SHIPPING AND THE ENVIRONMENT
From Regional to Global Perspectives
Gothenburg, October 24th, 2017

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

CSIC
Consejo Superior de Investigaciones Científicas

Framework

EEA

US EPA

EU - Turkey

Outline

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

2. Mitigation strategies:
   - Overview
   - Case study: environmental and health benefits of designating the Marmara Sea (Turkey) as an ECA

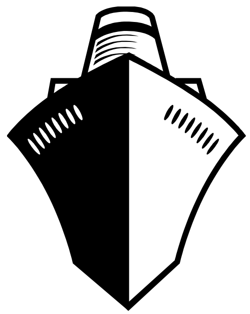
3. Conclusions

CSIC
Consejo Superior de Investigaciones Científicas

(1)
Impact of international shipping on European air quality

Rationale

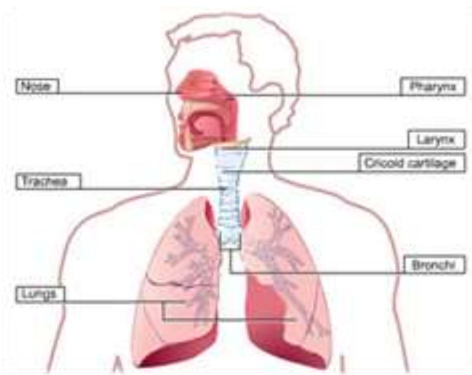
Emissions from the marine transport sector contribute **significantly** to air pollution globally



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

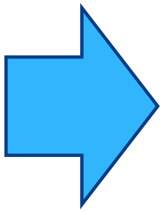


Climate

Ecosystems

How much of a problem?

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



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)

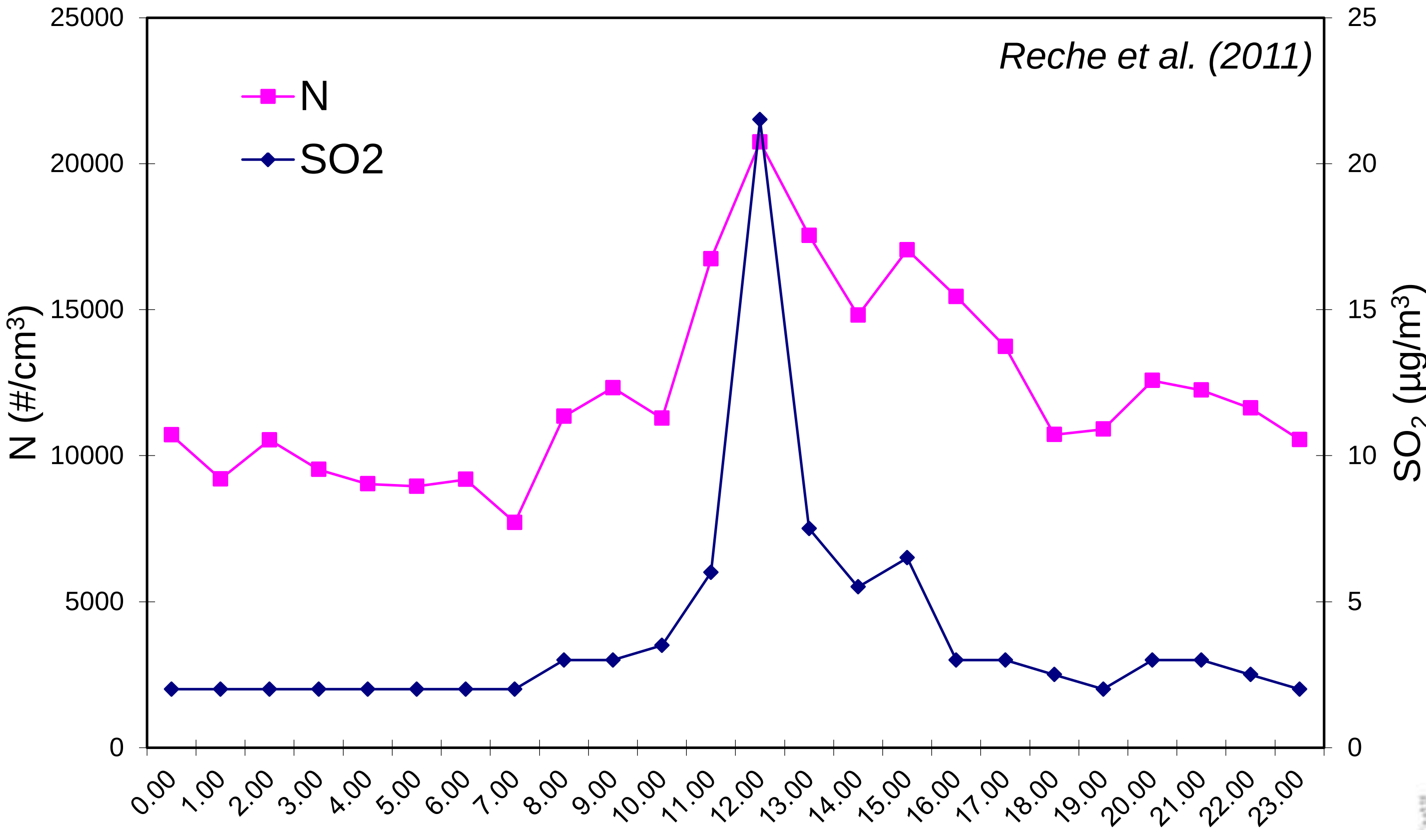
Tracers may be used in source apportionment models, BUT:
changing fuels result in changing tracers

CSIC

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)

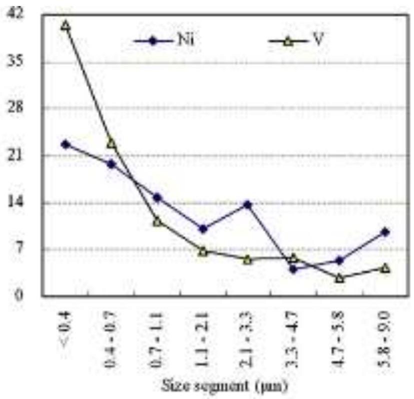


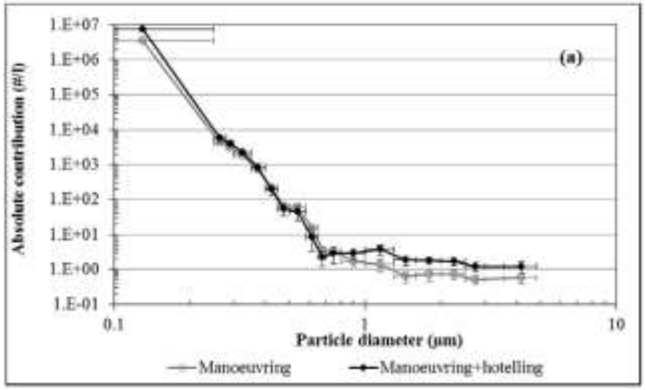
Particle size distribution

- Knowledge gap!
  - Difficult to discriminate from background
  - Depends on measurement location (distance)

- Direct plume: bimodal N size distribution (40 nm, 70 nm) *(Isakson et al., 2001)*
- In ambient air:
  - Stronger contribution to fine than coarse aerosols *(Viana et al., 2009)*
  - Primary particles predominantly submicron (<1 µm) *(Petzold et al., 2008; Healy et al., 2009);* modes at <250nm & 350nm *(Merico et al., 2016)*
  - Impact on N, thus ultrafine particles (UFPs, <0.1 µm) *(Saxe and Larsen,*
  - *2004; Reche et al., 2011)*
  - **Particle number or toxicity better metrics than mass?**

Zhao et al. (2013)

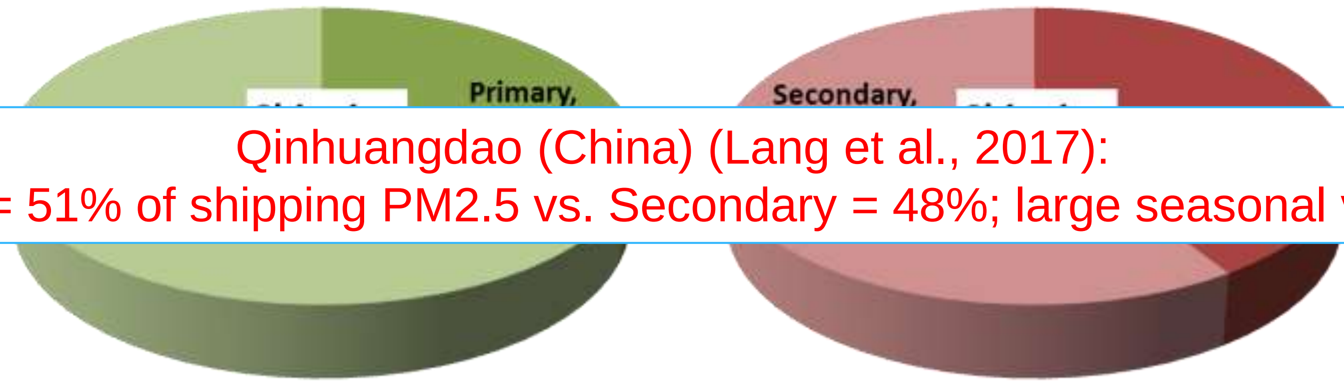




Merico et al. (2016)

Primary *vs.* Secondary particles

In Southern-Europe:



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)

Impact on ambient PMx

Source apportionment tools:

- dispersion models
- receptor models
- chemical tracer methods

Limitations:

- mixed with other combustion sources (common tracers)
- challenge of unique discrimination
- lack of comparability

Airborne particles				
Reference	Source	Contribution	Size fraction / PM component	Location
Kim & Hopke (2008)	Oil combustion	4-6%	$PM_{2.5}$	US
Mazzei et al. (2008)	Oil combustion	20%	PM_1	IT
Minguillón et al. (2008)	Shipping	<5%	OC	US
		<5%	$PM_{2.5}$	US
Viana et al. (2008)	Oil combustion	10-30%	PM_{10} and $PM_{2.5}$	EU
Amato et al. (2009)	Oil combustion	5%	PM_{10}	ES
		6%	$PM_{2.5}$	ES
		8%	PM_1	ES
Viana et al. (2009)	Shipping	2-4%	PM_{10}	ES
		14%	$PM_{2.5}$	ES
Hellebust et al. (2010)	Shipping	<1%	$PM_{2.5-10}$ and $PM_{0.1-2.5}$	IE
Pandolfi et al. (2011)	Shipping	3-7%	PM_{10}	ES
		5-10%	$PM_{2.5}$	ES
Becagli et al. (2012)	Shipping	30%	nss SO42-	IT
		3.9%	PM_{10}	IT
		8%	$PM_{2.5}$	IT
		11%	PM_1	IT
Hammingh et al. (2012)	Shipping	1-5%	$PM_{2.5}$	North Sea
		1-5%	$PM_{2.5}$	NL, UK, Be, DK, Fr, DE, LU, Norway, SE, Switz.
Keuken et al. (2014)	Shipping	0.5 $\mu g/m^3$	$PM_{2.5}$	NL
Pérez et al. (2016)	Harbour	9-12%	PM_{10}	ES
Pérez et al. (2016)	Harbour	11-15%	$PM_{2.5}$	ES

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)

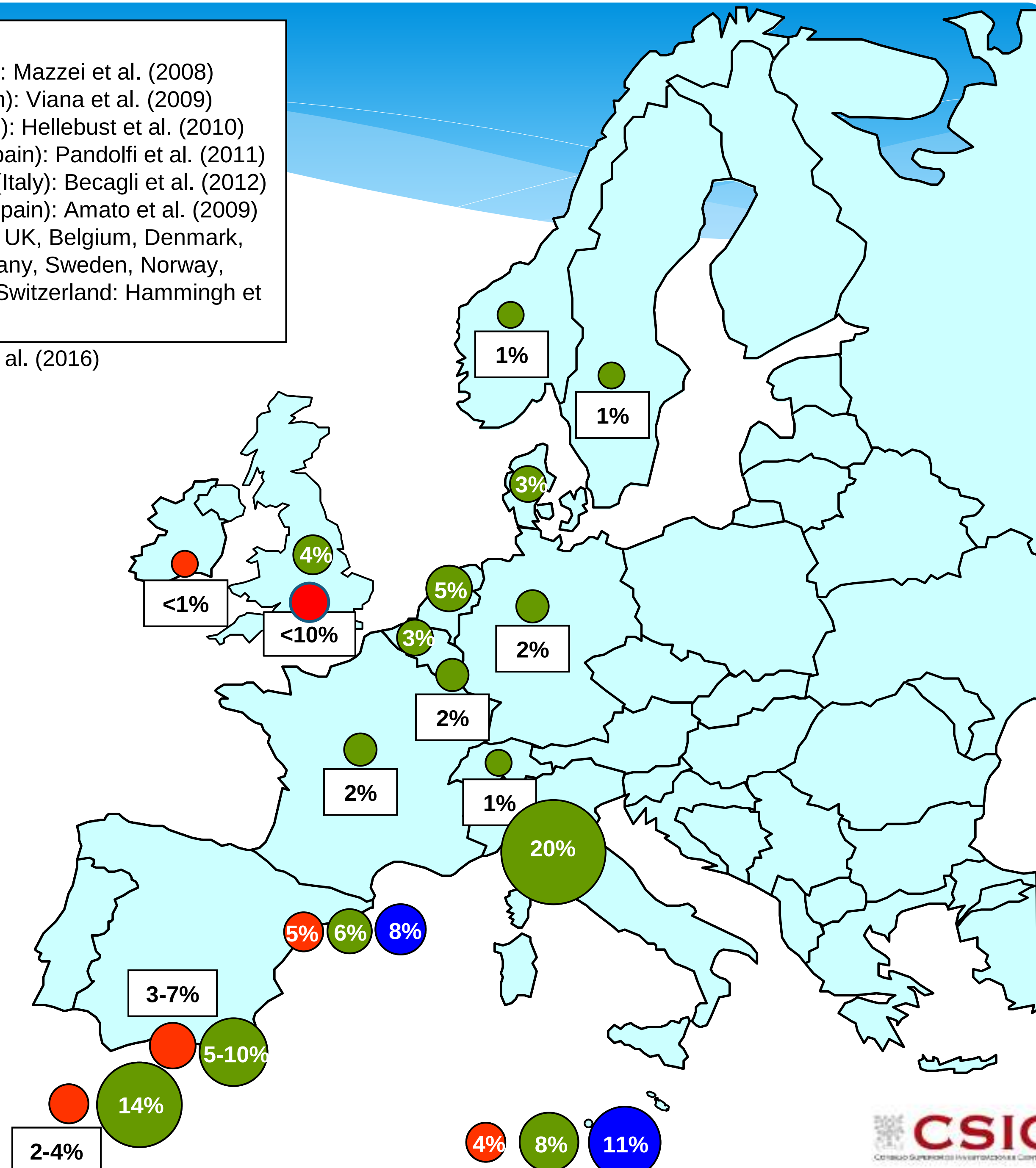
1-7% PM_{10}
1-20% $PM_{2.5}$
8-11% PM_1

Comparability?

PM_{10}

$PM_{2.5}$

PM_1



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)

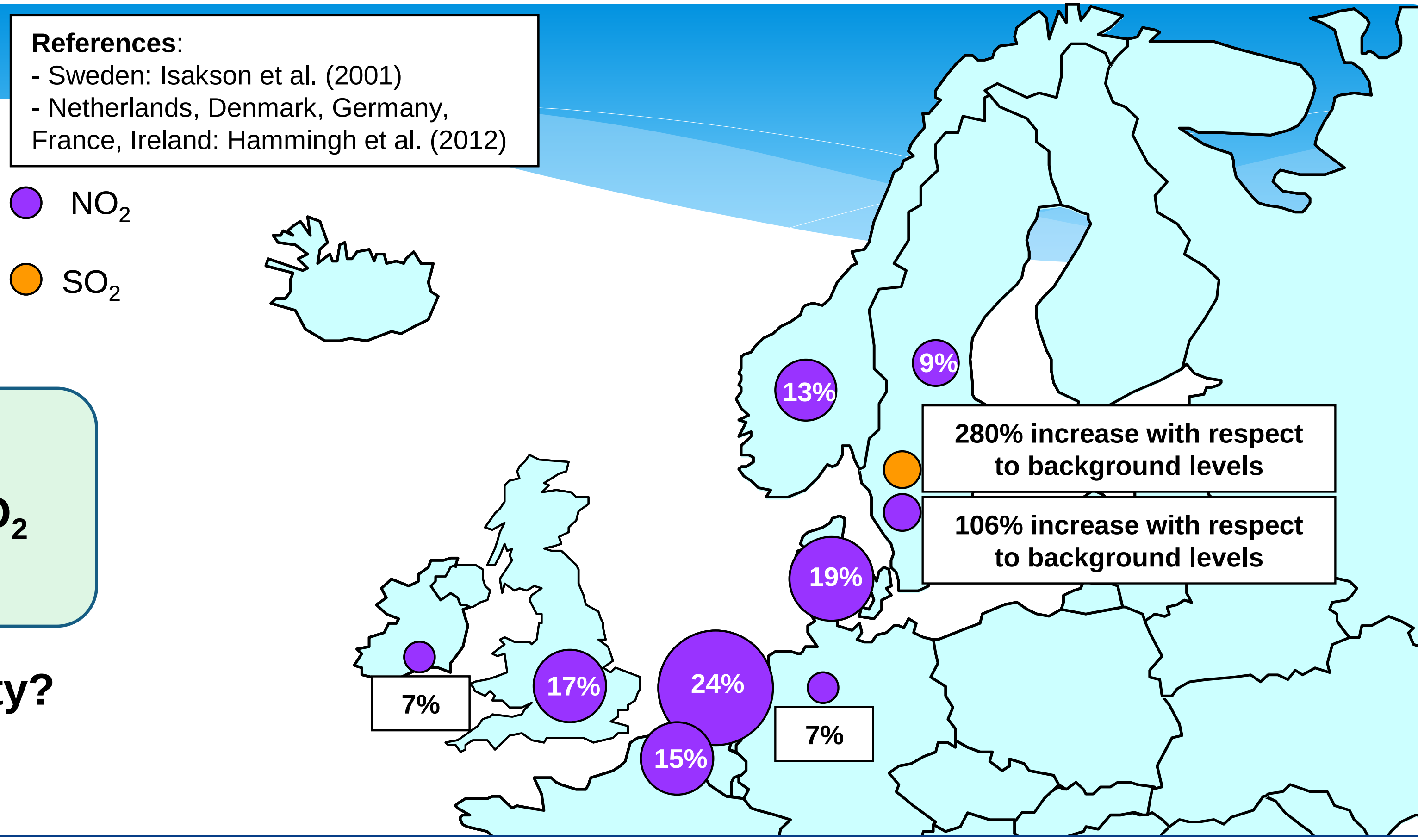
CSIC

Impact on gaseous pollutants

- Fewer number of studies compared to PMx
- Broader spatial coverage across EU (dispersion modelling tools)

Gaseous pollutants			
Reference	**Shipping contribution**	**Species**	**Location**
Isakson et al. (2001)	106%*	NO_2	Gothenburg (SE)
	281%*	SO_2	Gothenburg (SE)
Keuken et al. (2005)	5-7 ppb	NO_2	Rotterdam (NL)
Hammingh et al. (2012)	7-24%	NO_2	North Sea coastal countries
	24%	NO_2	The Netherlands
	19%	NO_2	Denmark
	17%	NO_2	UK
	15%	NO_2	Belgium
	13%	NO_2	Norway
	9%	NO_2	Sweden
	8%	NO_2	France
	7%	NO_2	Germany
	7%	NO_2	Ireland

CSIC



7-24% NO_2

Comparability?

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

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

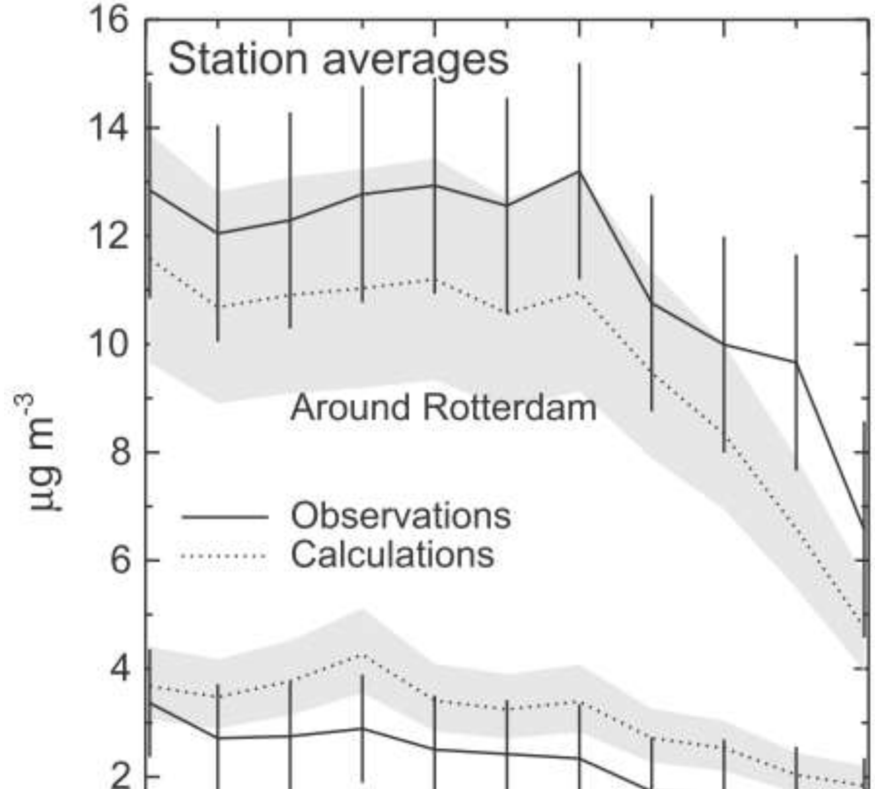
National regulations

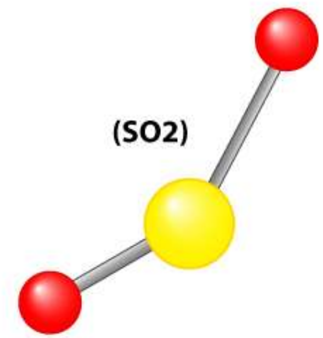
Technological measures:

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

CSIC

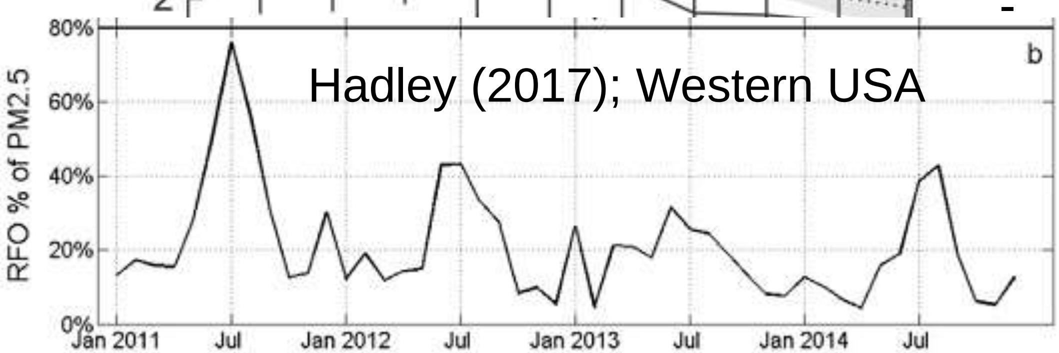
Mitigation strategies





Year 2010 << Years 2000-2006

(50%)

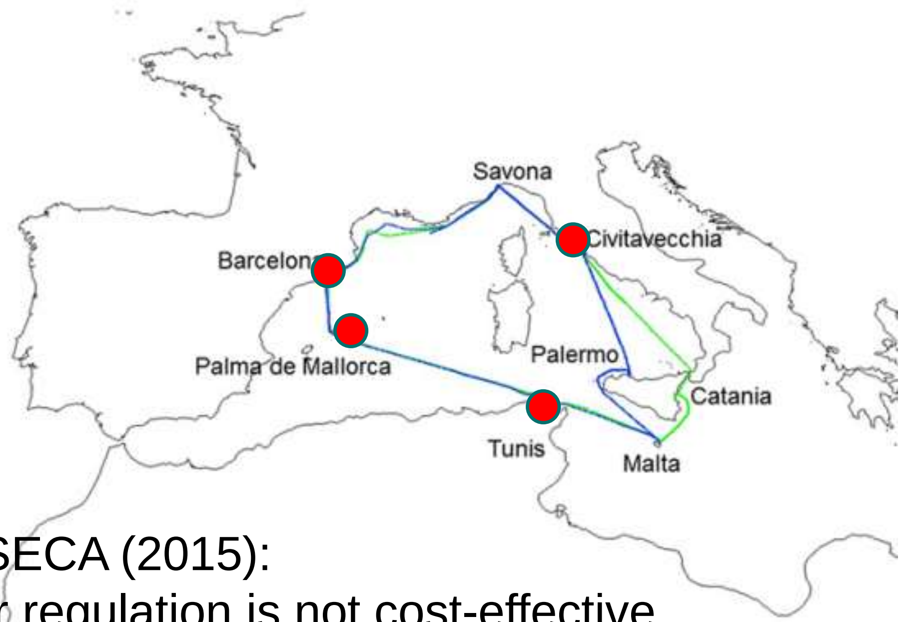


Hadley (2017); Western USA

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)

“Alternative fuel’, “Ship design” or “Operation”:
Highest reductions = “Operation”, with GHG emissions 10% lower than BAU

Winnes et al. (2015)

CSIC

Case study: ECA in the Marmara Sea

Rationale

The Turkish government aims to apply to International Maritime Organization (IMO) for the **Marmara Sea and the Turkish Straits** to be declared an **Emission Control Area (ECA) for SOx**

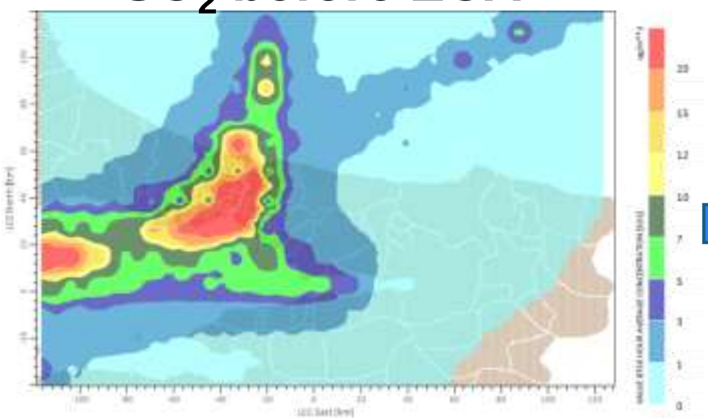
Health benefits modelling:
US-EPA BenMAP CE

To support the application to IMO**:**
quantify the environmental and health benefits
which would derive from designating the Marmara Sea and Turkish Straits as a sulphur ECA by the year 2020.

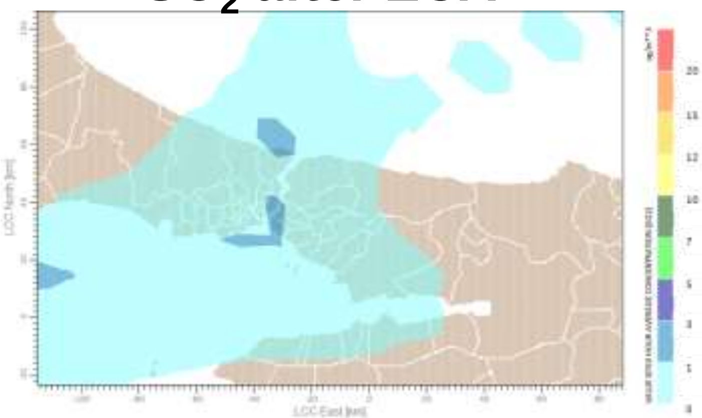
Challenges using BenMAP

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

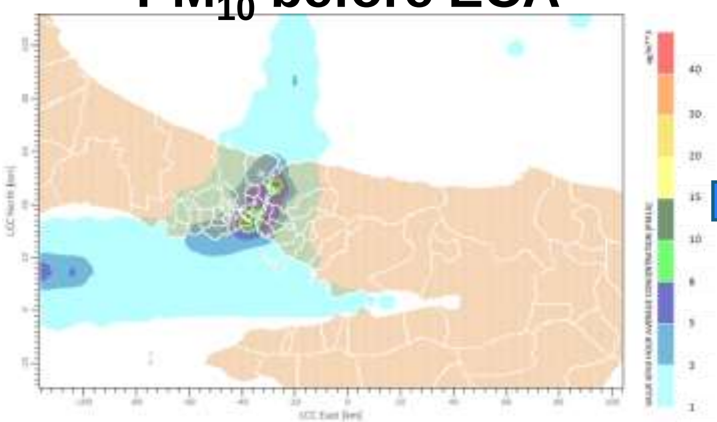
SO_2 before ECA



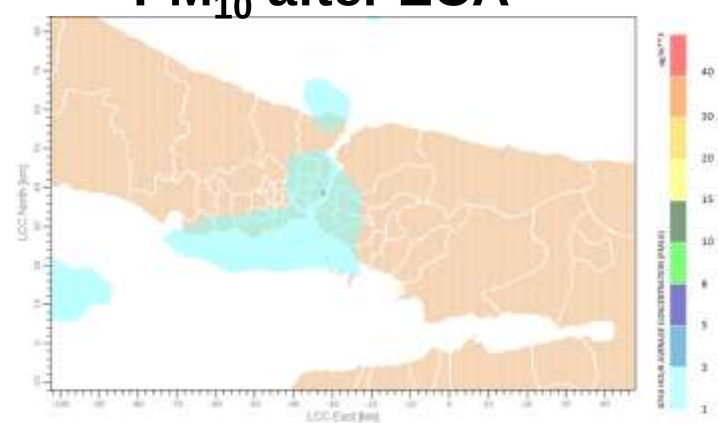
SO_2 after ECA



PM_{10} before ECA



PM_{10} after ECA

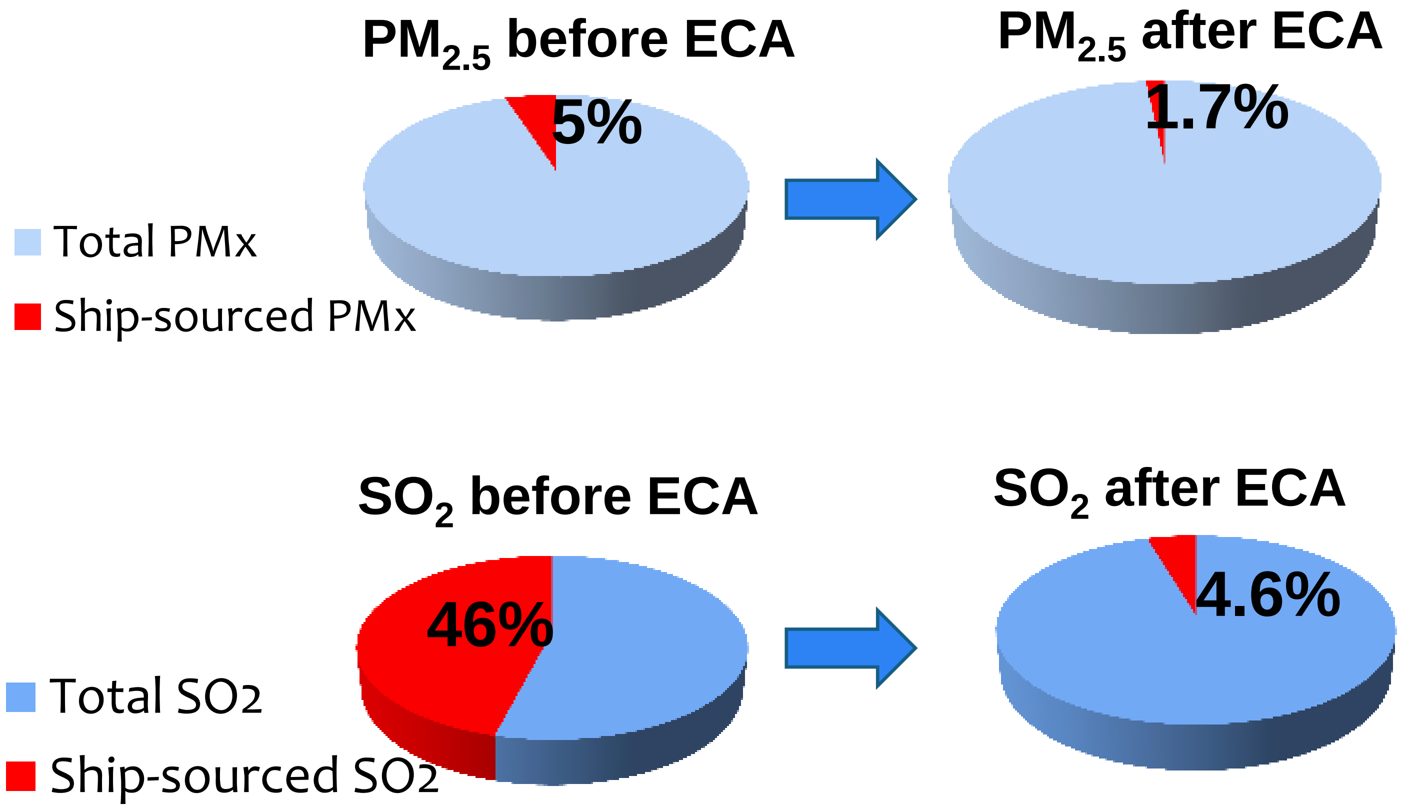


Highly spatially-resolved data

CSIC

Results: Environmental benefits

Istanbul: Air quality improvement



Results: Health benefits

		East domain (90% confidence intervals)		
Health outcome	Scenario	**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:
  - Number of studies on the impact of shipping emissions on air quality is not large, but increasing
  - Impact on PMx, NOx, SO_2, and new particle formation (N)
  - Ultrafine particles and toxicity, better tracers than mass (?)
  - Tracers are available: most commonly, V/Ni =3-5±1 in PM_{10} and $PM_{2.5}$
  - Contribution to PMx: 1-20% PMx, with large spatial variability

- What we don't know (so well):
  - Particle size distribution
  - Ratio primary to secondary particles? More efficient to reduce primary emissions (BC, V, Ni…)?
  - Discriminating sources with common tracers
  - Impact of harbour operations & how to mitigate them

CSIC

Conclusions & knowledge gaps (2)

- Mitigation strategies are efficient: 50-66% SO_2 reduction, and 2^{ary} PM
- Cost effectiveness?

- Case study: potential improvements in Istanbul
  - Environmental benefits: 5% to 2% reduction of ship-sourced PMx; 46% to 5% reduction of ship-sourced SO_2 (annual means)
  - Health benefits: 12-14% decreased hospital admissions due to SO_2; 10% reduced mortality due to SO_2; 1-2% decreased hospital admissions due to $PM_{2.5.}$
  - Overall, beneficial policy from an environmental and health perspective

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

CSIC

Thank you for your attention

mar.viana@idaea.csic.es