



## Policy frameworks and science for air quality

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**IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System**

(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-  
Mission 4 "Education and Research" - Component 2: "From research to business" - Investment  
3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures"



# Outline

The role of science in shaping air quality policies:

## 1) A historical perspective and recent developments

 **Historical evolution** of air pollution science and policies

 **Emergence** of international and EU frameworks

 **Scientific input into recent EU air quality policies and legislative updates**

## 2) Modern scientific tools for policy support



 What do you believe was the first instance where air pollution shaped a public action or policy?





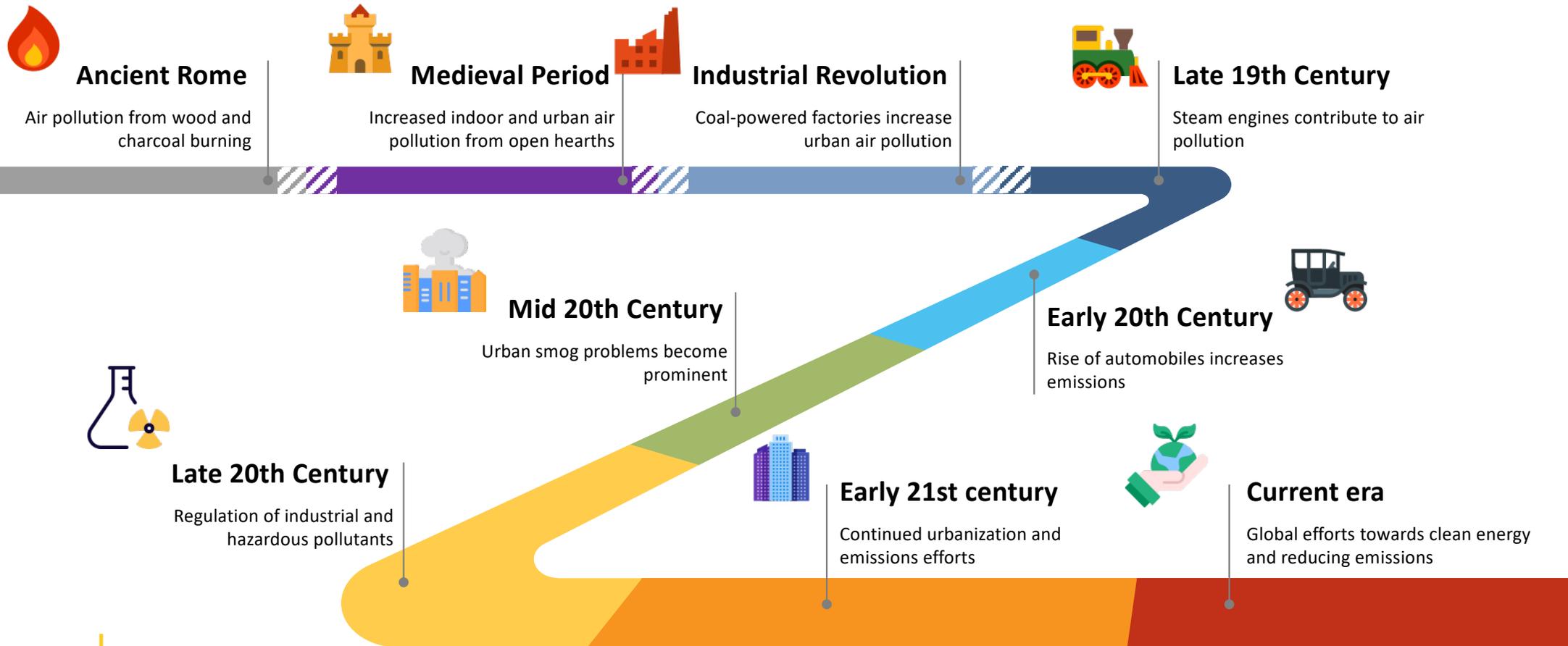
Getty Images  
Jeff J Mitchel

*... this goodly frame, the earth, seems to me a sterile promontory, this most excellent canopy, the air, look you, this brave o'erhanging firmament, this majestic roof fretted with golden fire, why, it appears no other thing to me than a foul and pestilent congregation of vapours.*

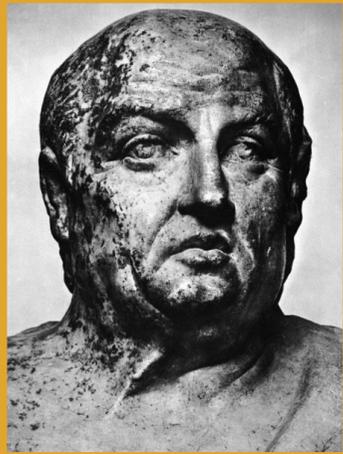
William Shakespeare (1564-1616), Hamlet, Act II, Scene II

# Knowledge and policy development

*a short history*



Buildings erected between 753 B.C. and the reign of Augustus 29 B.C., shown in green thus:—  
 Buildings erected after 29 B.C., in black thus:—  
 Regions of Servius are marked thus:—  
 Thirteen Regions of Augustus thus:—



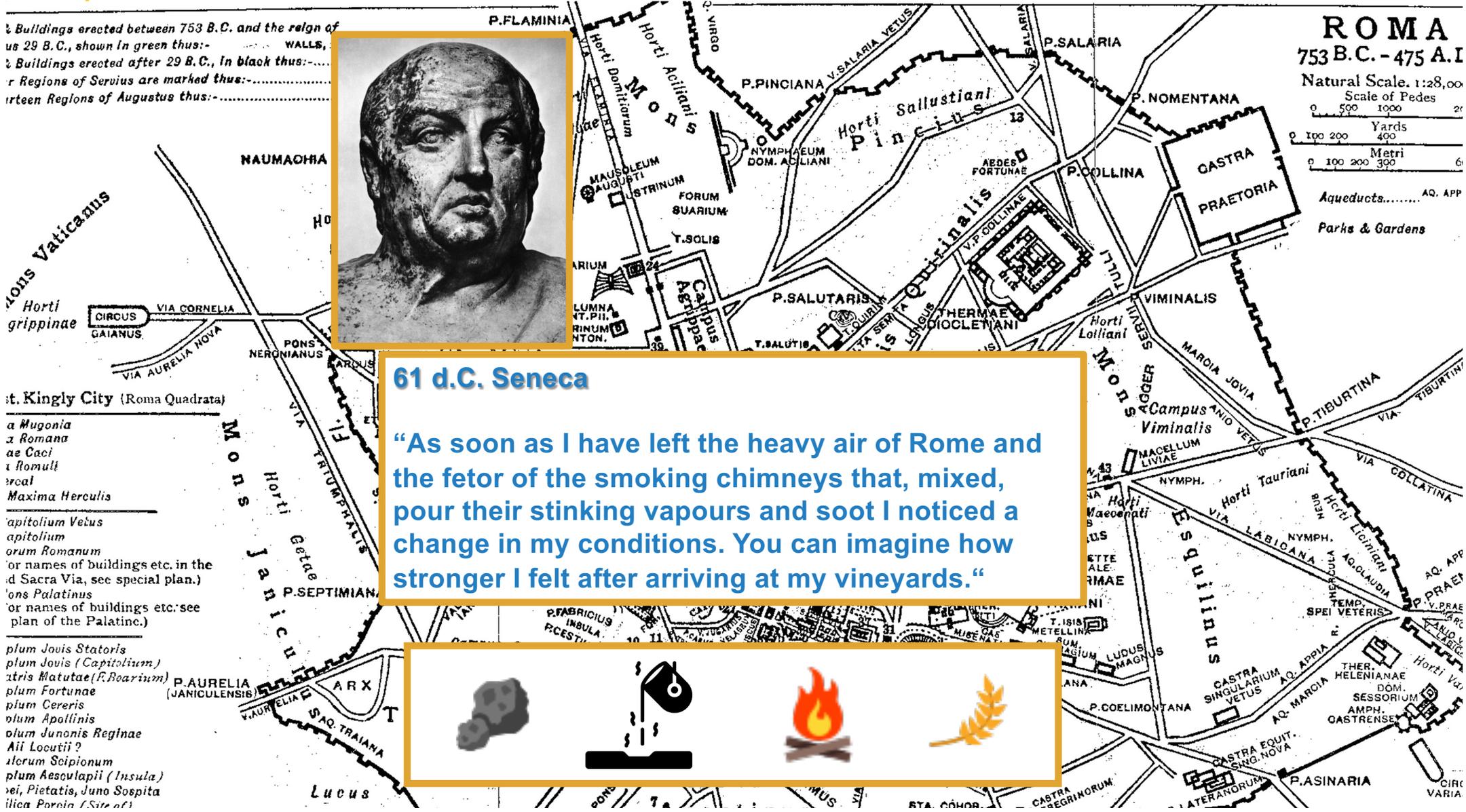
**61 d.C. Seneca**

“As soon as I have left the heavy air of Rome and the fetor of the smoking chimneys that, mixed, pour their stinking vapours and soot I noticed a change in my conditions. You can imagine how stronger I felt after arriving at my vineyards.”

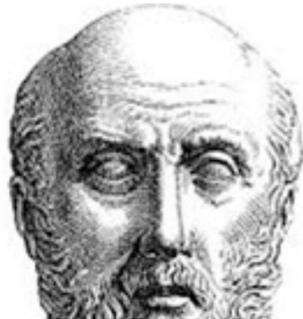


**ROMA**  
 753 B.C. - 475 A.D.  
 Natural Scale. 1:28,000  
 Scale of Pedes  
 0 500 1000 2000  
 Scale of Yards  
 0 100 200 400  
 Scale of Metri  
 0 100 200 300 600  
 Aqueducts..... AQ. APP  
 Parks & Gardens

- Kingly City (Roma Quadrata)
- Mugonia
- Romana
- Caeli
- Romuli
- Maxima Herculis
- Capitolium Velus
- Capitolium
- Forum Romanum
- Forum names of buildings etc. in the old Sacra Via, see special plan.)
- Forum Palatinum
- Forum names of buildings etc: see plan of the Palatine.)
- Forum Iovis Statoris
- Forum Iovis (Capitolium)
- Forum Matutae (F. Boarium)
- Forum Fortunae
- Forum Cereris
- Forum Apollinis
- Forum Junonis Reginae
- Forum Aii Locutii?
- Forum Scipionum
- Forum Aesculapii (Insula)
- Forum Pietatis, Juno Sospita
- Forum Ilicia Porcia (Site of)



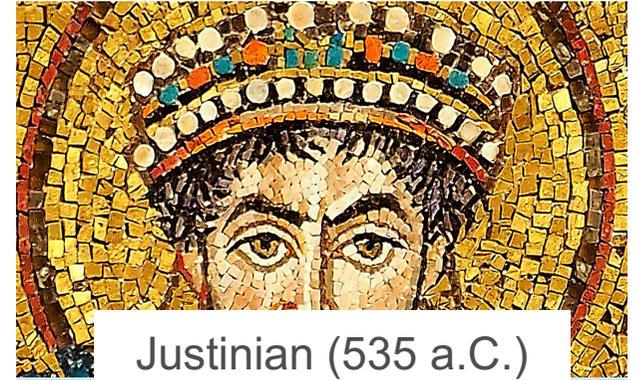
## Effects and first policies



Corpus Ippocratico  
(400 b.C.) Air, Water,  
Sites: underlines the  
importance of good  
air quality



Jurist Aristo (I century  
a.C.), declare that “a  
cheese shop should  
not emit smoke into  
the upper floor”



Justinian (535 a.C.)  
“For the law of nature  
the following things  
are common goods  
for mankind: air,  
water and sea”

# England: first actions and research!

(XIII-XV century)

1285

In London a commission to investigate the issue of bad air quality due to the use of coal is established

1307-1327

Edward I: enacts a royal decree to **prohibit the use of coal** due to its negative effects on citizens and the damage to human health

1377-1399

Edward II: a man is **tortured** for having polluted air with the stinking smell of coal

1413-1422

Riccardo III, Enrico V: first kind of **taxation** to reduce the use of coal, committee to investigate coal flows in the city of London



Angus Stevenson

# The dawn of knowledge...

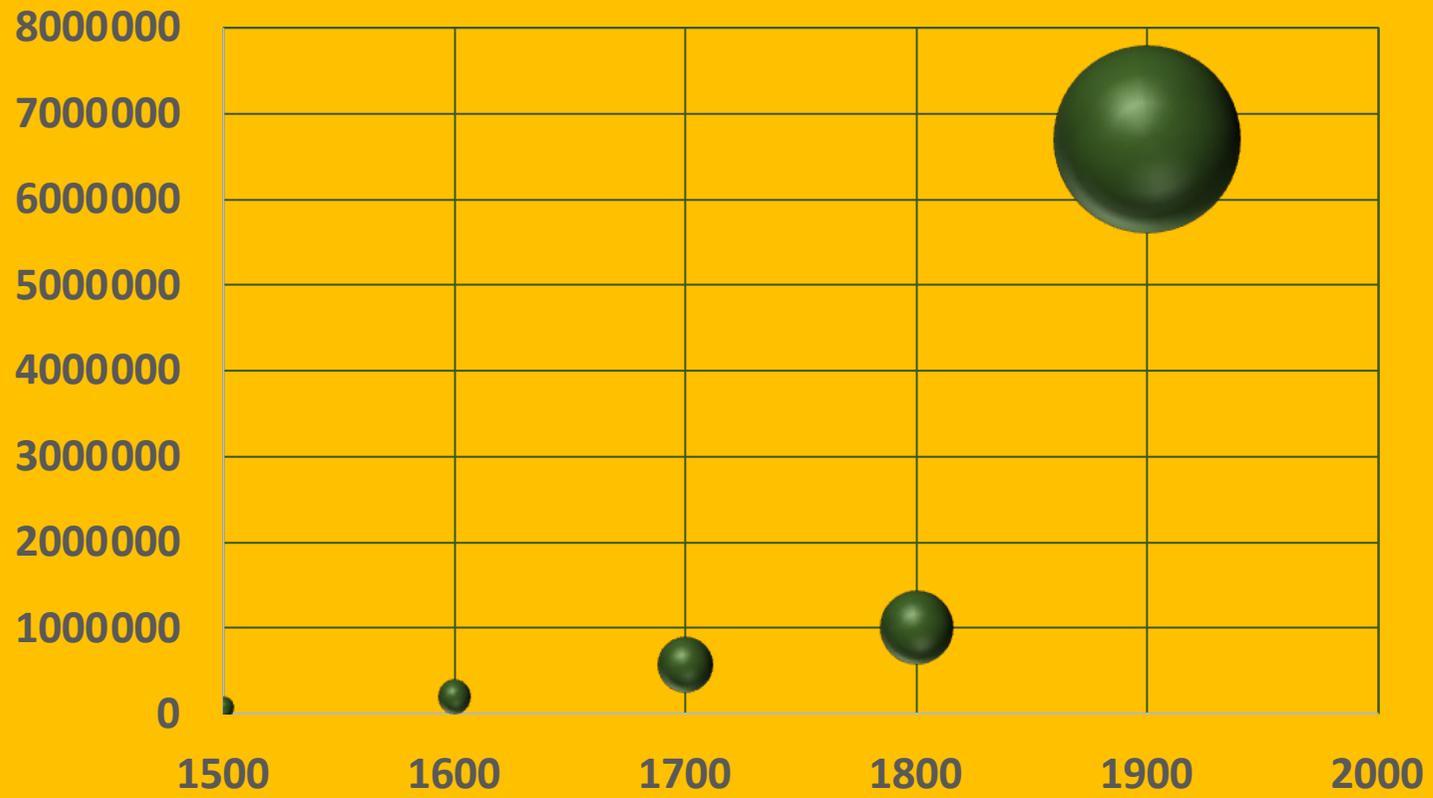
## 1661 John Evelyn

Understands **sources, effects and control** aspects. Suggests a correlation between the mortality rate contained in documents from London and the frequencies of particularly severe fog episodes



FUMIFUGIUM:  
OR  
The Inconveniencie of the AER  
AND  
SMOAK of LONDON  
DISSIPATED.  
TOGETHER  
With some REMEDIES humbly  
PROPOSED  
By J. E. Esq;  
To His Sacred MAJESTIE,  
AND  
To the PARLIAMENT now Assembled.

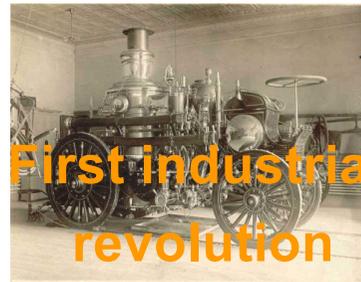
# Population of London



# The industrial revolution

Development of textiles and metallurgy  
Electricity and chemical products  
are introduced

Agricultural  
commercial  
craft  
system



First industrial  
revolution



Second industrial  
revolution

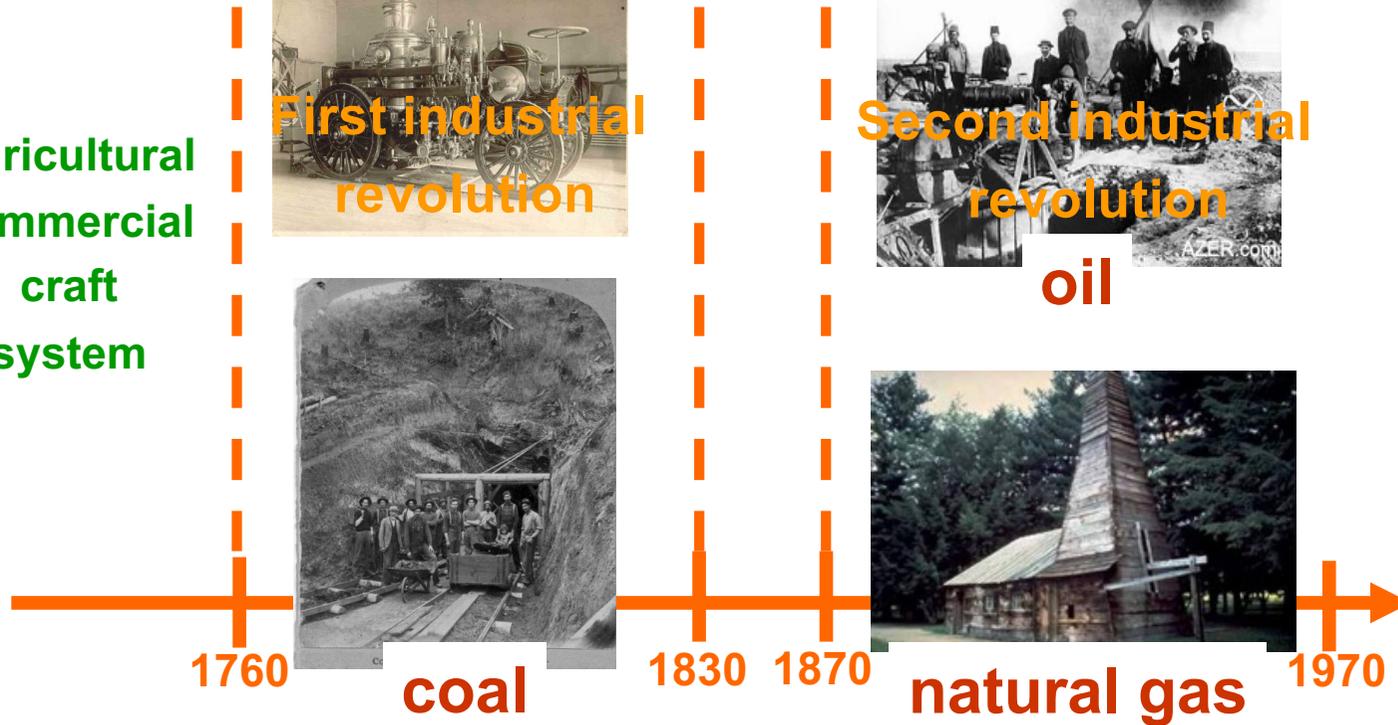
oil



coal

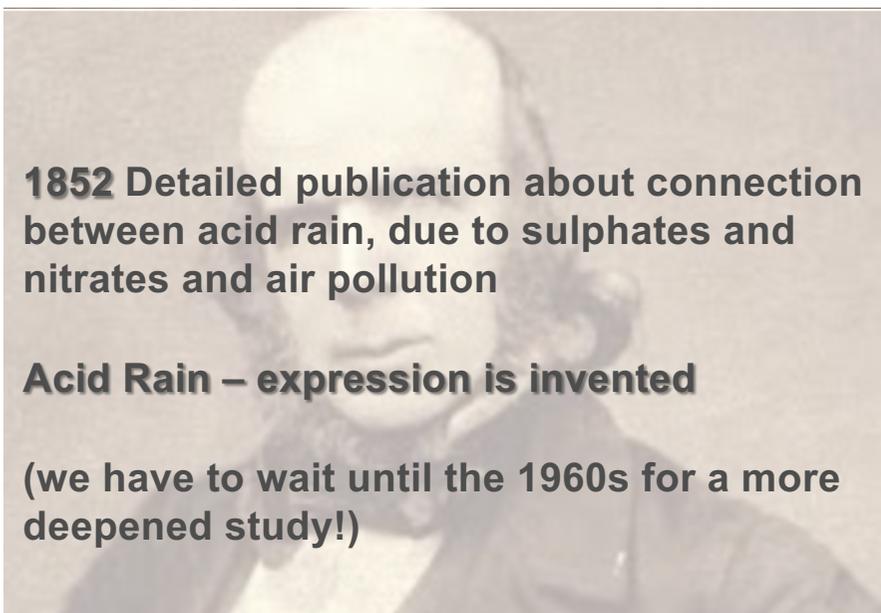


natural gas

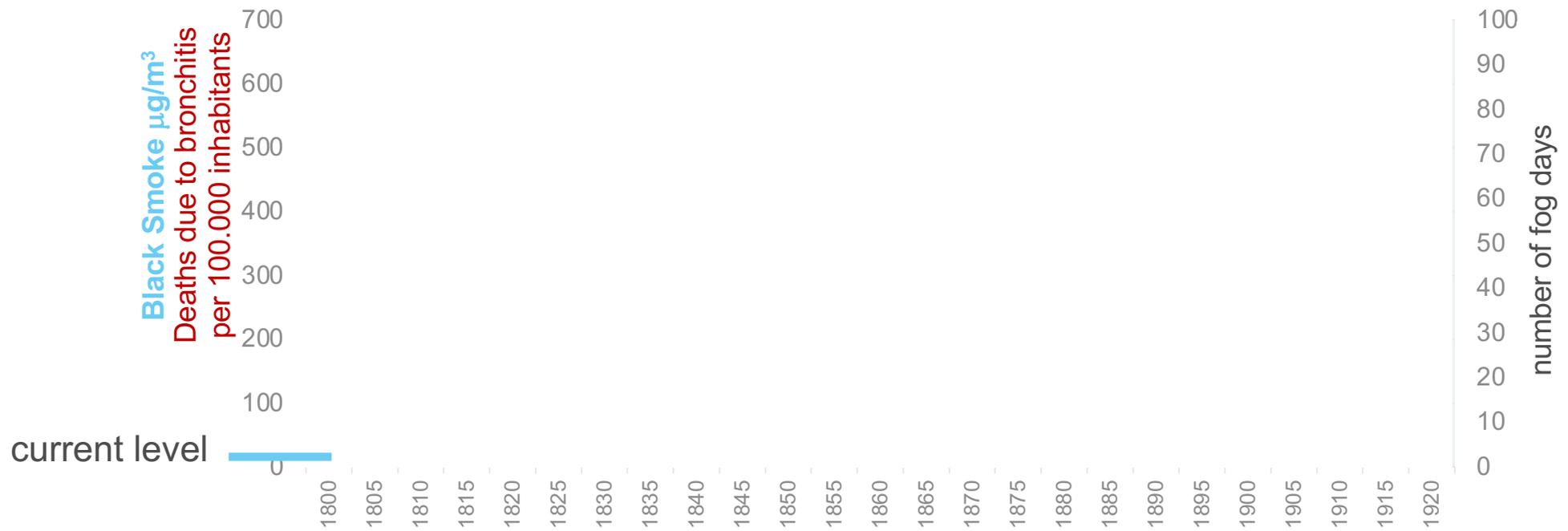


# Acid rain..... and ordinances

Robert Angus Smith



# Air quality in London 1800-1920

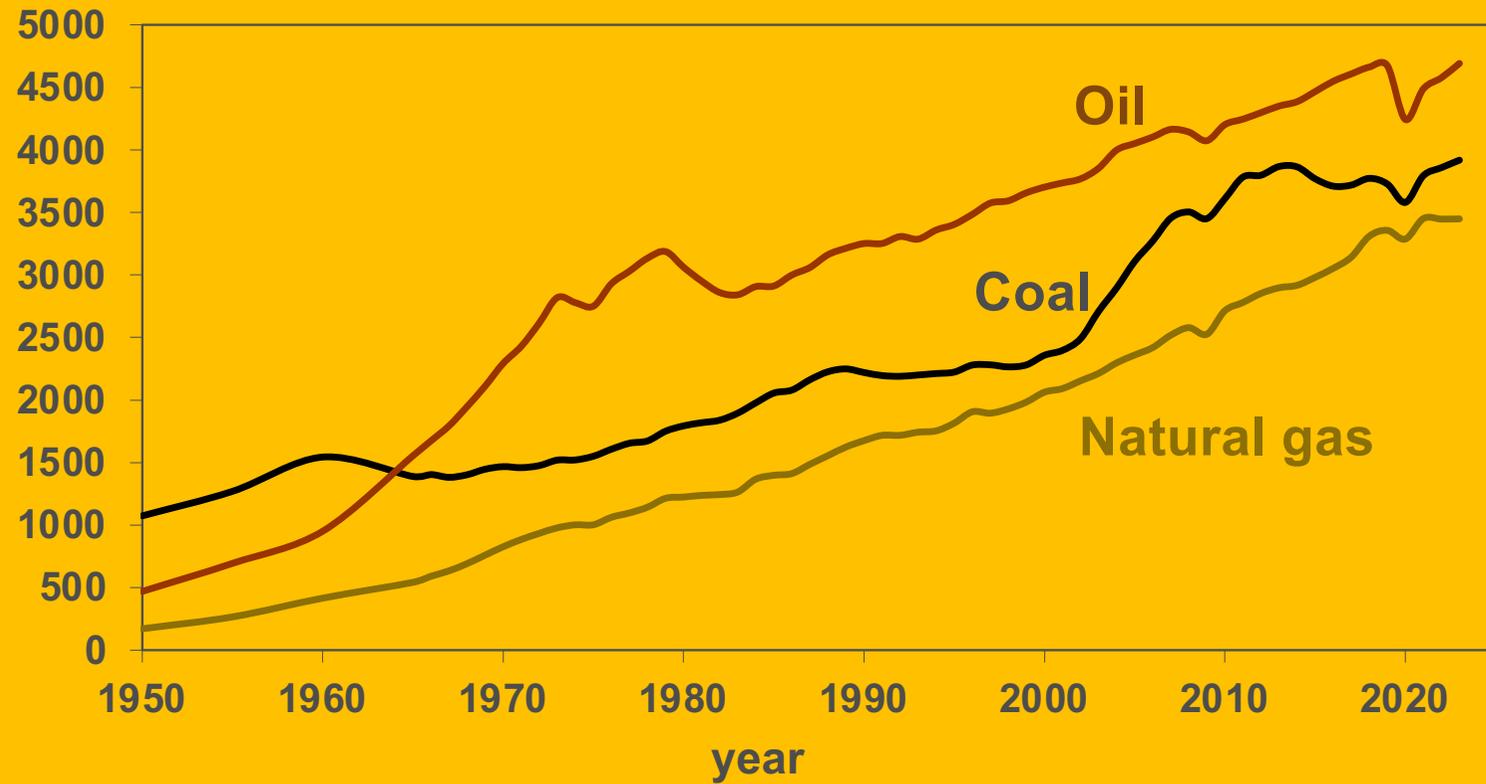


from Brimblecombe (1987) and Death Register General

# Global use of fossil fuels



Consumption (million tons oil equivalent)



(Data from U.S. Energy Inf. Admin, BP, Int. Energy Agency, and UN)

# The boost of development prevails: the big disasters



**1930 Meuse Valley, Belgium**  
6 days: combination of low T,  
fog and lack of wind;  
63 deaths and 6000 ill



**1943 Los Angeles, USA**  
1 day: smog invades the city  
Inflammation of throat and eyes  
People believe it is a Japanese  
attack



**1948 Donora, USA**  
6 days: cold, lack of wind,  
thick fog;  
20 deaths and 6000 ill



# The boost of development prevails: the big disasters



**1952 London, The Big Smoke**  
4 days: cold, lack of wind, thermal inversion; 3000-4000 deaths and about 100.000 ill

Preceded by a cold period with a larger use of coal in buildings and in power plants



## More efficient policies: Clean Air Acts

### 1956 CLEAN AIR ACT, UK

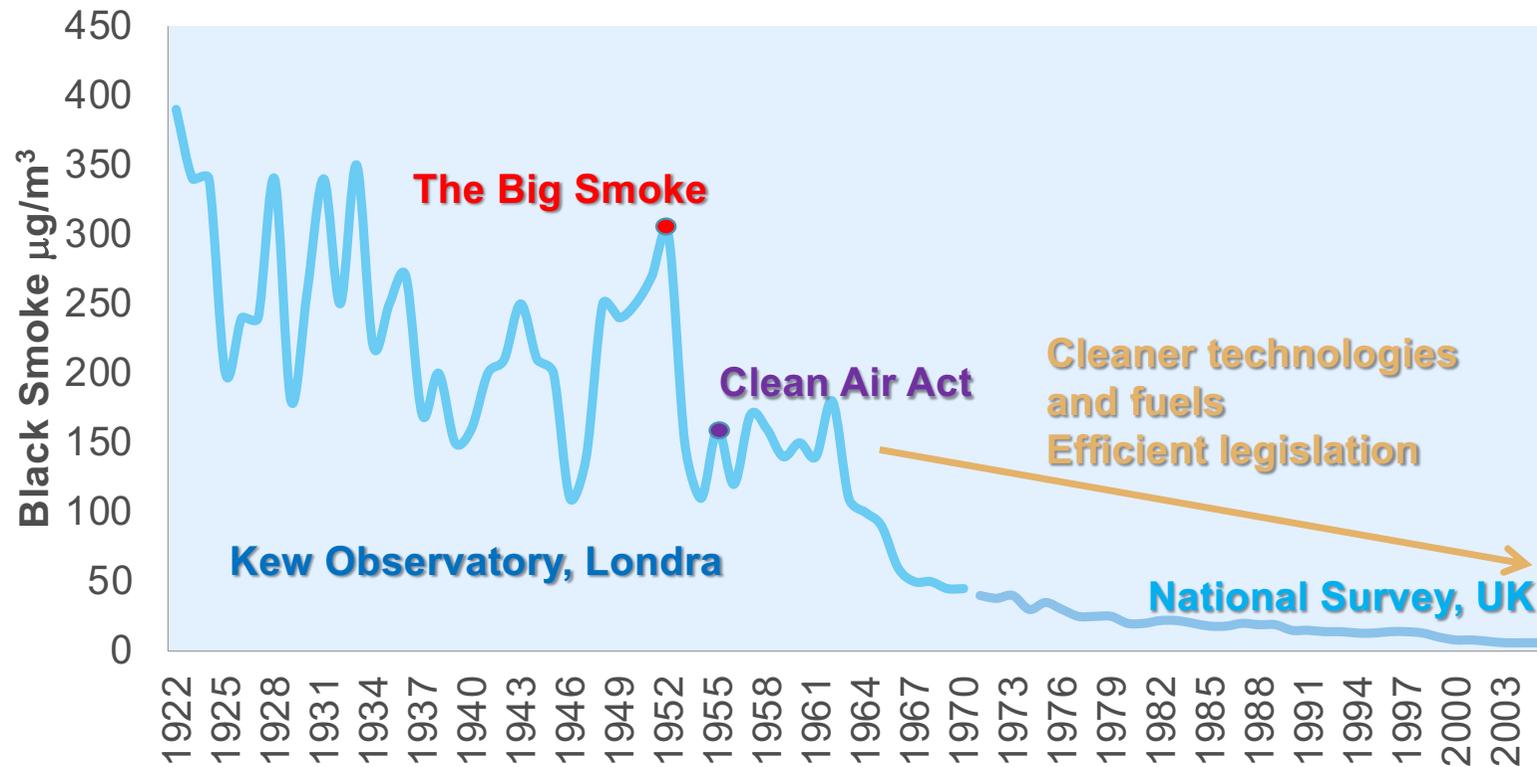
- Measures to reduce air pollution
- 'smoke control areas' in some towns and cities where
- ✓ only fuels that did not emit "smoke" could be burnt
- ✓ **reducing then the use of coal**



### 1963 CLEAN AIR ACT, USA

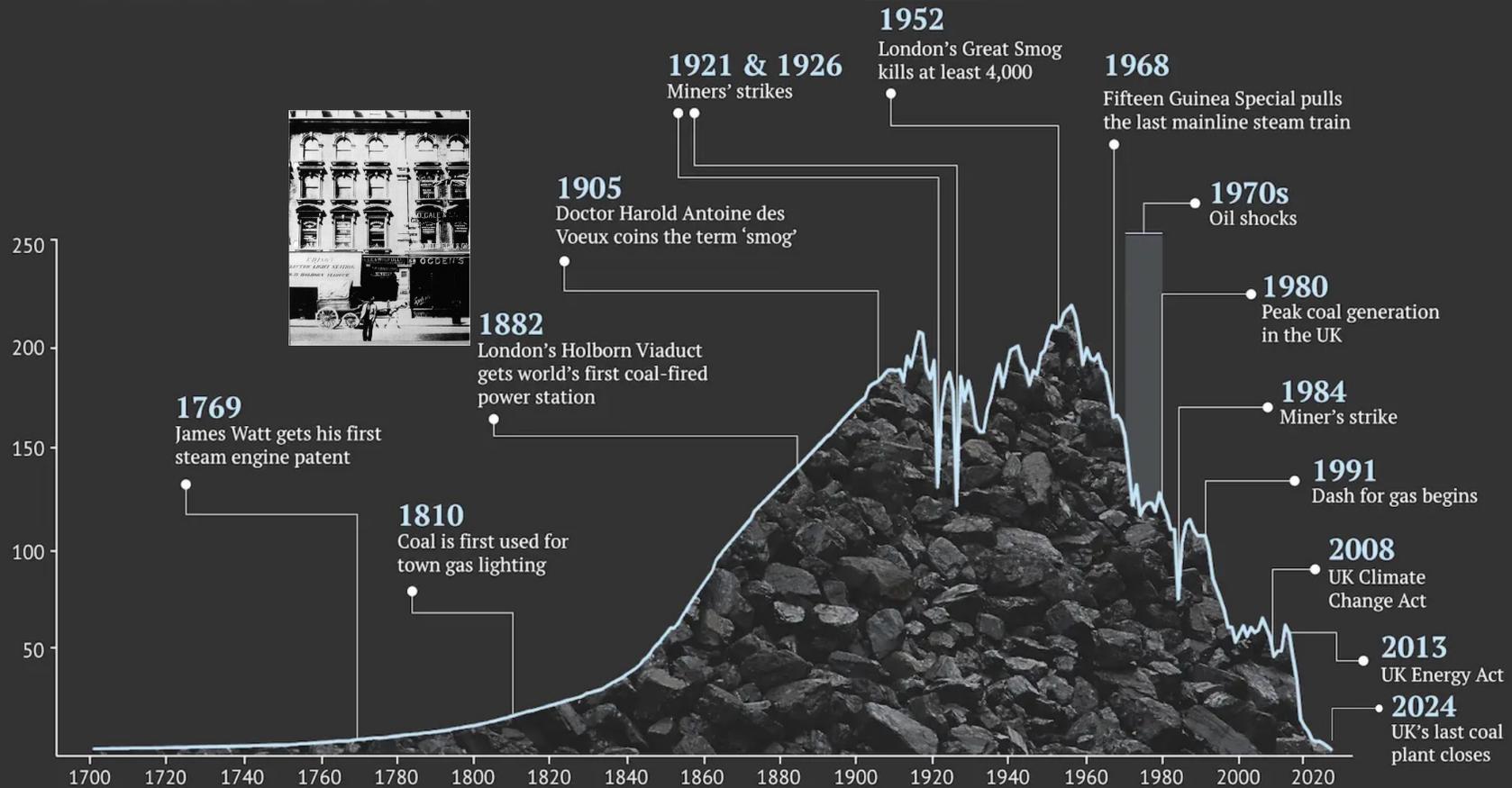
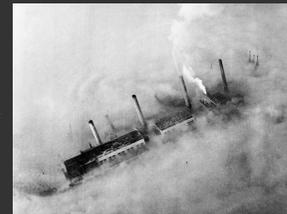
- Promote good air quality
- encourage prevention and control programmes
- provide technical and financial assistance for prevention at local and national level

# A positive ... decay



# Coal use surge and decay

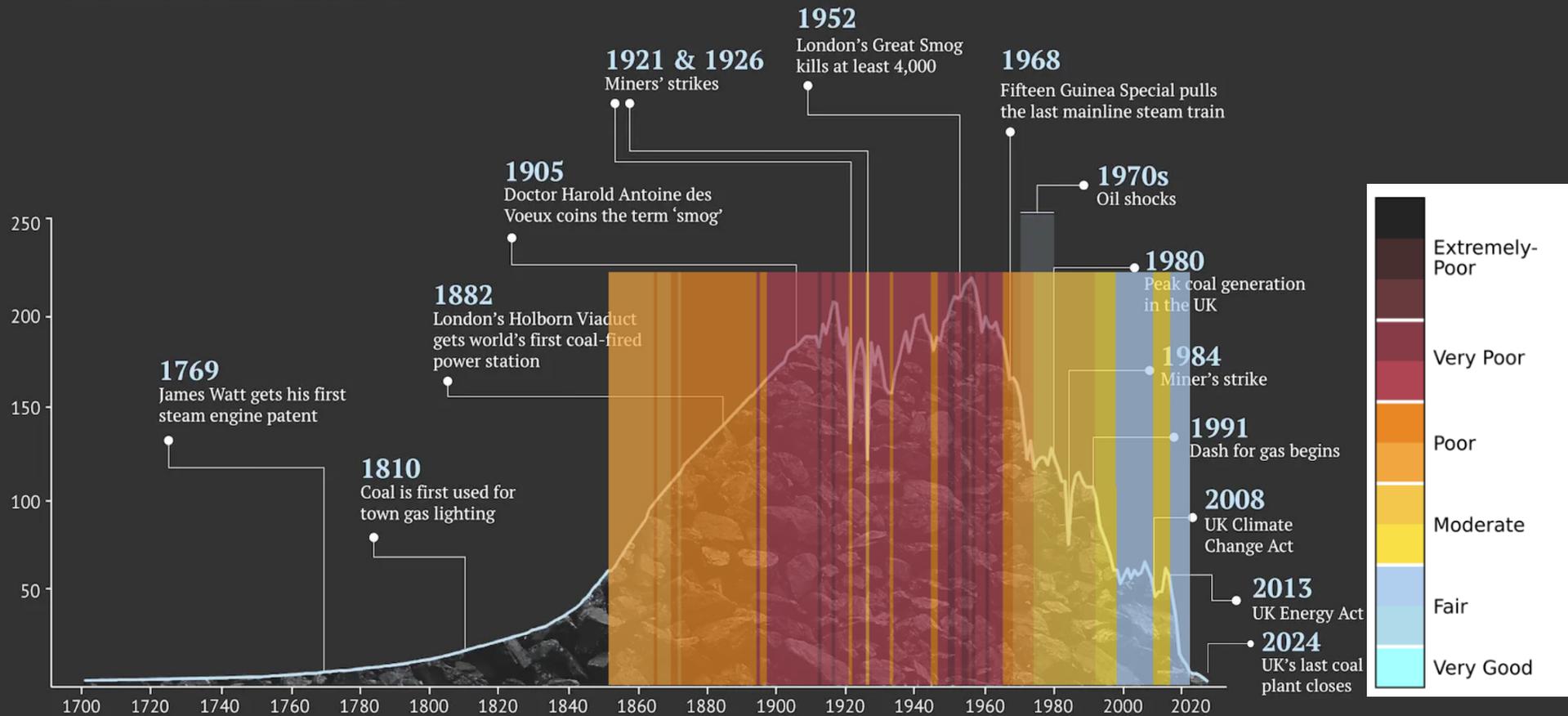
UK coal demand in million tonnes (Mt)



Source: Carbon Brief analysis and data from DESNZ and Paul Warde.

# Coal consumption and air quality in London

UK coal demand in million tonnes (Mt)



Source: Carbon Brief analysis and data from DESNZ and Paul Warde.

[airqualitystripes.info](http://airqualitystripes.info)

# The limits to growth, 1972

*A groundbreaking environmental warning*

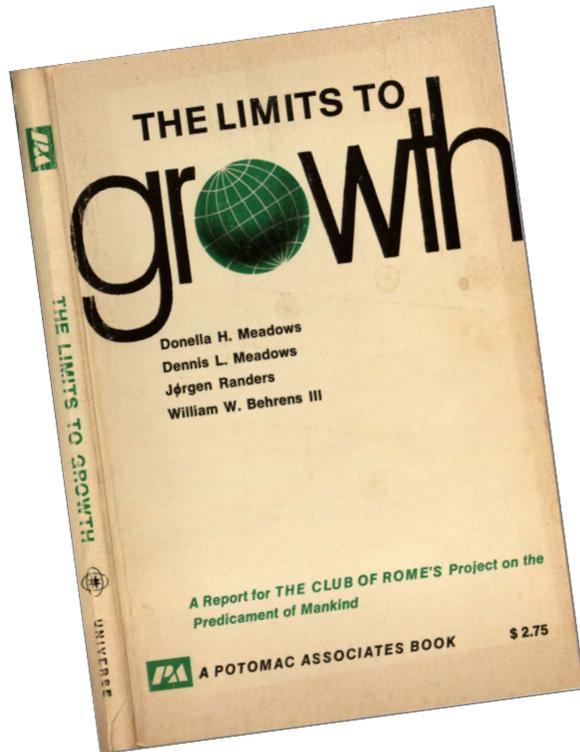


Figure 35 WORLD MODEL STANDARD RUN

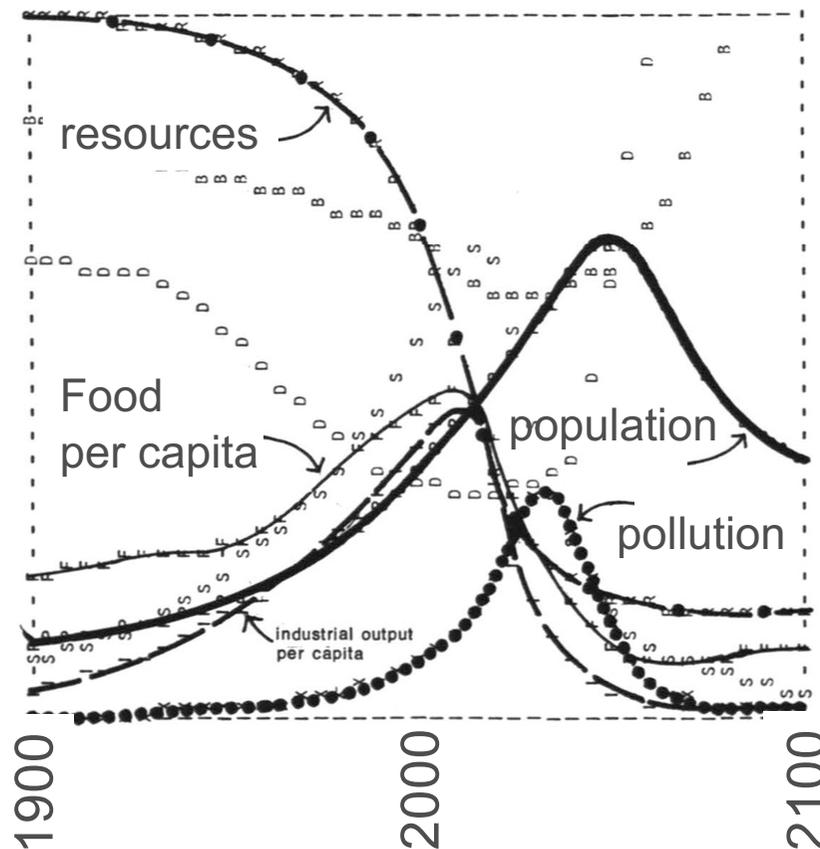
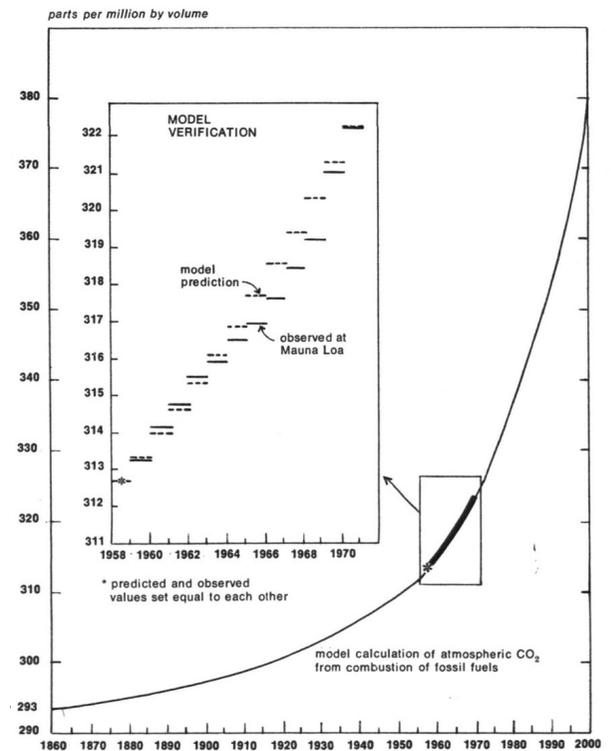


Figure 15 CARBON DIOXIDE CONCENTRATION IN THE ATMOSPHERE

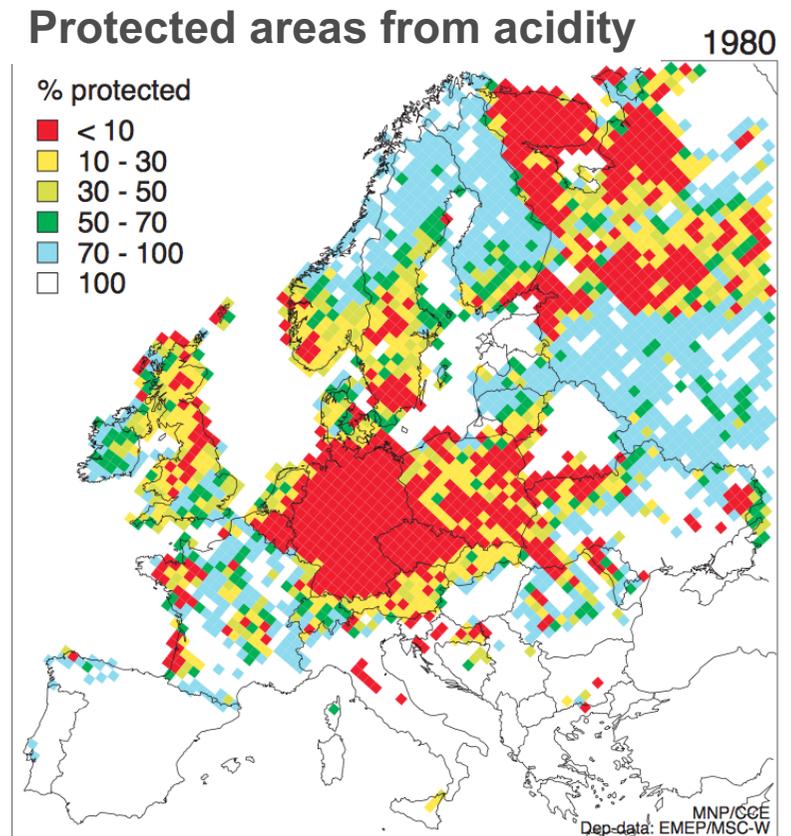


Measured CO<sub>2</sub> in 2000: 370 ppm!

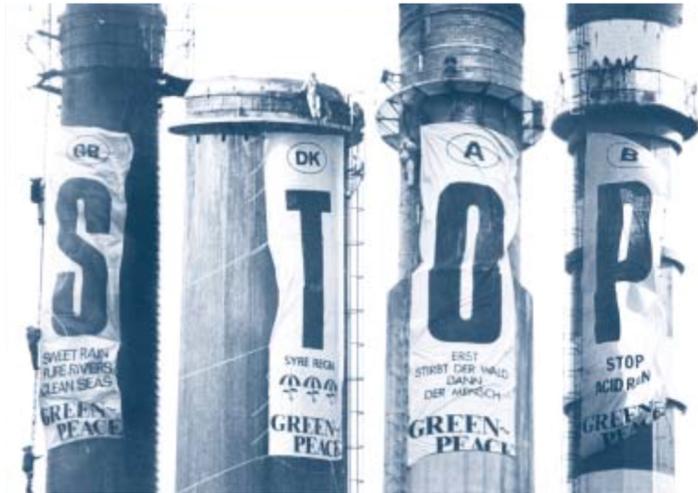
# Europe ravaged by acid rain...



- Acid rain extensively described in the '60s
- Ground-level ozone threat to ecosystems identified in the '70s
- Forest decline recognized in the '80s
- Eutrophication of ecosystems by nitrogen deposition recognized in the '80s-'90s



.....with the public awareness growing...



Greenpeace (1971)

The German Green Party (1980)



Earth day (1970)

# ...develops its environmental policies



**1972**

European Council establishes the **European Environment Policy**  
First **European Environmental Programme**



**1981**

European Commissions sets up its **Directorate General for Environment**



**1983**

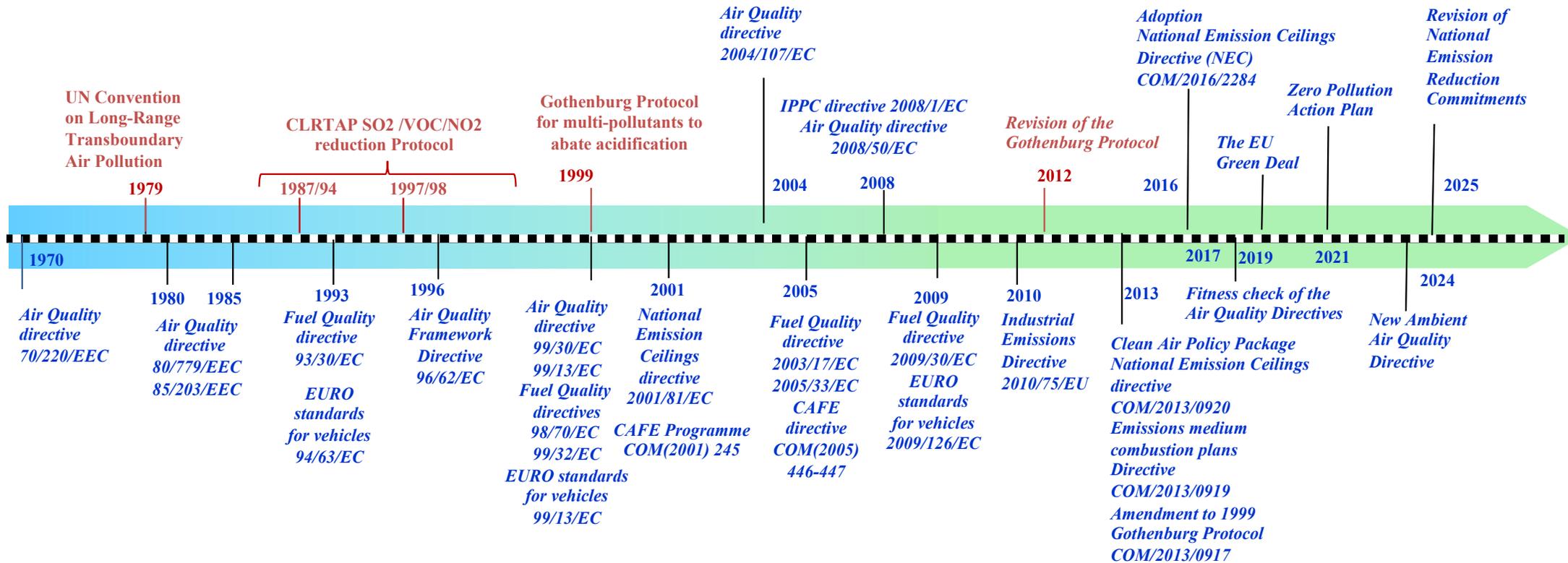
UN Convention on **Transboundary Air Pollution** enters into force



**1985**

European Commission launches **CORINE programme** that will inspire the birth of **European Environment Agency**

# Overview of Air Quality policies

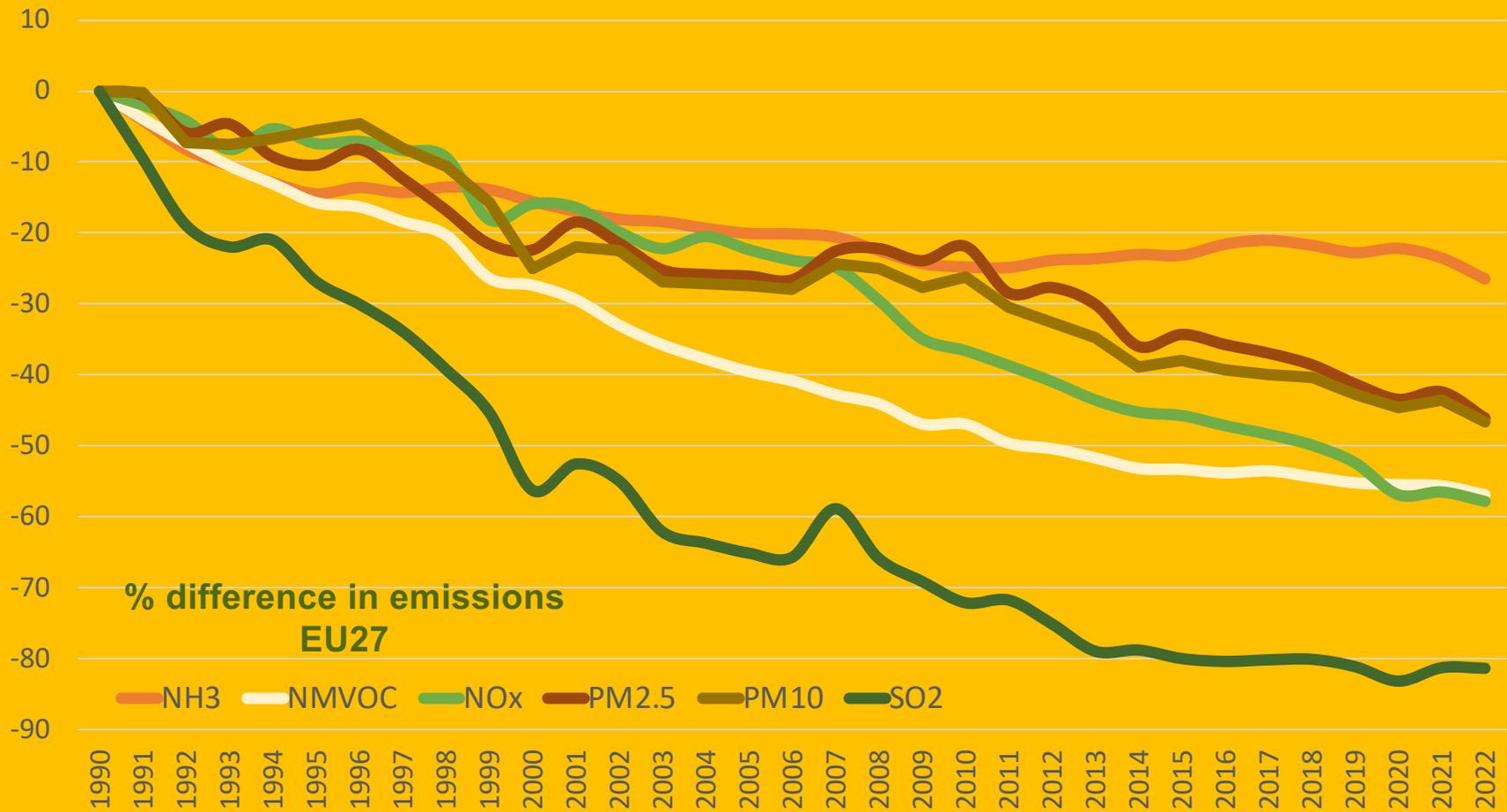


Blue = European Union

Red = International

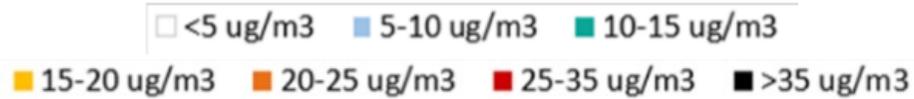
# Have EU air quality policies worked?

*scientific evidence*

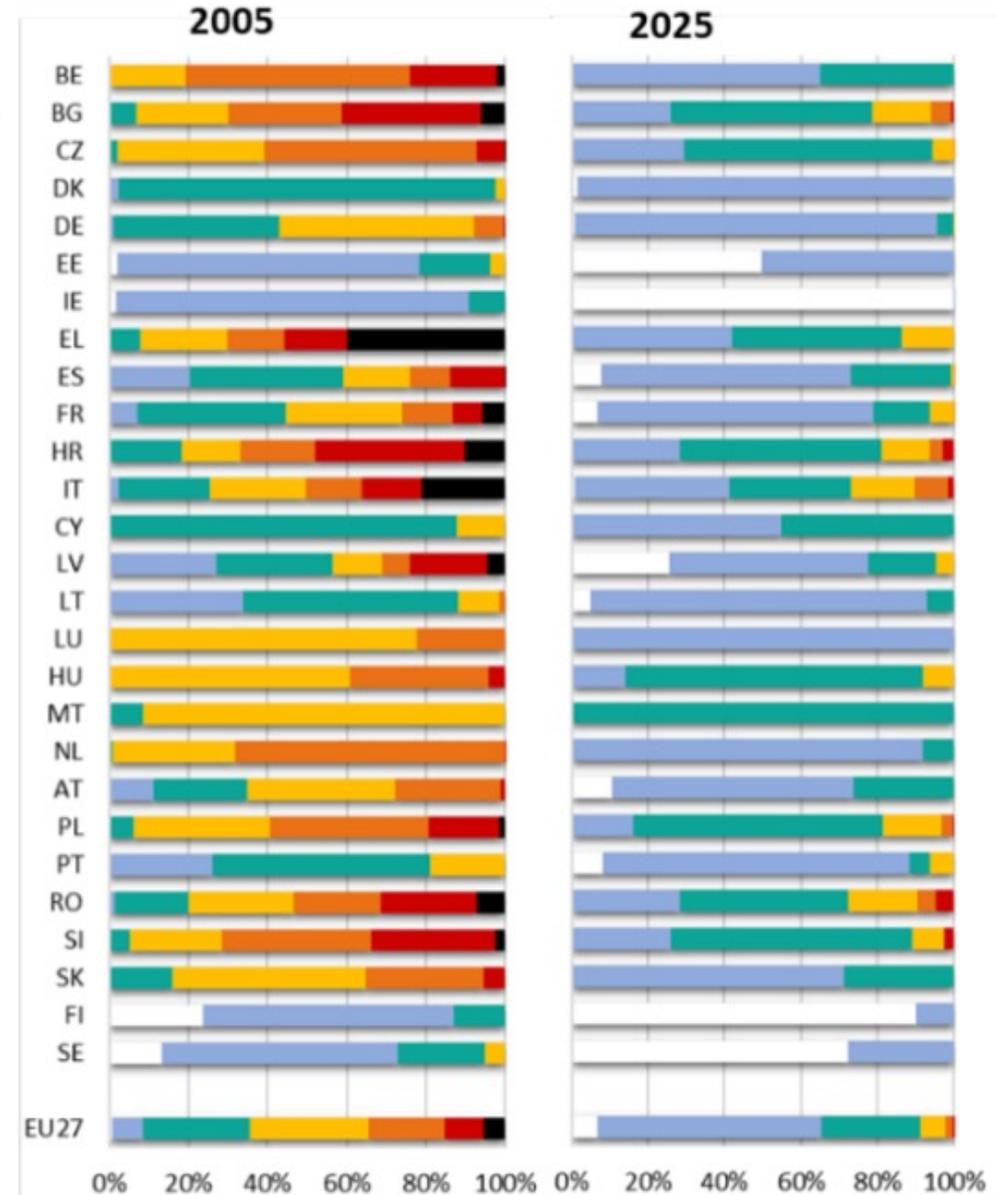


# 30 years of improvements air quality in EU

**EU-27 population exposed to different concentrations of PM2.5**



↑  
Above the  
limit value

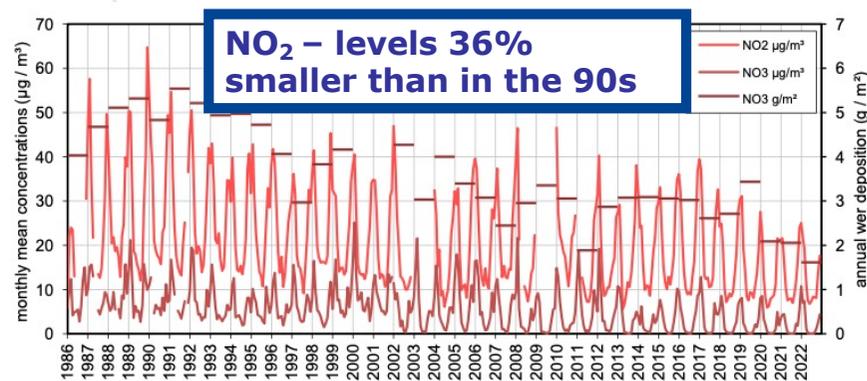
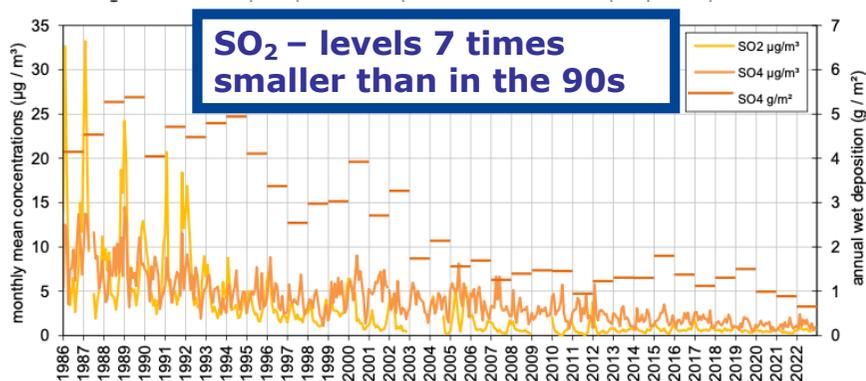
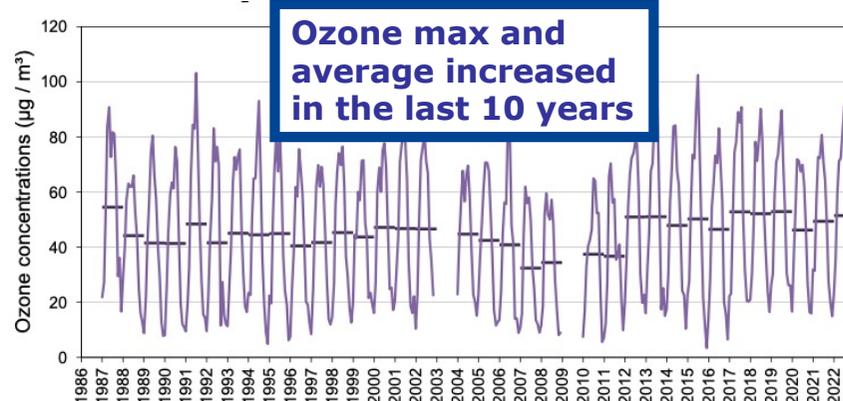
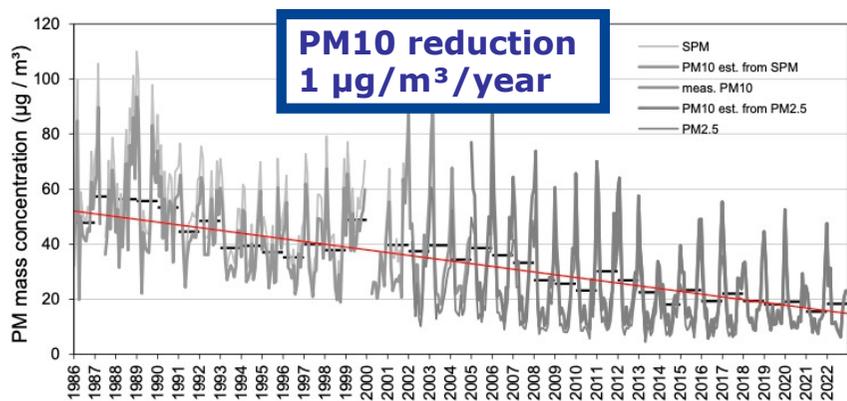


The Fourth Clean Air Outlook, 2025

# Achieved results from Ispra site (VA)



European  
Commission  
Atmospheric  
Observatory  
Ispra



# Key scientific inputs across time

## 1 Health impact studies

Research linking air pollutants (SO<sub>2</sub>, NO<sub>2</sub>, PM10, PM2.5, lead, ozone) to respiratory diseases, cardiovascular conditions, and premature death.

1

## 2 WHO guidelines

The WHO's evolving air quality guidelines have been central to setting EU air quality standards, with each update spurring tighter regulation.

2

## 3 Transboundary pollution research

Studies showing that air pollution crosses national borders have led to EU-wide emission ceilings and collective action to reduce pollution.

3

6

## 6 Real-Time and Long-Term air quality data

Increased data availability and the ability to monitor pollution trends over time have been critical in evaluating the success of policies and adjusting them as necessary.

5

## 5 Integrated climate and air quality research

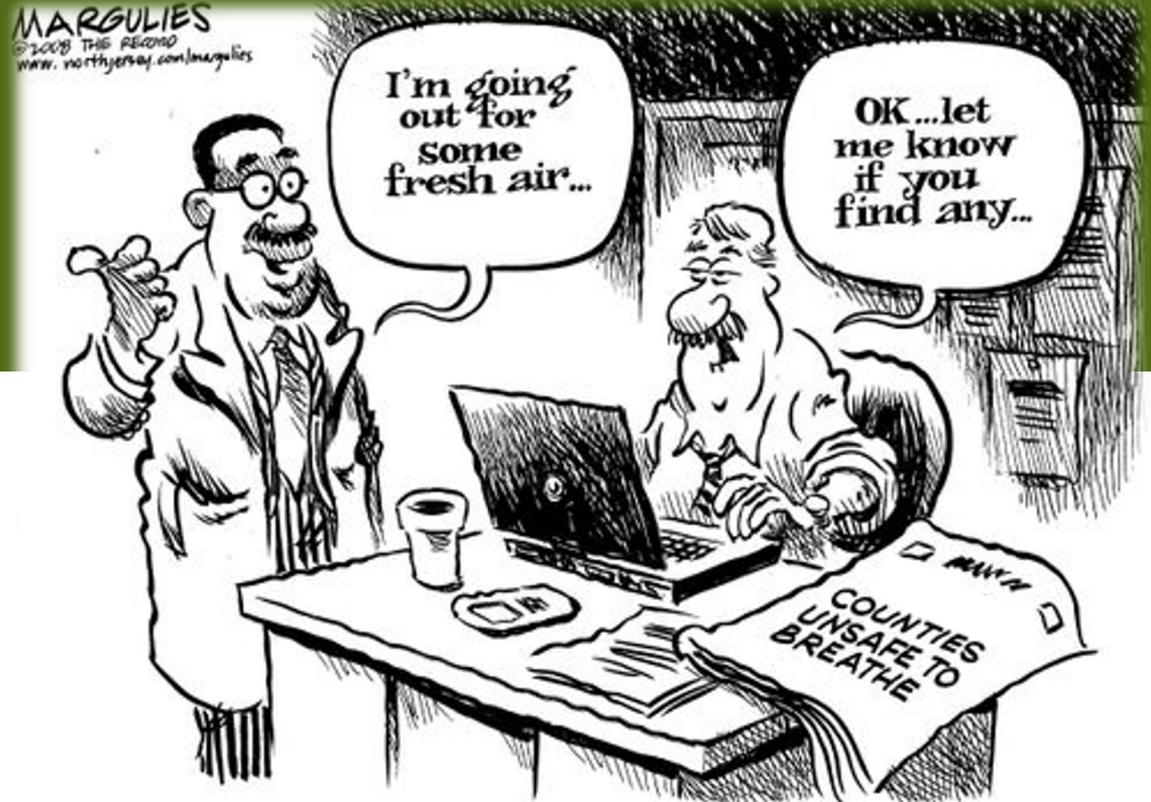
Studies showing the co-benefits of reducing greenhouse gases and air pollutants have driven policies that address both climate change and air quality.

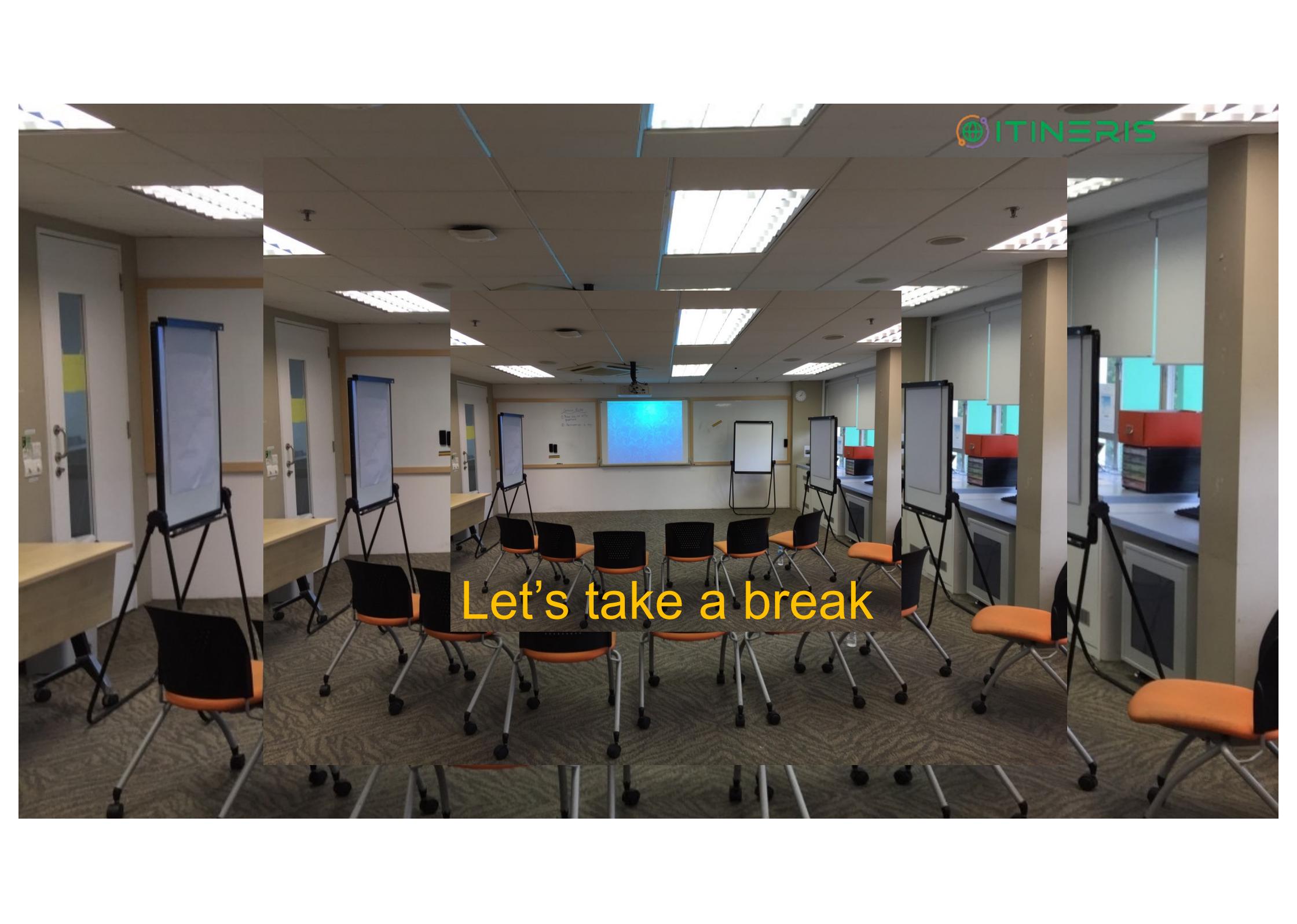
4

## 4 Technological advances

Improved air quality monitoring and data collection have provided more precise measurements of pollution levels, informing policy decisions.

# Questions?



A wide-angle photograph of a modern conference room. The room is carpeted with a grey and brown pattern. Several black office chairs with orange seats are arranged in a circle. There are several whiteboards on tripods around the room. In the background, a large screen displays a blue abstract image. The ceiling has recessed lighting and a central projector. The text "Let's take a break" is overlaid in the center of the image.

Let's take a break

# How do air quality policies work together?



## At international level

UNECE Air Convention and its Protocols (e.g. the Gothenburg Protocol with national emission limits for 2010 and 2020)

## At EU level

**STRATEGIC OBJECTIVES:** EU Clean Air Programme  
**EMISSION LIMITS:** National Emission Reduction Commitments (NEC) Directive  
**AIR QUALITY LOCAL LIMIT VALUES:** Ambient Air Quality Directives  
**SOURCE SPECIFIC LEGISLATION:** Industrial Emissions Directive, Euro and energy efficient standard, etc.

## At National level

National Legislation and local instruments

# Role of science in current air quality policies



**At international level**

UNECE Air Convention



**At EU level**

EU Green Deal

Air Quality Directive



**At National level**

Cities and air pollution

# UN ECE Air Convention

*United Nations Economic Commission for Europe*



# UN ECE Air Convention

*United Nations Economic Commission for Europe*

## 8 PROTOCOLS

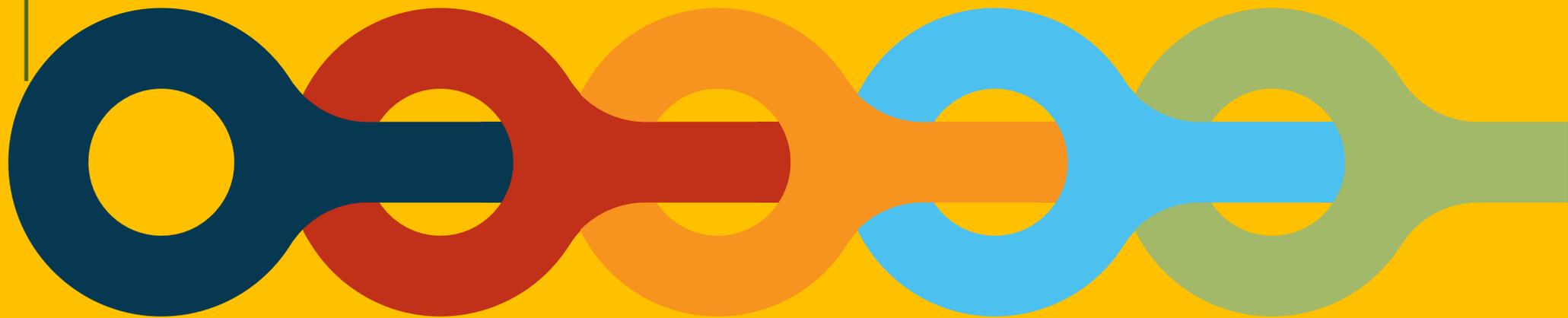
setting emission reduction commitments for various pollutants

## SOLID

science-policy interface

## EFFECTIVE

compliance mechanism



## INFORMING

Capacity-building programme

## INVOLVING

outreach beyond the UNECE region



# Role of science in current air quality policies

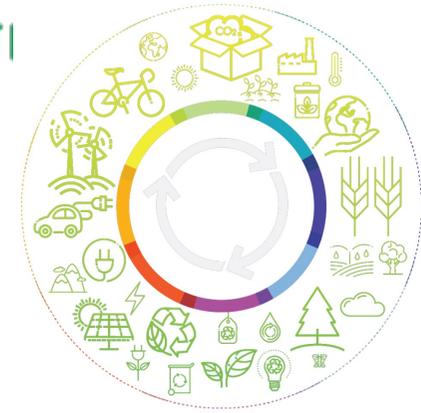


**At EU level**

**EU Green Deal**

**Designing the new  
Air Quality Directive**

# Air Quality and the urgency to act a path toward a Clean Planet for All



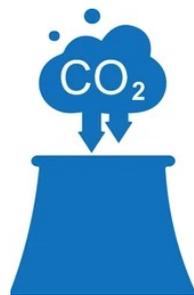
Maximising benefits  
Energy efficiency, renewables  
....



Competitive industry and circular economy



Embrace clean, safe, connected mobility



Develop Carbon capture and storage



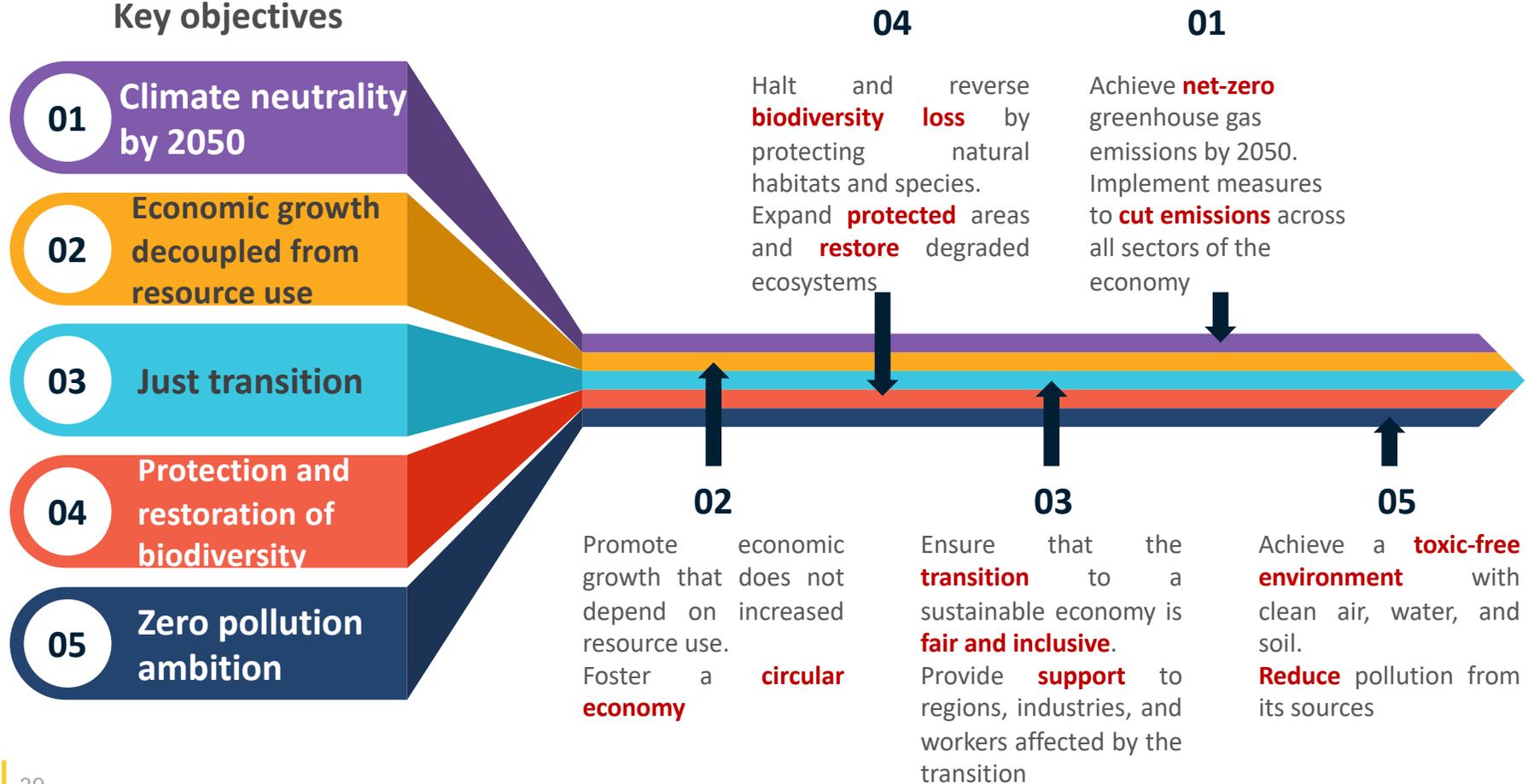
Full benefits of bioeconomy and carbon sinks

Air pollution costs and benefits	2050 vs 2015
Premature deaths ozone and PM 2.5 (1000 cases per year)	-146
Air pollution control costs (bn€/yr)	-45
SUM pollution control costs & health damage (bn€/yr)	-218 to -459

In depth analysis with scenarios in support to the Commission Communication “A Clean planet for all”, 2018

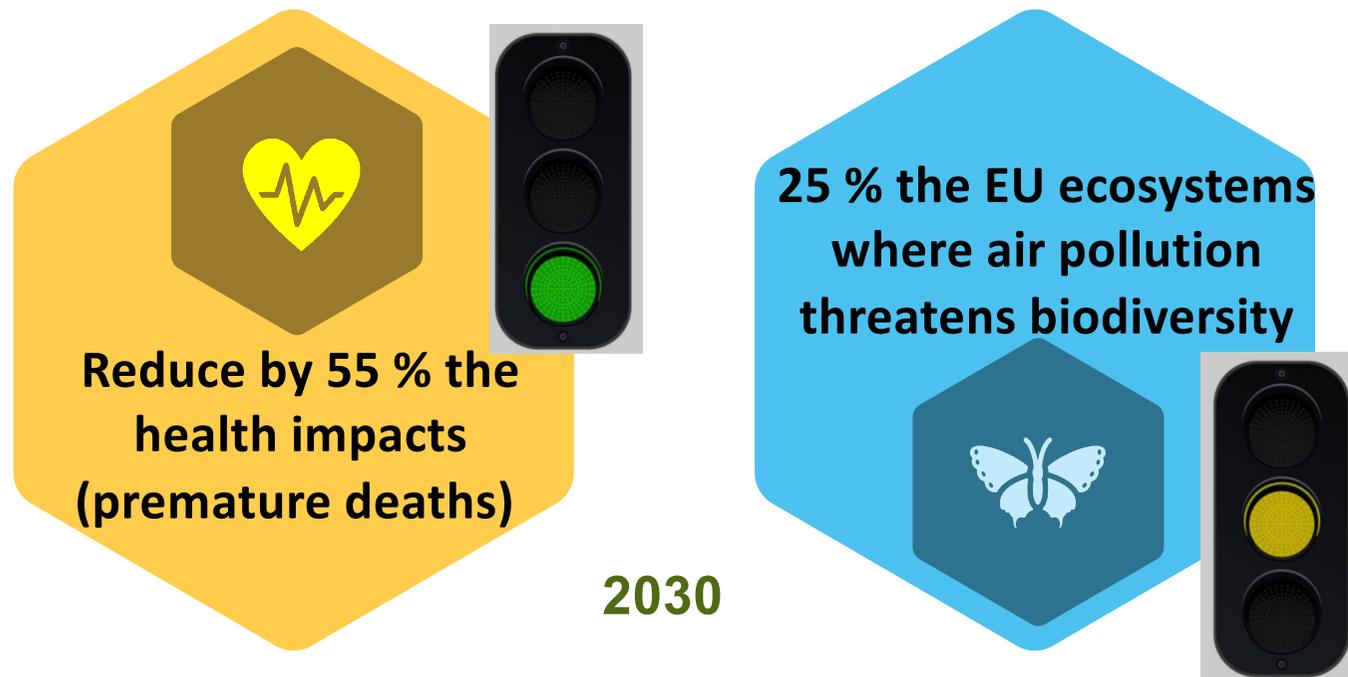
# EU Green Deal

## Key objectives



# Air quality targets

Cross-sectoral strategies  
agriculture, transport, energy and industry



# Towards a new EU air quality Directive

*setting new objectives, standards and limits*

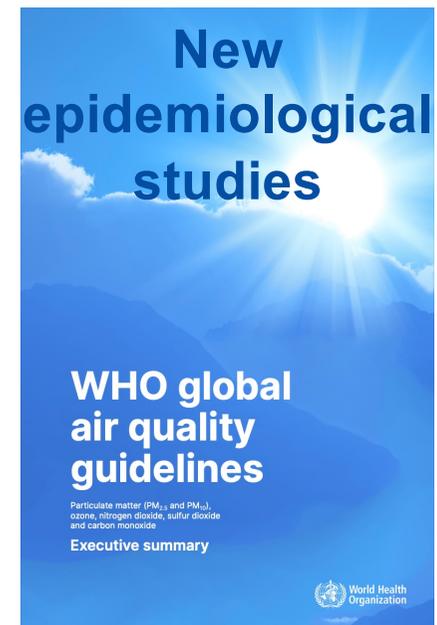


## Ambient Air Quality (AAQ) Directives

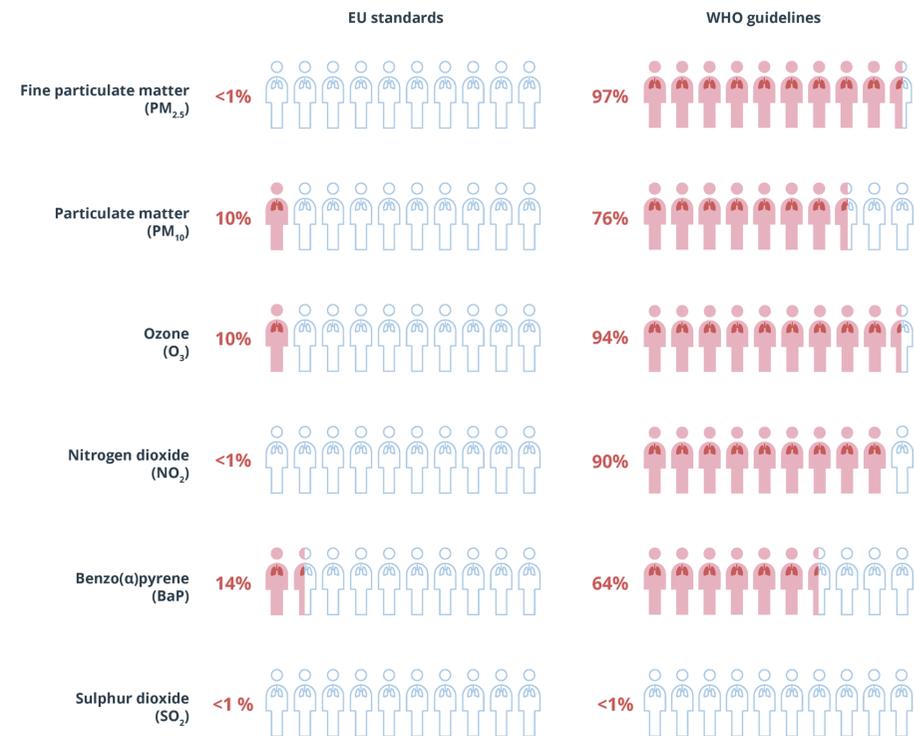
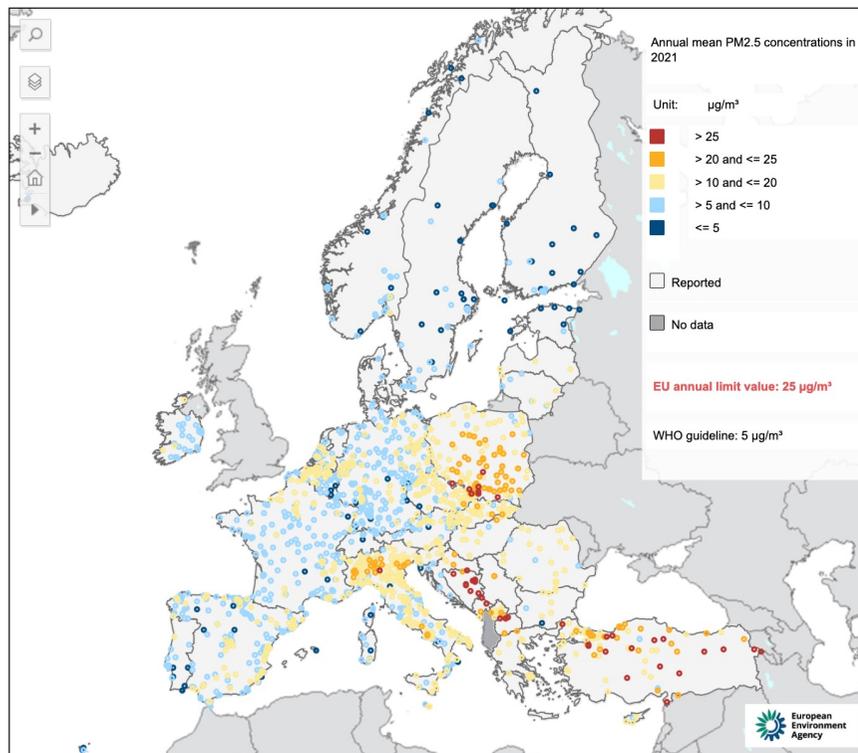
Maximum concentrations of  
air polluting substances

(PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, O<sub>3</sub>, SO<sub>2</sub>, CO, C<sub>6</sub>H<sub>6</sub>, BaP, As, Cd, Ni, Pb)

$\mu\text{g}/\text{m}^3$	2008 Directives
PM <sub>2.5</sub>	
annual	25
daily	
PM <sub>10</sub>	
annual	40
daily	50
NO <sub>2</sub> , annual	40
Ozone, 8 hour average	120

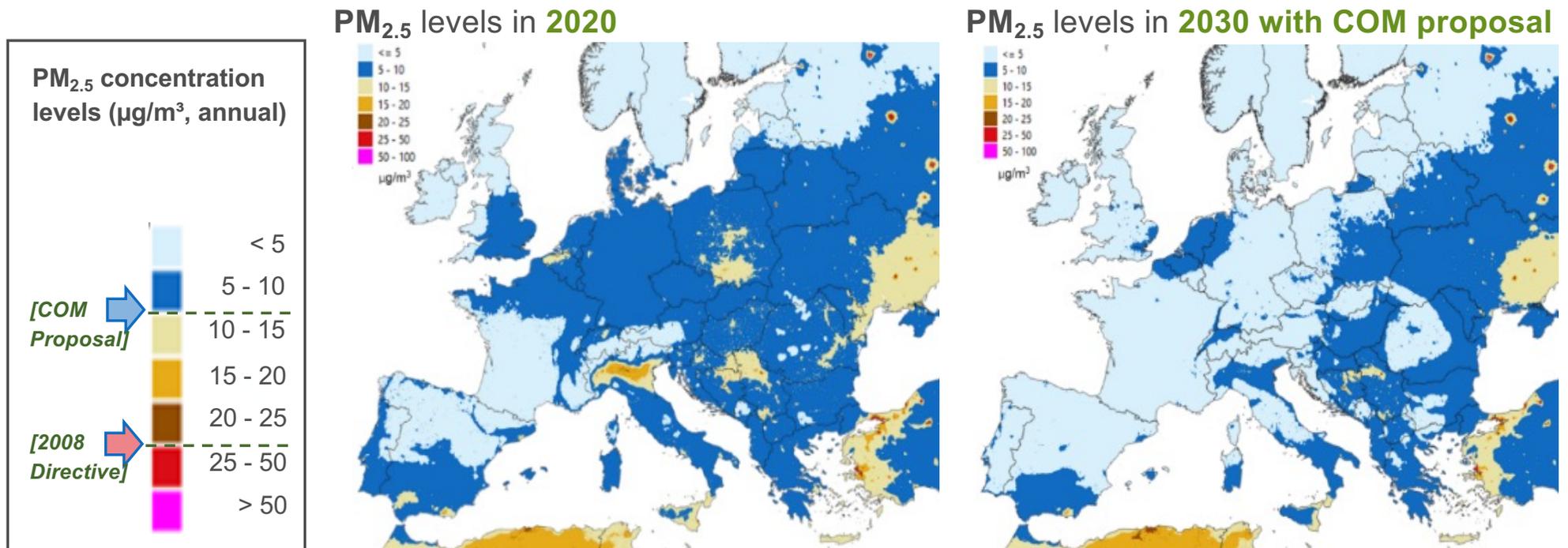


# Measured and reported data; exposure to evaluate the status



# Scenario modelling of policy impacts

*to design the new Directive*



Impact Assessment Report EC, Proposal for the new Air Quality Directive, 2022

# Towards a new EU air quality Directive

*setting new objectives, standards and limits*



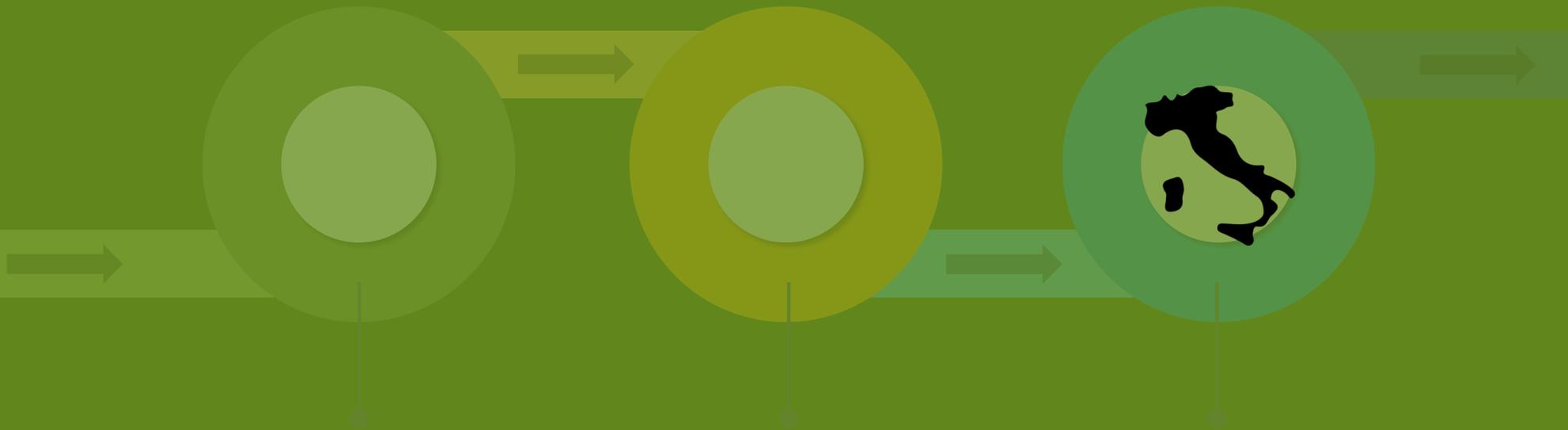
## Ambient Air Quality (AAQ) Directives

Maximum concentrations of  
air polluting substances

(PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, O<sub>3</sub>, SO<sub>2</sub>, CO, C<sub>6</sub>H<sub>6</sub>, BaP, As, Cd, Ni, Pb)

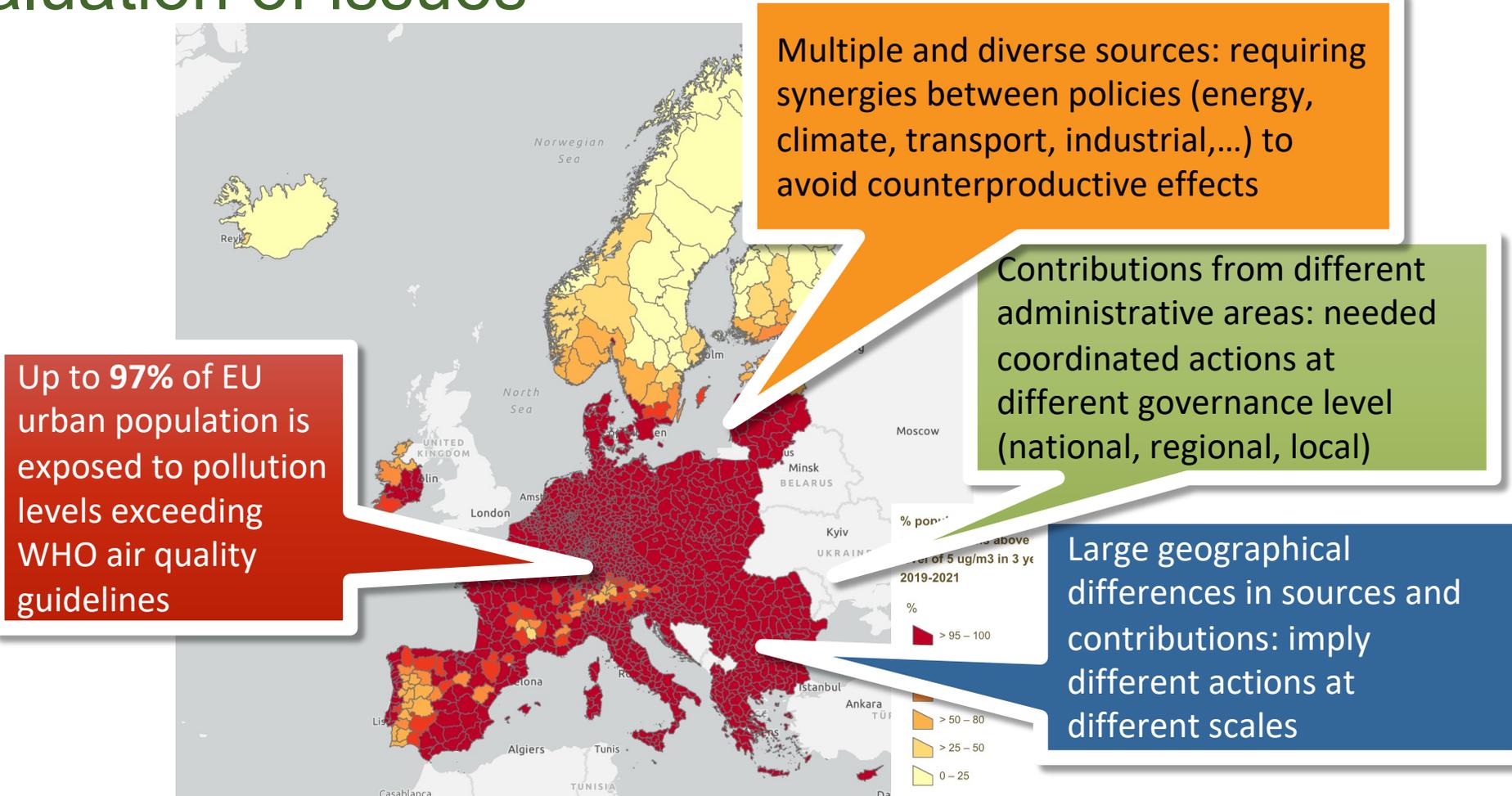
µg/m <sup>3</sup>	2008 Directives	WHO guidelines 2021	New Directive
<b>PM<sub>2.5</sub></b>			
annual	25	5	10
daily		15	25
<b>PM<sub>10</sub></b>			
annual	40	15	20
daily	50	45	45
NO <sub>2</sub> , annual	40	10	20
Ozone, 8 hour average	120	100	120

# Role of science in current air quality policies



**At National level**  
Cities and air pollution

# Evaluation of issues



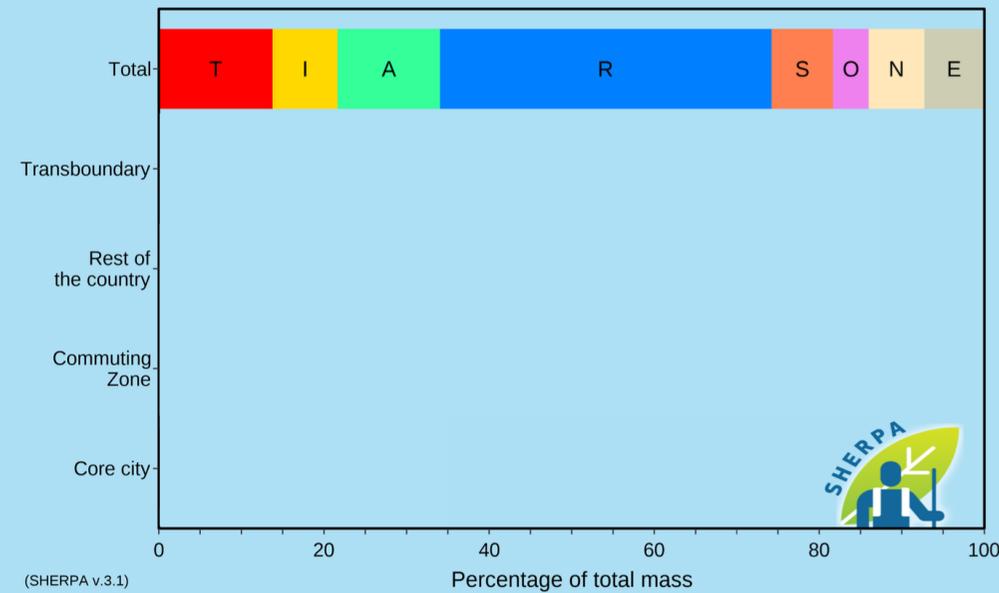
European Environment Agency, 2024

# From challenges to solutions

*Understanding city role to design a mitigation plan*



PM<sub>2.5</sub> from which sources? from where?



## Sectors

- T - Transport
- I - Industry
- A - Agriculture
- R - Residential
- S - Shipping
- O - Other
- N - Natural
- E - External



 What factors have contributed to the success or failure of the air quality policies?



# Outline

## The role of science in shaping air quality policies:

### 1) A historical perspective and recent developments

 **Historical evolution** of air pollution science and policies

 **Emergence** of international and EU frameworks

 **Scientific input into recent EU air quality policies and legislative updates**

### 2) Modern scientific tools for policy support

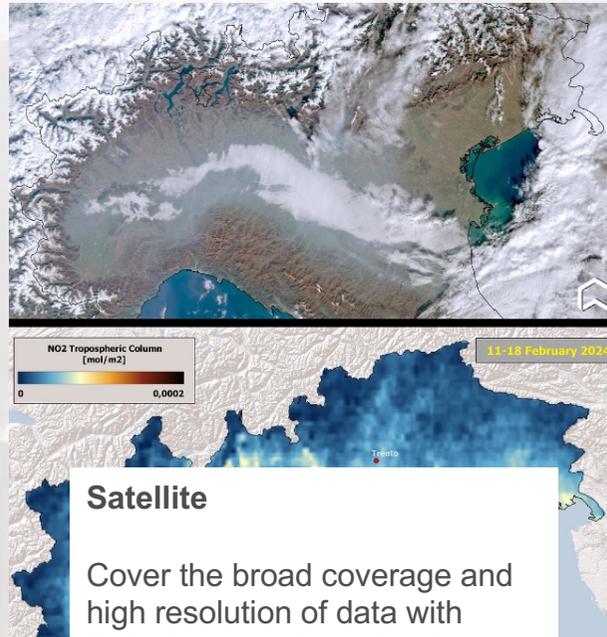


# Assessing air quality: monitoring



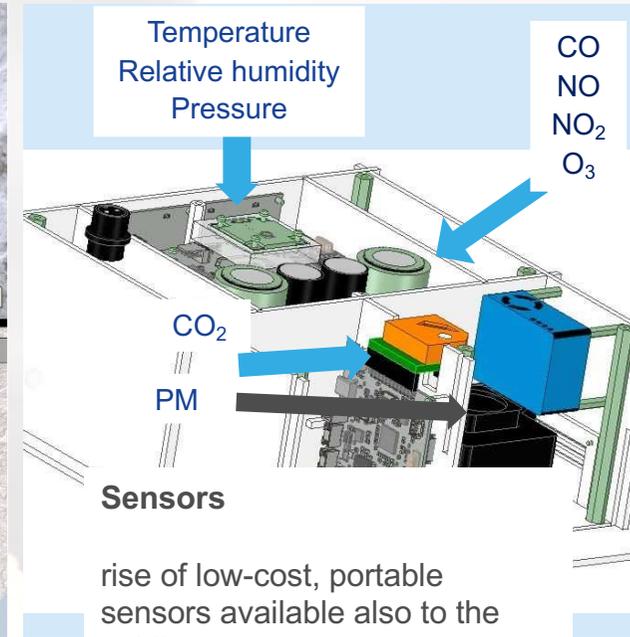
## Fixed monitoring stations

Crucial role of government and environmental agencies in maintaining networks of fixed air quality monitoring stations



## Satellite

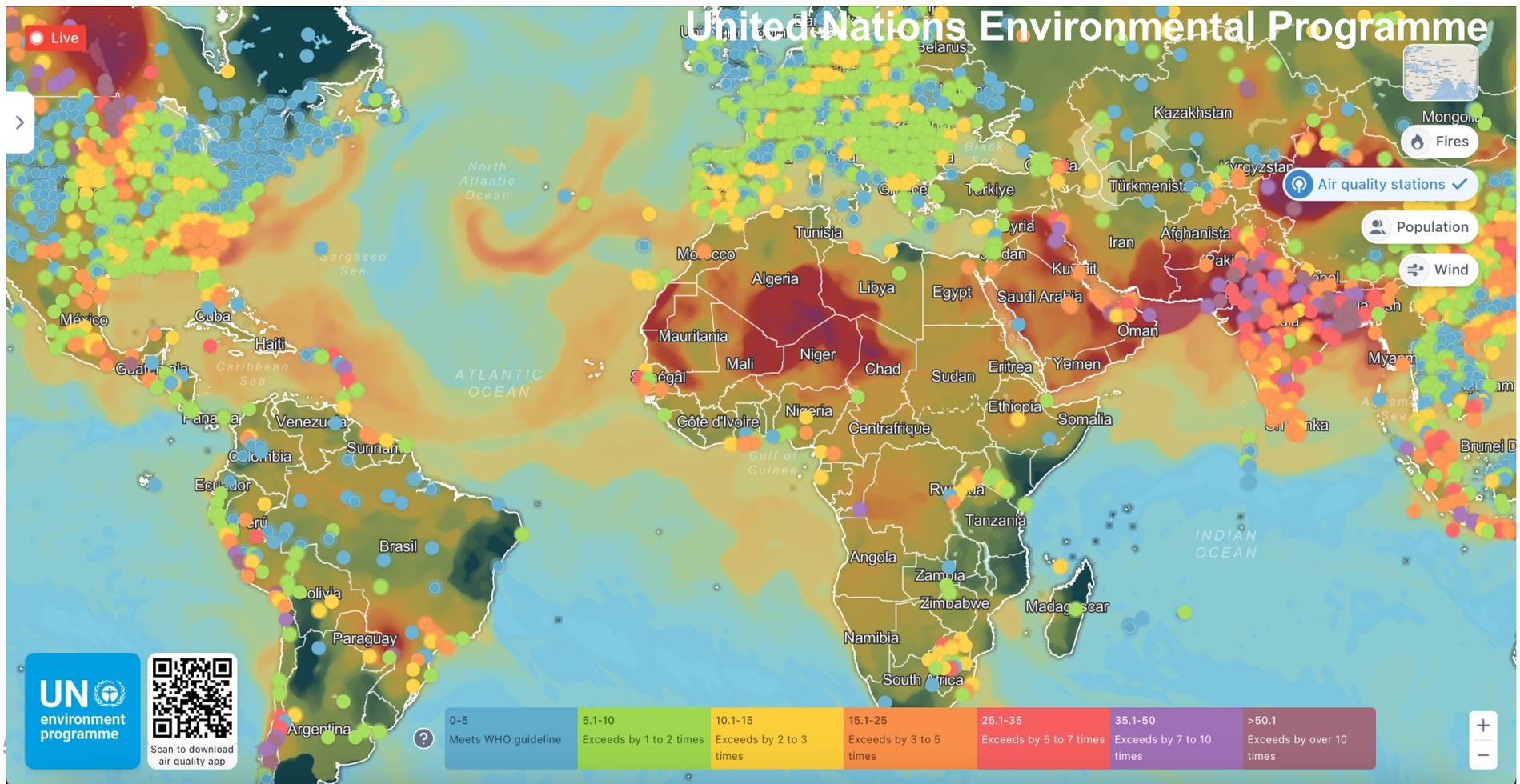
Cover the broad coverage and high resolution of data with limitations, such as cloud cover and lower accuracy compared to ground-based measurements



## Sensors

rise of low-cost, portable sensors available also to the public

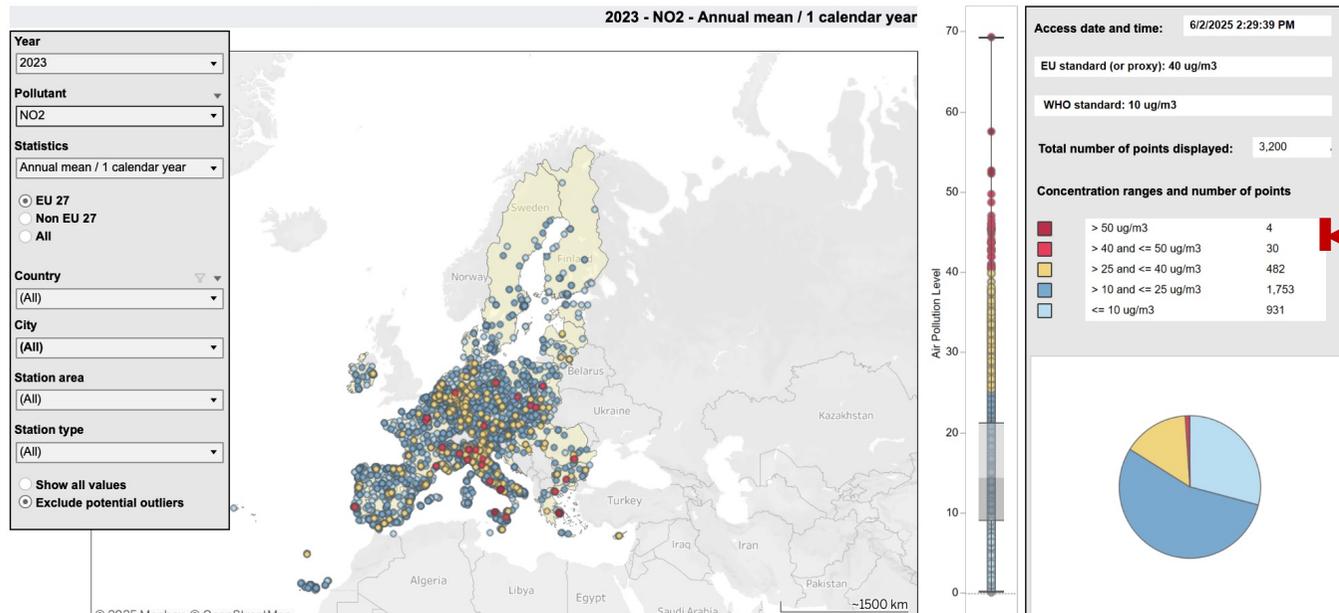
# Networks of fixed stations for a global view



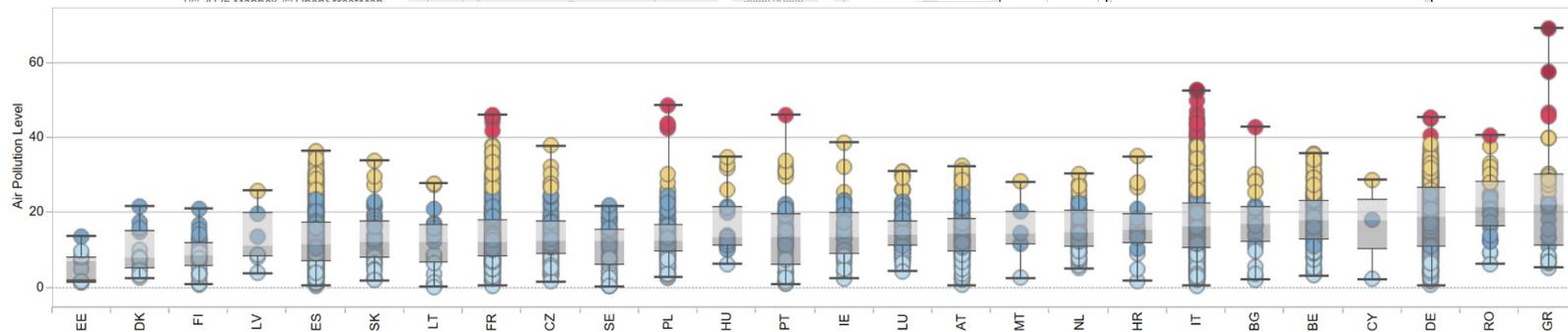
# Observations for reporting obligations



European Environment Agency

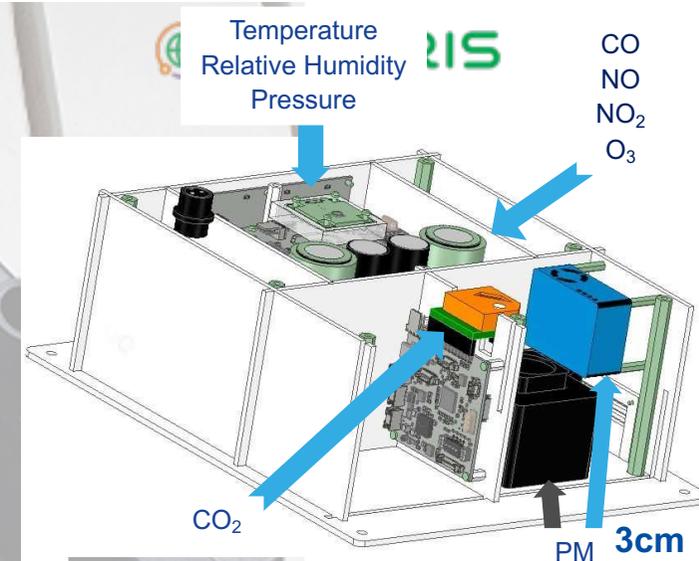


← Above the limit value

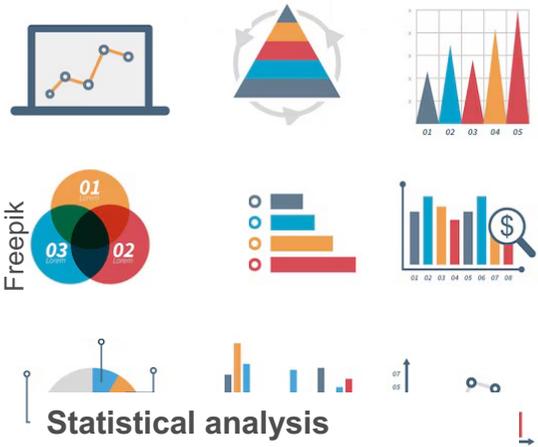


# Low-cost sensor systems

- 1) Allow for a finer scale assessment
- 2) Increase spatial cover over the territory
- 3) Suffer from higher level of uncertainties
- 4) Technological improvements led to more accurate measurements
- 5) Are practical options

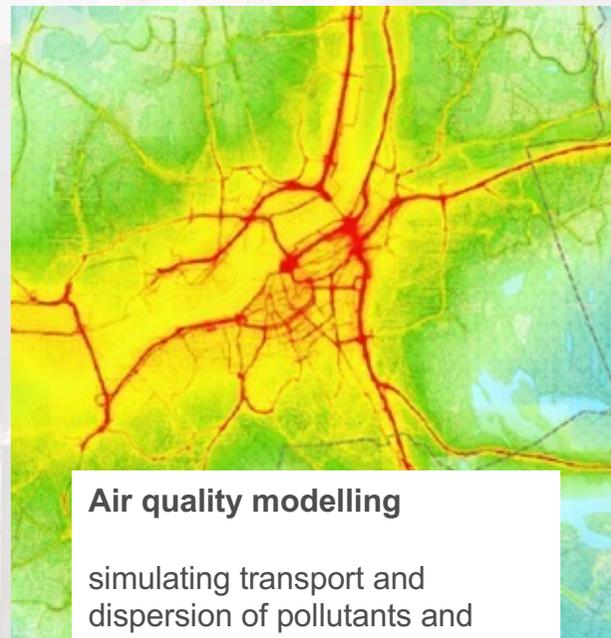


# Analytical tools and methods



**Statistical analysis**

time-series analysis, spatial analysis, and statistical modeling: R, Python, and specialized software



**Air quality modelling**

simulating transport and dispersion of pollutants and understanding source contributions



**Machine learning and Artificial Intelligence**

machine learning models can predict air quality levels based on historical data and weather patterns

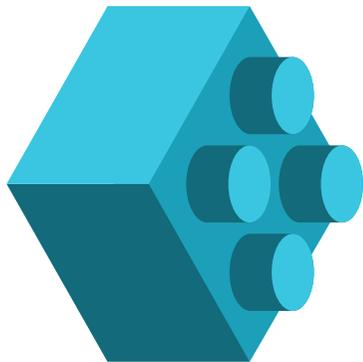
# Understanding air pollution through models

Main components

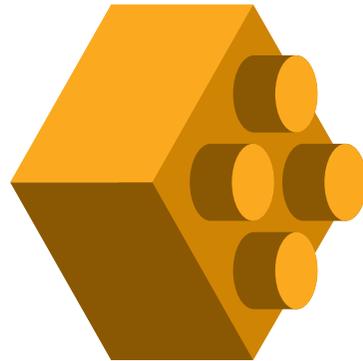
Chemical processes

**Other components**

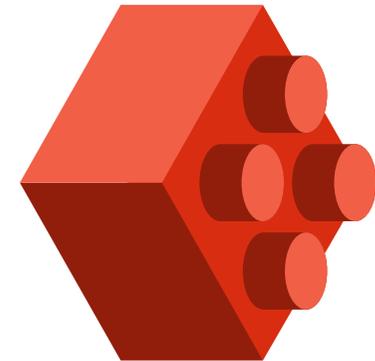
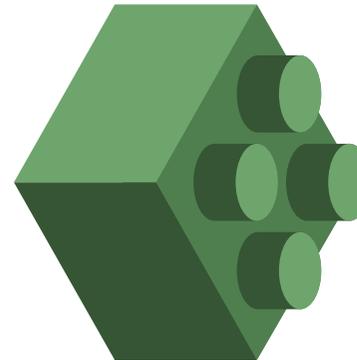
Topography, land use, wet and dry deposition of pollutants



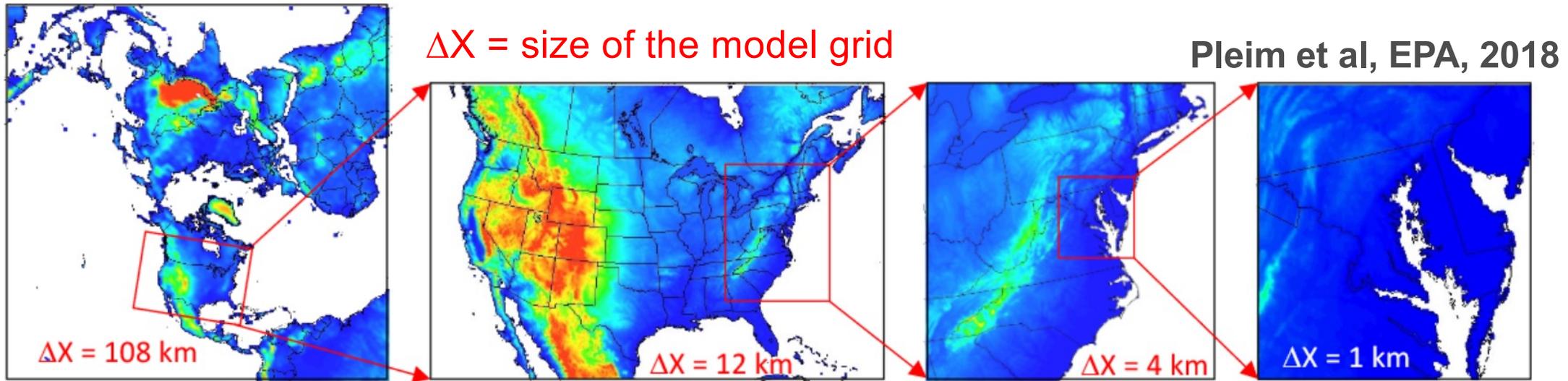
**Emissions**



**Meteorology**



# From global to local scale

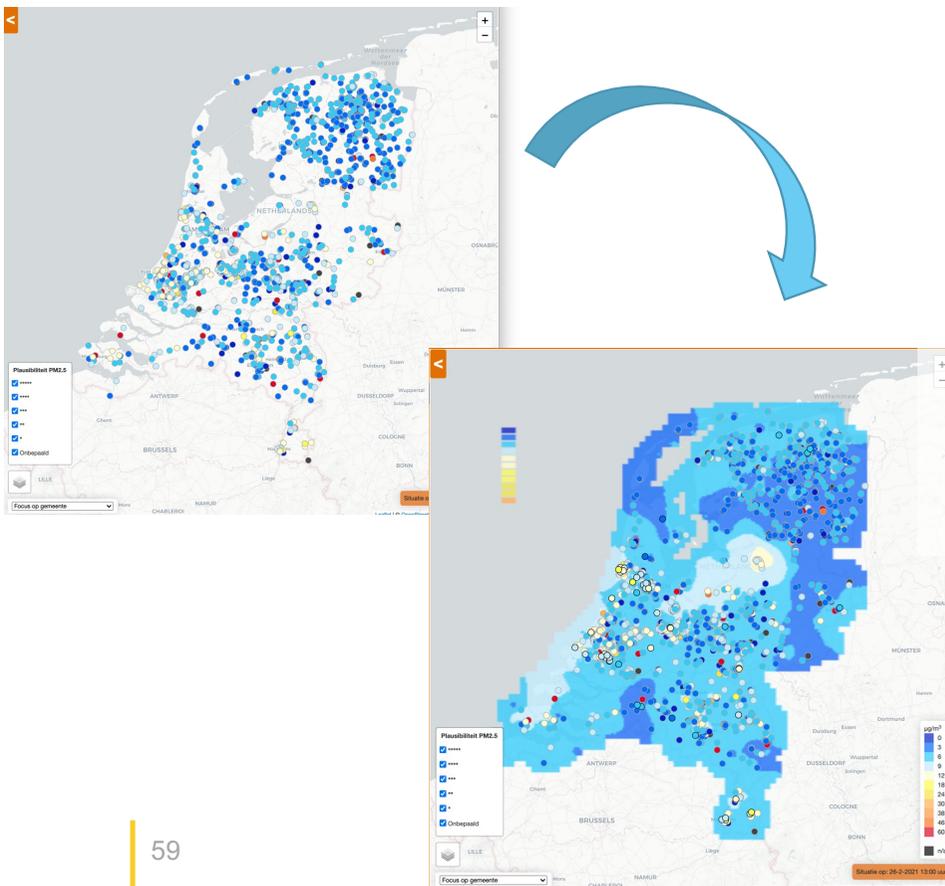


## Best use

- Long range transport
- Background pollution levels
- International policy assessments
- National/regional air quality planning
- Policy scenario assessment
- Episode analysis
- Urban air quality
- Hotspot identification
- Health exposure analysis

# Integrating measurements and models

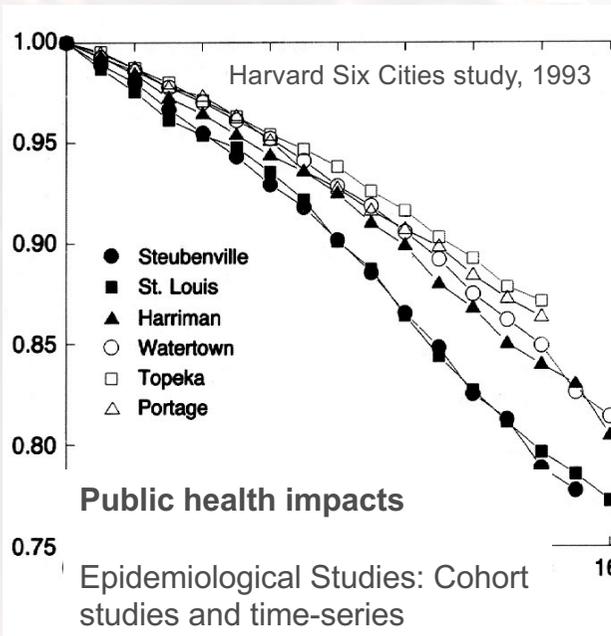
*each with distinct strengths and limitations*



1) Model uncertainties mitigated through model validation with observations or their integration (data assimilation)

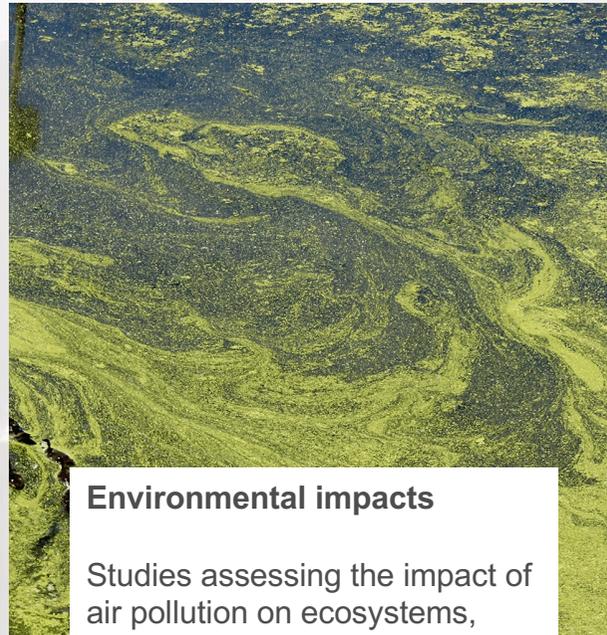
2) Model offer support in interpolation of measurements

# Assessing Impacts of Air Quality



## Public health impacts

Epidemiological Studies: Cohort studies and time-series analyses that link air pollution exposure to health outcomes



## Environmental impacts

Studies assessing the impact of air pollution on ecosystems, including acid rain and its effects on forests and lakes and on crop yields



## Economic impacts

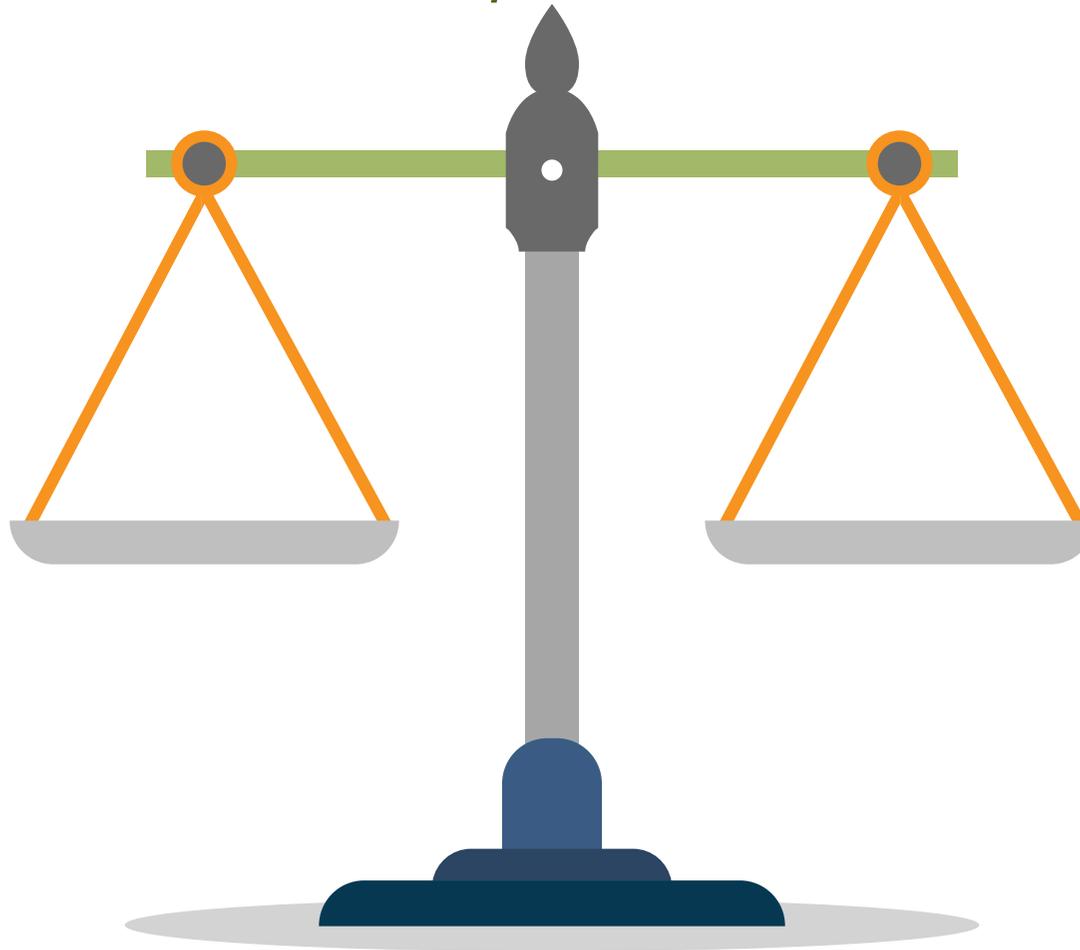
Cost-Benefit Analysis: economic models are used to assess the financial impact of air pollution on healthcare costs and productivity

# Is clean air worth it?

*evaluating economics behind pollution control*

## Costs

- Curb air quality emissions
- Administrative actions to improve AQ management



## Benefits

- Health
- Environmental
- Economic
- Social

# Cost-Benefit Analysis for EU policies

*How cost-benefit analysis shaped the new Air Quality Directive*

Attainment WHO  
guidelines



		Baseline	Policy option 3	Policy option 2	Policy option 1
		2025		To attain in 2030	
Air Quality standard	PM <sub>2.5</sub>	25 µg/m <sup>3</sup>	15 µg/m <sup>3</sup>	10 µg/m <sup>3</sup>	5 µg/m <sup>3</sup>
	N <sub>2</sub> O	40 µg/m <sup>3</sup>	30 µg/m <sup>3</sup>	20 µg/m <sup>3</sup>	10 µg/m <sup>3</sup>
<b>Key economic impacts</b>					
Mitigation costs		0	€ 3.3 bn	€ 5.6 bn	€ 7.0 bn
Benefits		0	€ 29-90.4 bn	€ 36.2-115.7 bn	€ 37.9-123.6 bn

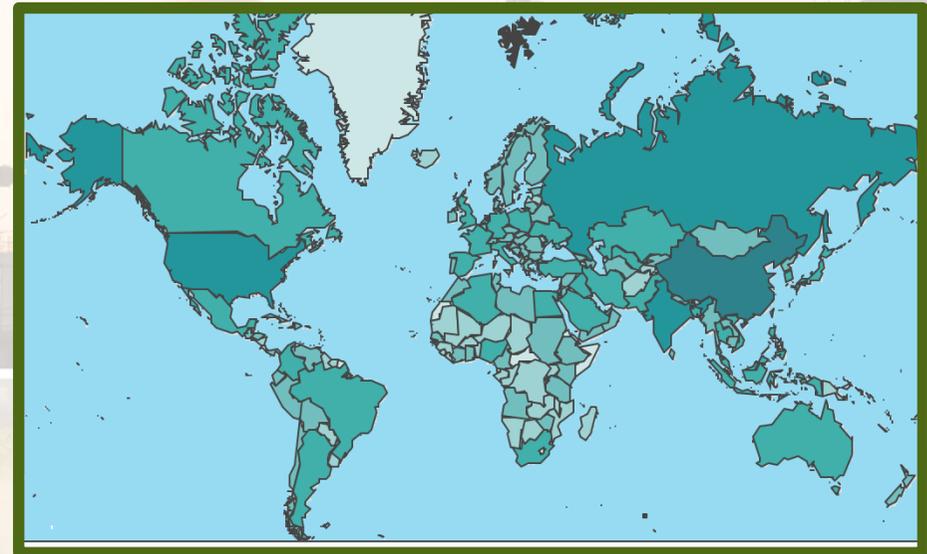
**chosen  
option**

Impact Assessment Report, SWD(2022) 545 final, 2022

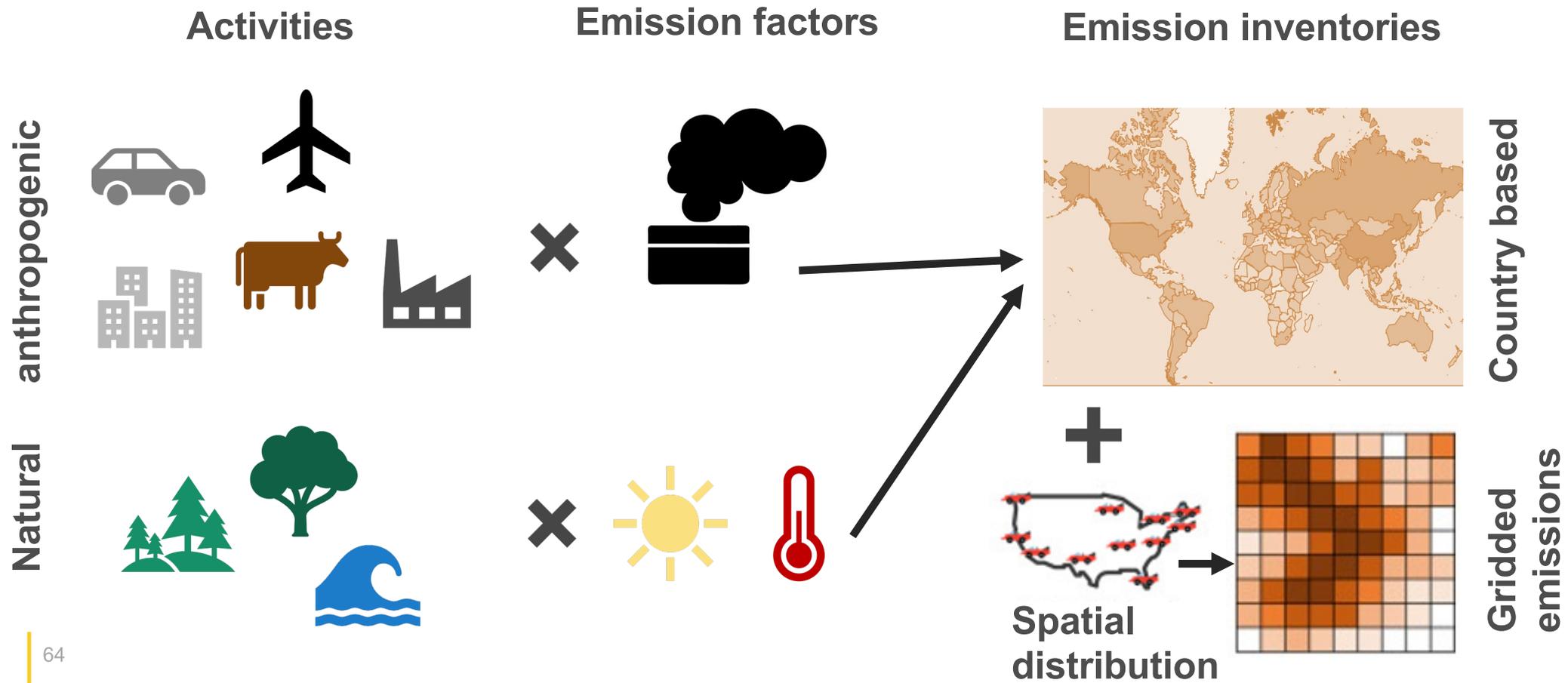
# Emission inventories

*central data to climate and air quality modelling and policy*

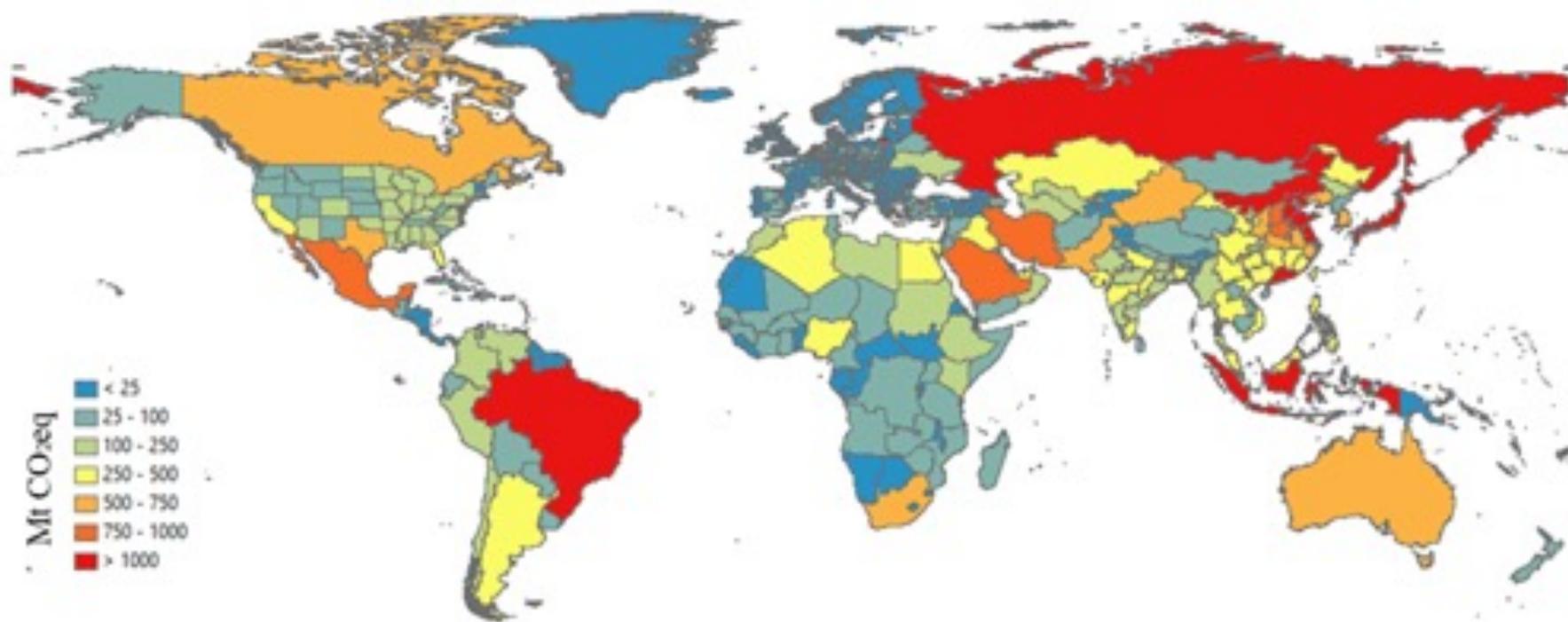
An emissions inventory is a database that lists, by source, the amount of pollutants discharged into the atmosphere during a time period



# How to compile them?



# Global greenhouse gas emissions

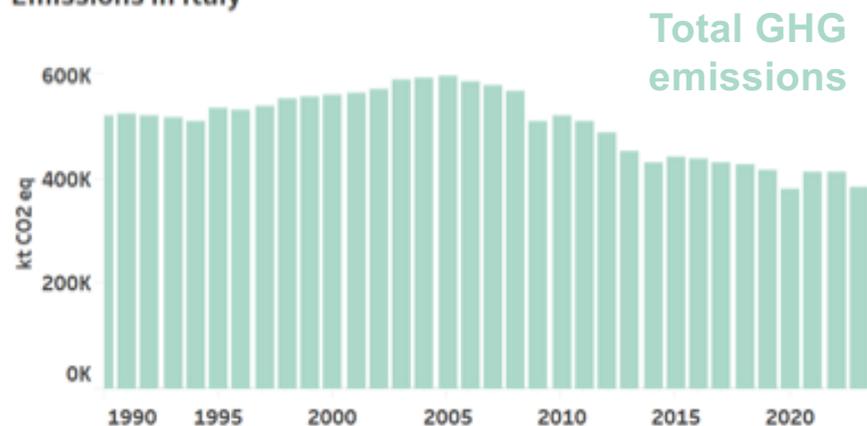


At national and subnational level

Crippa et al, ESSD, 2024

# Inform about the status of country emissions reporting obligations; checking the target achievement

Emissions in Italy



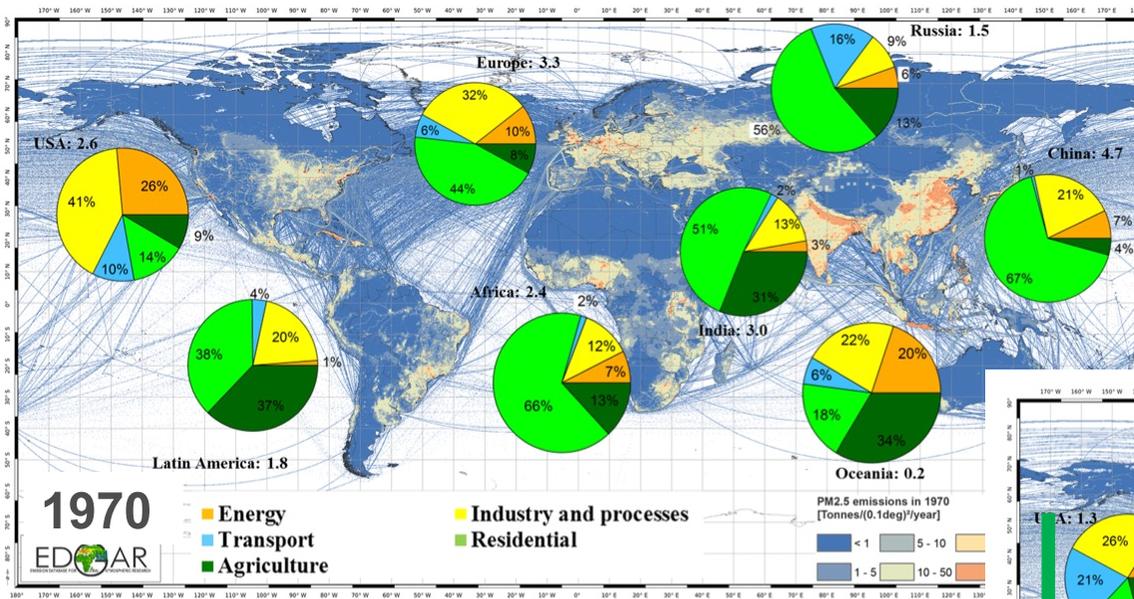
European Environment Agency, 2025

Italy  
EU27

Total net GHG emissions 2022-1990 (% change)	Total net GHG emissions 2022-2015 (% change)	GHG intensity of GDP 2022-2015 (% change)	Projected net GHG emissions by 2030 (tonnes per capita)	Projected net GHG emissions by 2050 (tonnes per capita)
<b>-25%</b>	<b>-4%</b>	<b>-9%</b>	<b>5.3</b>	<b>4.6</b>
-32%	-10%	-20%	5.1	3.6

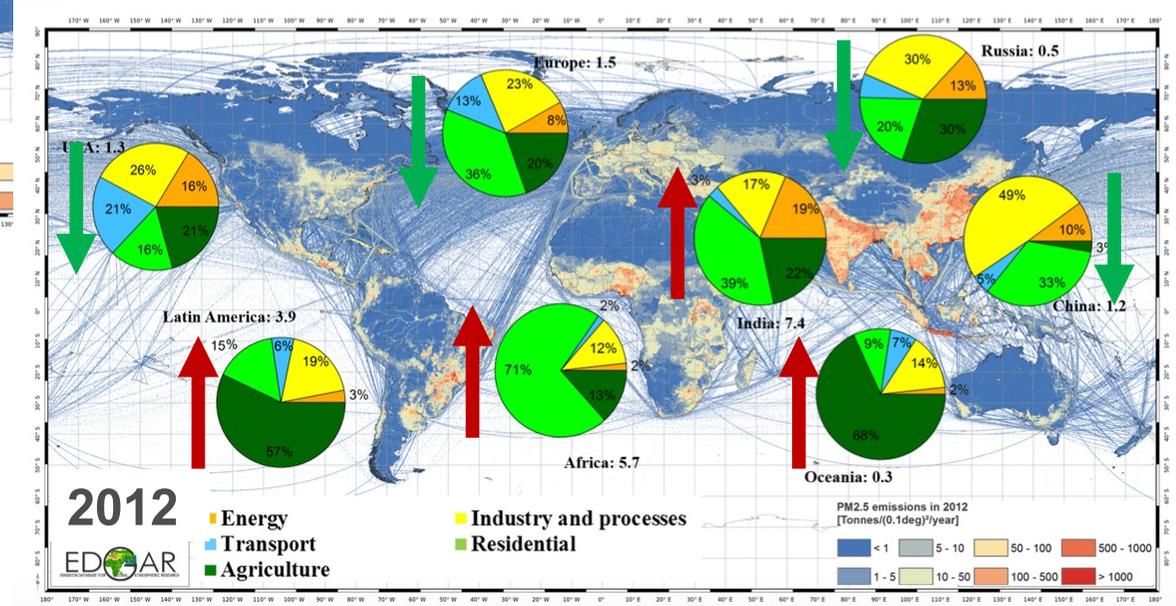
Climate Action Progress Report 2023, Country profile: Italy

# Tracking changes in air pollutant emissions for policy and scientific purposes



PM<sub>2.5</sub> emissions

Crippa et al, ESSD, 2018



# Questions?



"You question my methodology? Perhaps you should question your questionology."

 Using one scientific method we discussed today, what environmental question would you try to answer and why?



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# THANKS!

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**IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System**  
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-  
Mission 4 “Education and Research” - Component 2: “From research to business” - Investment  
3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

