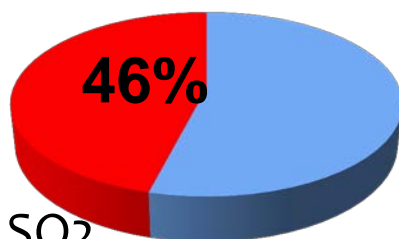
SO_2 after ECA — 4.6%
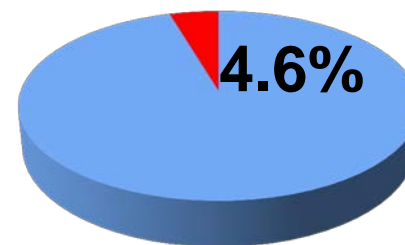
- Total SO2
- Ship-sourced SO2

Results: Health benefits

Health outcome	Scenario	East domain (90% confidence intervals)		
		PM$_{10}$	**PM$_{2.5}$**	**SO$_2$**
Hospital admissions for respiratory diseases (ICD-10 J00-J99)	Baseline (total burden)	13,000 (4,900 to 20,000)	18,000 (6,800 to 20,000)	1,200 (-830 to 3,200)
	Policy scenario (number avoided)	150 (57 to 230)	330 (125 to 370)	180 (-108 to 460)
	% Change	-1%	-2%	-14%
Hospital admissions for circulatory system diseases (ICD-10 I00-I90)	Baseline (total burden)	4,300 (770 to 7,800)	6,000 (1,900 to 9,700)	1,700 (770 to 2,500)
	Policy scenario (number avoided)	45 (8.1 to 82)	97 (30 to 160)	190 (90 to 290)
	% Change	-1%	-2%	-12%
All-cause mortality (ICD-10 A00-R99)	Baseline (total burden)	120 (50 to 190)	670 (140 to 1,000)	17 (15 to 19)
	Policy scenario (number avoided)	1 (0.4 to 1.6)	13 (2.7 to 19)	2 (1.7 to 2.2)
	% Change	-1%	-2%	-10%

Viana et al. (2015)

(3)
Conclusions

Conclusions & knowledge gaps (1)

- What we know:
  - Nr. studies not large, but increasing
  - Impact on PMx, NOx, SO_2, and new particle formation (N)
  - Contribution to PMx: 1-20% PMx, with large spatial variability

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

Conclusions & knowledge gaps (2)

- Mitigation strategies:
  - Efficient: 50-66% SO_2 reduction, and 2^{ary} PM
  - Cost effective?

- Case study: potential improvements in Istanbul
  - Environmental benefits: 46% to 5% reduction of ship-sourced SO_2
    Health benefits: 12-14% decreased hospital admissions due to SO_2; 10% reduced mortality due to SO_2
  - **Overall, beneficial policy from an environmental and health perspective**

- Limitations:
  - Uncertainties in emissions modelling & AQ measurements
  - Need for regionally-specific health impact functions

Thank you for your attention

mar.viana@idaea.csic.es