$PM_{2.5}$ sources, health impacts and costs in EU Enlargement countries

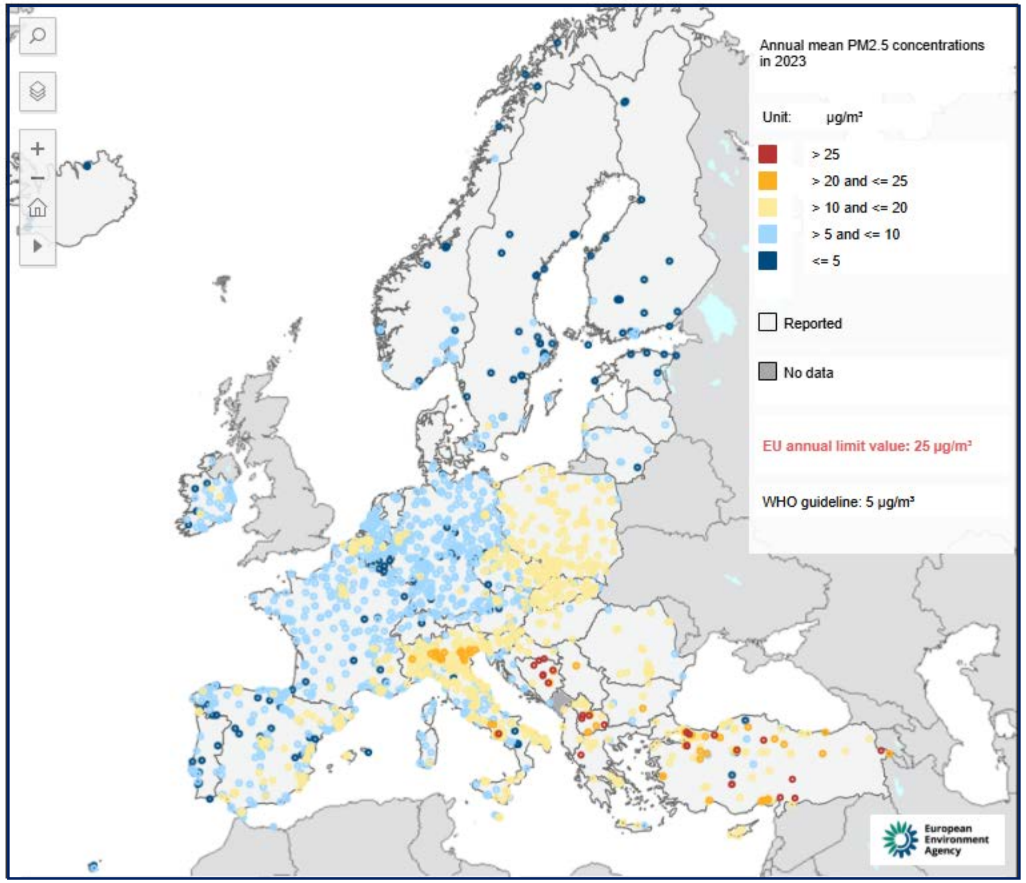
Claudio A. Belis, Project leader, Unit Clean Air and Climate

55th session of the Task Force on Integrated Assessment Modelling
22 – 23 April 2026, Brussels, Belgium

Outline of the presentation

- Air Quality in the Enlargement countries
- Methodology
- Target oriented cost-benefit analysis in the Western Balkans
- Sources of $PM_{2.5}$ in cities of EU Enlargement policy region
- Conclusions

Air Quality in the Enlargement region

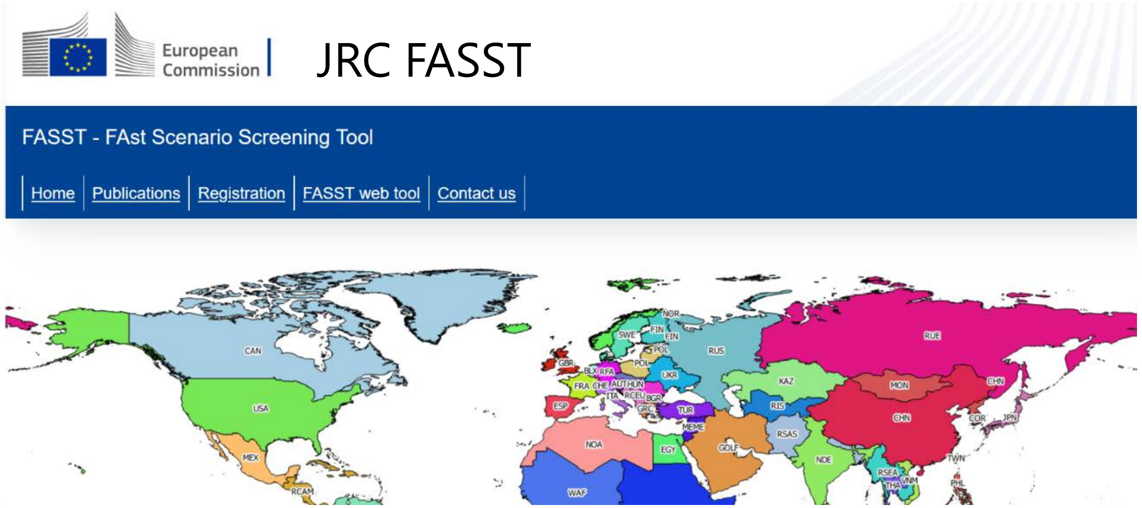


In many cities from countries involved in the EU Enlargement policy pollution levels are frequently above the EU limit values currently in force and the guidelines of the World Health Organization (WHO, 2021).

Despite the decreasing $PM_{2.5}$ and PM_{10} trend reported between 2017 and 2023 in most Western Balkan economies, the EU limit values currently in force are not always achieved (Belis et al., 2024).

The health impacts of $PM_{2.5}$ in Western Balkans are considerable higher than those in the EU (Belis et al., 2023).

JRC Integrated Assessment Tools for Air Quality


European Commission | JRC FASST

FASST - FAst Scenario Screening Tool

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https://tm5-fasst.jrc.ec.europa.eu/

Impacts of emissions on:
- Health (mortality, morbidity),
- Agricultural crop yields,
- Radiative forcing of SLCP
- Economic valuation of impacts

Domain: Global Country level

jenvman.2022. v 219 115738
ACP, 2023, v 23, 8225–8240


SHERPA
Screening for High Emission Reduction Potential on Air

European Commission
Joint Research Centre

Scenario Analysis

This module answers the following question: What is the impact of a given emission reduction scenario (e.g. a specific air quality plan) on air quality in my region? Based on a user selected control area where specific emission reductions are applied, SHERPA produces an air quality impact map over the selected region and surrounding areas. Emission reduction percentages can freely be introduced by the user in terms of sectors and precursors. This module also computes costs of the end-of-pipe technologies needed to reach the required emission reductions. The computation is based on the GAINS database of measures.

Source allocation

Sectoral

This module answers the following question: What is the relative contribution of the various emission sectors to the overall impact of an emission reduction strategy? Based on a user selected control area where emission reductions are applied, SHERPA produces source apportionement estimates in terms of sectors.

By clicking on this module, you can also access to the "Urban PM2.5 Atlas, 2023 report" results for more than 700 EU cities.

Precursors

This module answers the following question: What is the relative contribution of the various emission precursors to the overall impact of an emission reduction strategy? Based on a user selected control area where emission reductions are applied, SHERPA produces apportionement estimates in terms of precursors.

Version: 20/11/2023

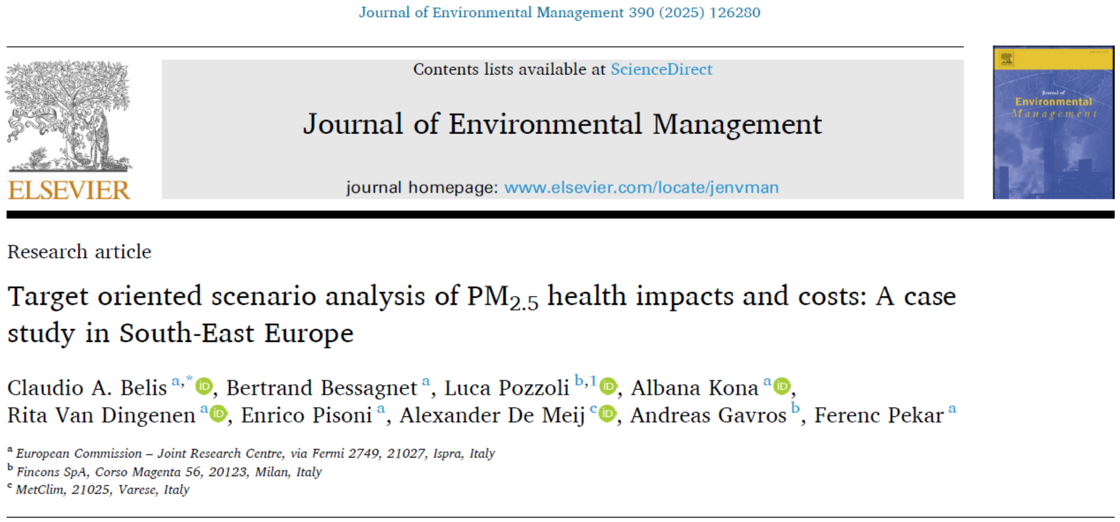
https://aqm.jrc.ec.europa.eu/Section/Sherpa/

- Scenario Analysis
- Sectoral Analysis
- Precursor Analysis

Domain: Europe, national – regional levels

EMS, 2024, v176, 106031

Target oriented Cost Benefit Analysis



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Research article

Target oriented scenario analysis of $PM_{2.5}$ health impacts and costs: A case study in South-East Europe

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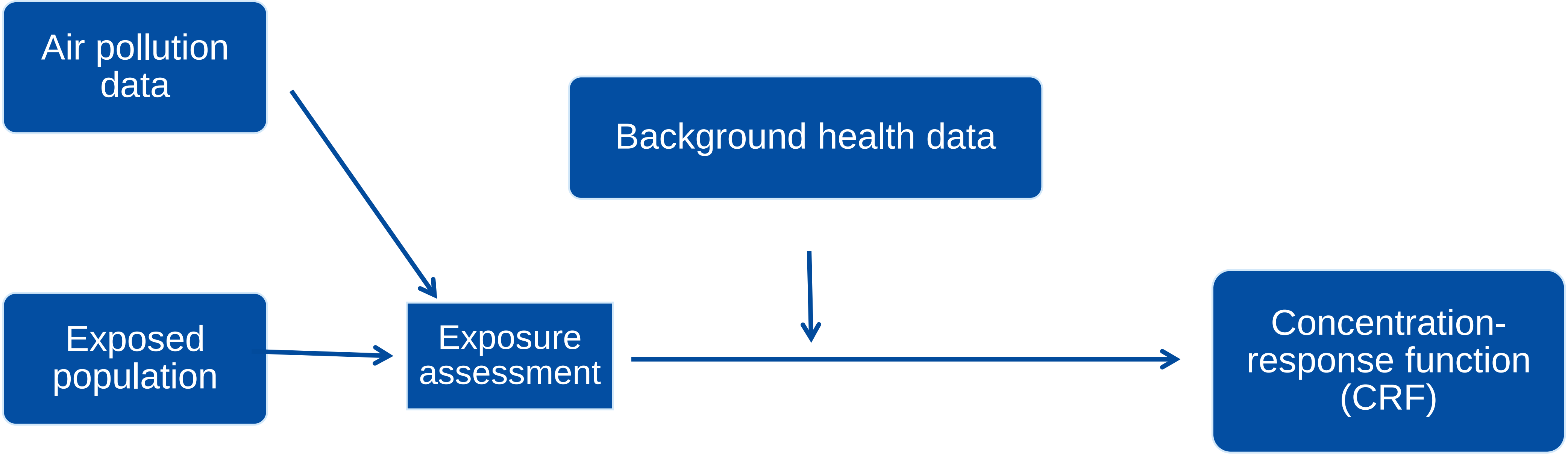
The objective of the present study is to assess the national emission reduction potential for $PM_{2.5}$ precursors compatible with the Zero Pollution Action Plan target (-55% mortality) in the Western Balkans, and to identify a cost-effective reduction strategy to achieve such target*.

Steps

1. Emission scenarios from energy and climate models (input)
2. Air quality modelling (JRC FASST)
3. Health impact assessment
4. Target oriented filter (optimisation) to compute emission reduction needed to achieve ZPAP target
5. Additional reduction scenarios (ARS)
6. Health impact valuation
7. Estimation of the cost of measures

*The methodology adopted in this study is different from the one used in the impact assessment underpinning the NEC Directive and proposing binding emission reduction commitments for the Western Balkan economies is beyond the purpose of this work.

Health Impact Assessment (FASST*)


Air pollution data

Exposed population

Exposure assessment

Background health data

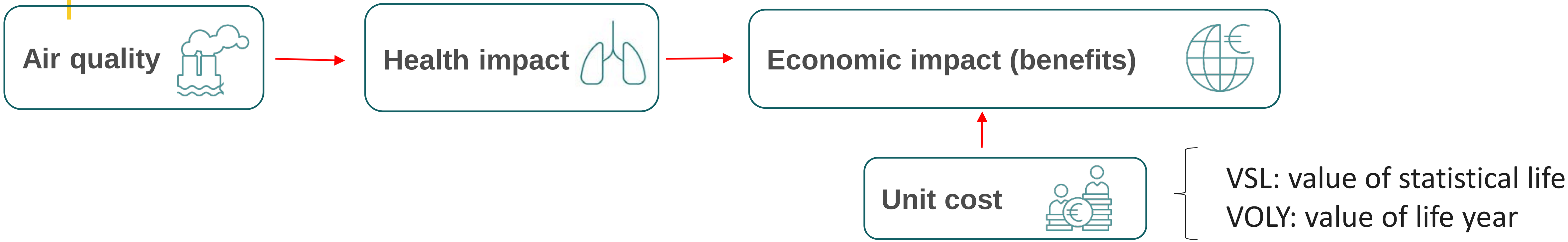
Concentration-response function (CRF)

Pollutant	Metric	Type	Health outcome	CRF central	CRF low	CRF high	Interval (µg/m^3)	Source
$PM_{2.5}$	annual mean	mortality	Mortality, all-cause (natural)	1.08	1.06	1.09	10	Chen and Hoek, 2020

* FASST is the JRC FAst Scenario Screening Tool (https://tm5-fasst.jrc.ec.europa.eu)

Health cost (=benefit) estimation

Quantification of costs (benefits) is one the elements needed to support policy decisions.



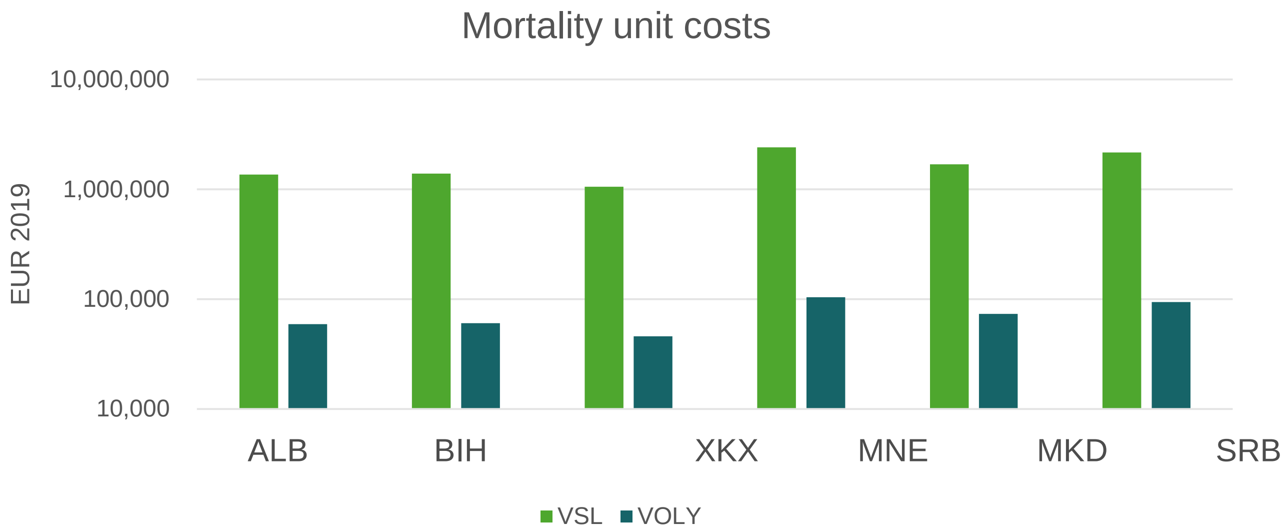
Air quality → **Health impact** → **Economic impact (benefits)**

Unit cost → **Economic impact (benefits)**

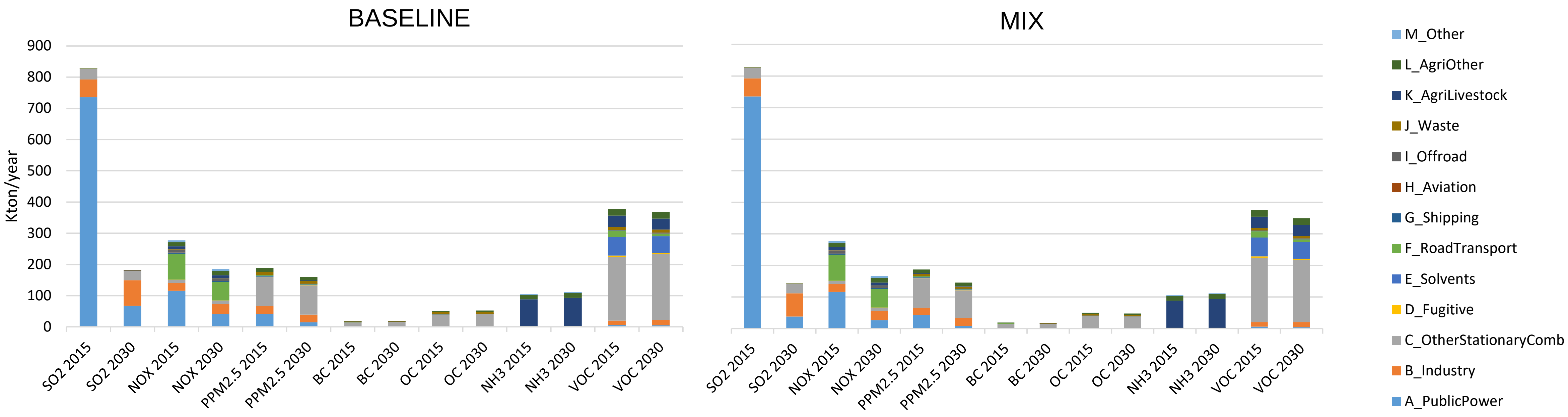
VSL: value of statistical life
VOLY: value of life year

Unit cost

VSL estimated by
Willingness to Pay method (OECD, 2012)
Derived by value transfer based on GDP per capita
VOLY was derived from VSL



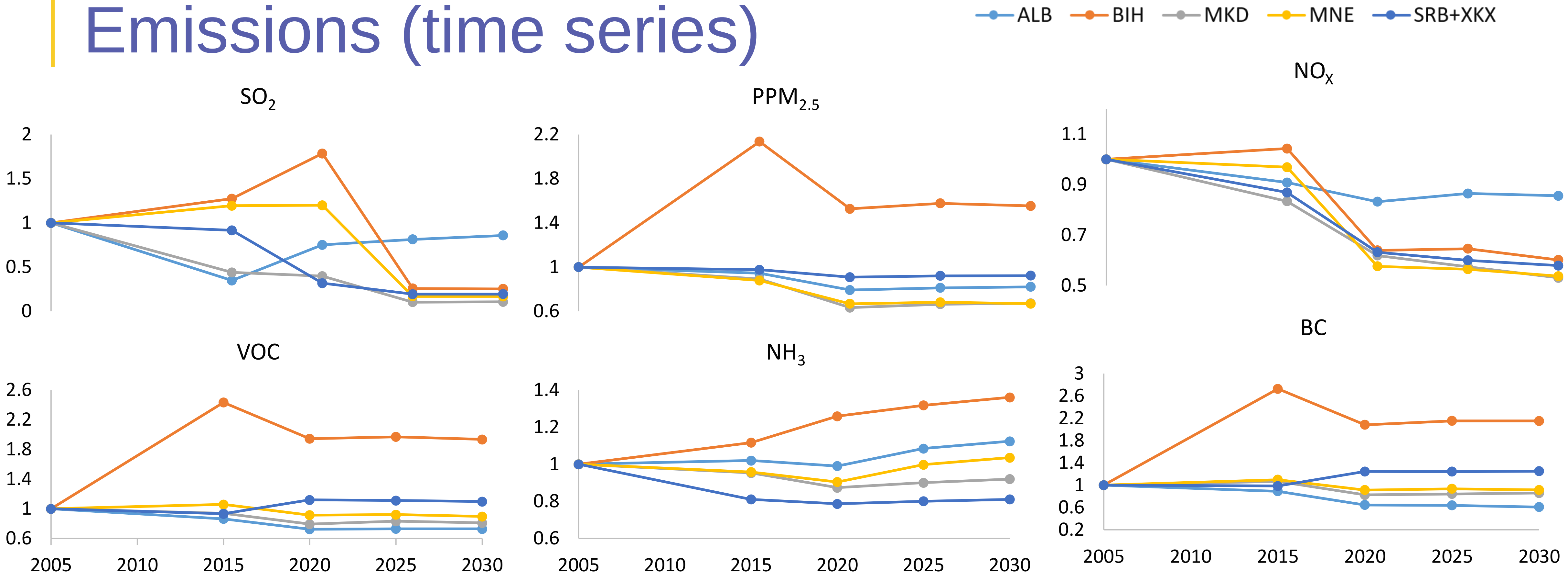
Emissions (from previous work)



Western Balkans 2015; 2030 emissions by precursor and by sector in the BASELINE and MIX scenarios.

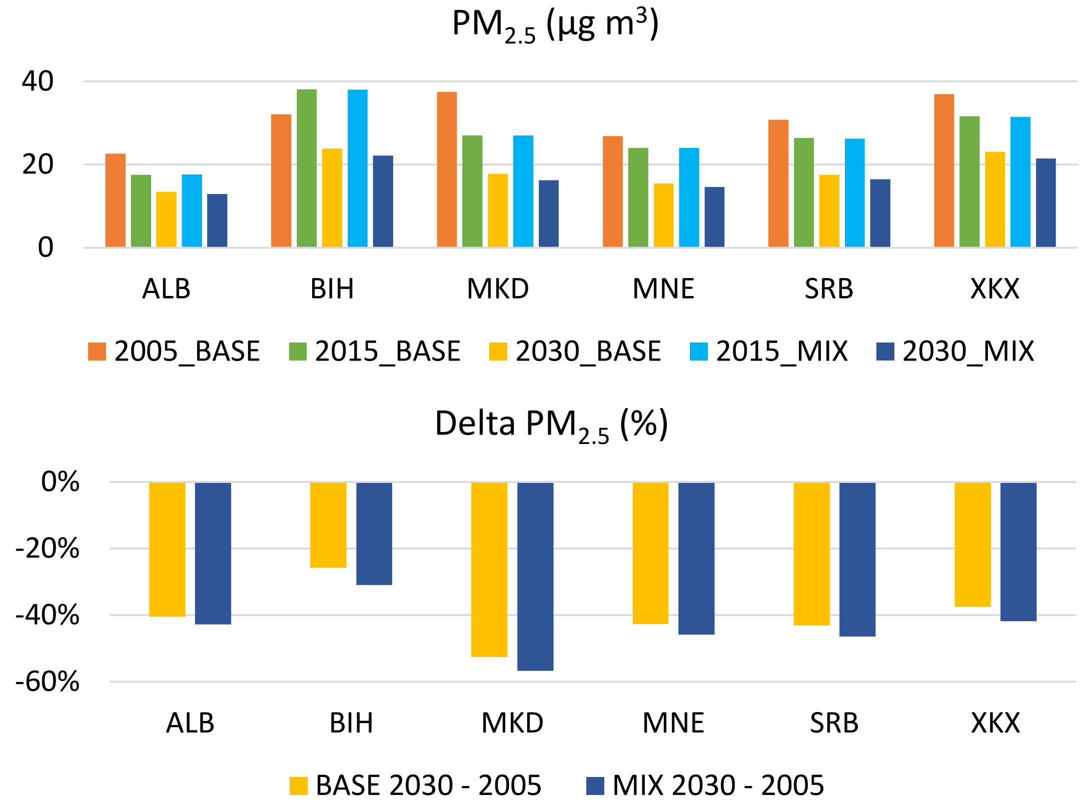
The air pollution emission scenarios used as input for this study were produced by E3 Modelling S.A. Consulting Services and IIASA for DG ENER in the frame of the project “Extension of the EU energy and climate modelling capacity to include the Energy Community and its nine Contracting Parties”.

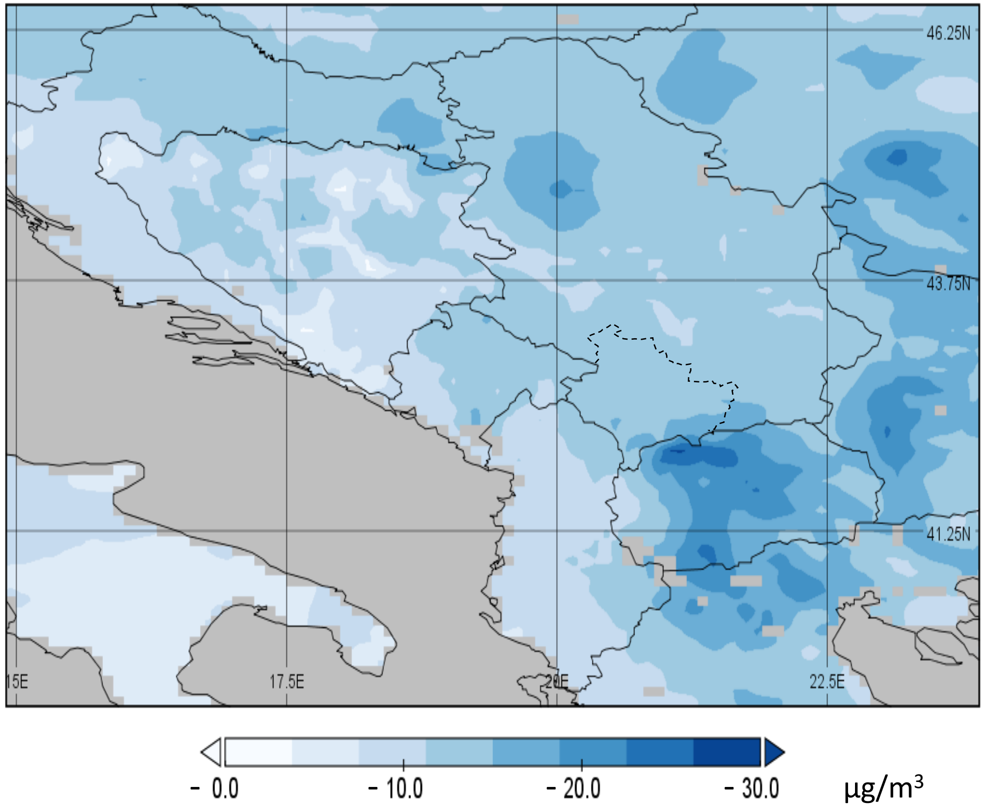
Emissions (time series)



Ratios of $PM_{2.5}$ precursors' emissions compared to year 2005 in the WB economies based on BASELINE emissions. Sulphur dioxide (SO_2), nitrogen oxides (NOx), ammonia (NH_3), volatile organic compounds (VOC), black carbon (BC) and Primary Particulate Matter ($PPM_{2.5}$). OC (not shown) follows the same trend as BC.

Concentrations (JRC FASST)





Population weighted mean of PM$_{2.5}$ concentration (left top) and variation (left bottom) in 2030 compared to 2005 by WB economy in both scenarios BASELINE and MIX. Difference map of PM$_{2.5}$ concentration between 2030 and 2005 in the BASELINE scenario (right).

Target oriented filter 1

In this study, we consider the objective **function z** = f(x_1, x_2, x_3, x_4): f (ΔSO_2, ΔNH_3, ΔNO_x, $\Delta PPM_{2.5}$) is a function that correlates the reduction of concentration ($\Delta PM_{2.5}$) as a function of reductions of the precursor emission (i.e. ΔSO_2, ΔNH_3, ΔNOx, $\Delta PPM_{2.5}$)

The **function *g*** correlates the reduction in mortality to the reduction of concentration $\Delta PM_{2.5}$, and therefore a function of reductions of the precursor emission in percentages (i.e. ΔSO_2, ΔNH_3, ΔNO_x, $\Delta PPM_{2.5}$)

The function *g* is subject to the **constraint** (x_1, x_2, x_3, x_4) = D_{EMT} ,
where the D_{EMT} is the delta mortality between the ARS scenario and the mortality in year 2005, defined as

$D_{EMT} = (1 - 0.55)*\mathit{Mortality}_{2005}$.

In our case the constraint is equal to the ZP target, i.e. - 55 % $\Delta PM_{2.5}$.related mortality in 2030 compared to 2005.

Target oriented filter 2

The Lagrangian problem is:

$$\min (L = (f(x_1, x_2, x_3, x_4) - \lambda^*[D_{EMT} - g(x_1, x_2, x_3, x_4)]))$$

the first ordinary condition for an extremum (min or max) of a n-variable function expressed as total differential is set to zero.

This lets to a system of five equations in five variables from which to find the critical values of $x = (x_1, x_2, x_3, x_4)$ and λ which represents the sensibility of the function f (delta concentration) against mortality target.

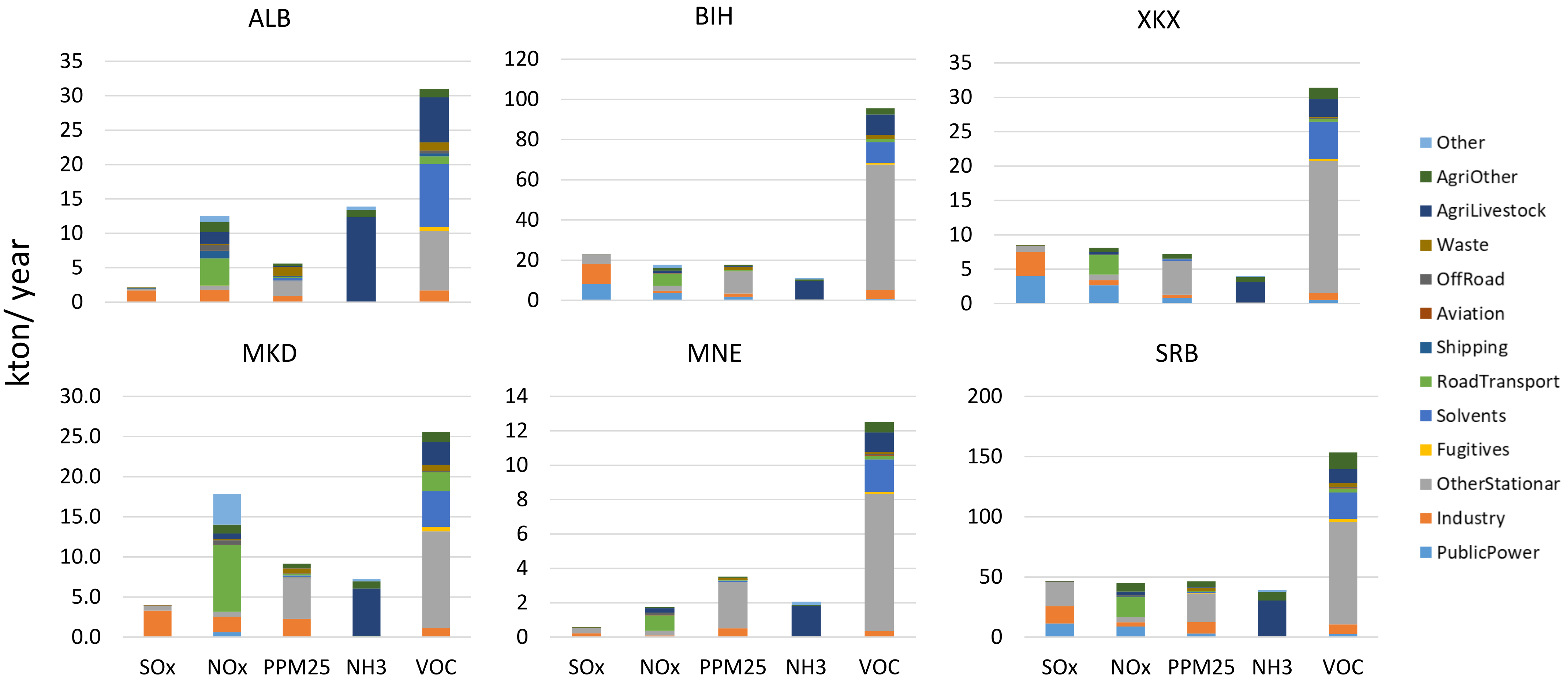
$$\delta L / \delta\lambda = D_{EMT} - g(x_1, x_2, x_3, x_4) = 0$$

$$\delta L / \delta x_i = \delta f / \delta x_i - \lambda^* \, \delta g / \delta x_i = 0 \text{ (for I = 1 to 4)}$$

Combination of $PM_{2.5}$ precursor emission reductions (ARS) closest to the 55% premature mortality reduction target by economy

		Additional emission reduction to MIX scenario by $PM_{2.5}$ precursor (%)				Reduction (%)
Code	WB economy	PPM2.5	SO_2	NH_3	NO_x	$PM_{2.5}$ mortality
ARS2	ALB	40	30	25	40	-55%
ARS2	BIH	60	55	60	55	-55%
ARS2	MNE	20	5	10	20	-55%
ARS2	SRB	40	25	25	25	-68%
ARS2	XKX	40	25	25	25	-55%

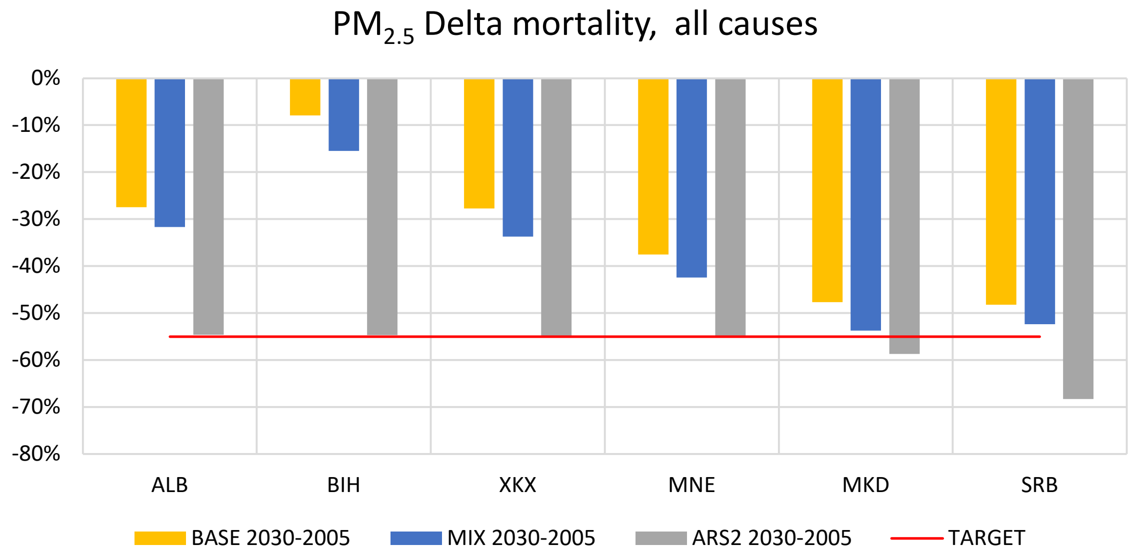
Emissions in the new scenario ARS2

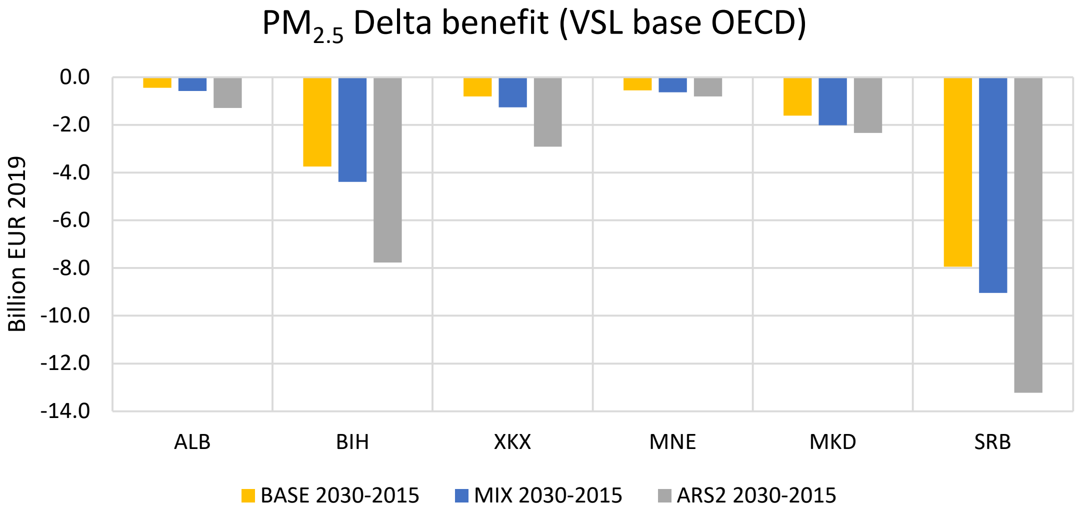


Emissions in 2030 with sector for each WB economy in scenario ARS2

Mortality and benefits

Mortality (all causes) attributable to $PM_{2.5}$ (# of attributable deaths) by WB economy between 2005 and 2030 in the BASELINE (BASE) and MIX scenarios (pre-existing) and in the enhanced scenario ARS2.





Delta of benefits in 2030, with respect to 2015, in the original scenarios: BASELINE (BASE) and MIX and in the new scenario ARS2.

European Commission

Cost of measures

Steps of the cost calculation algorithm

1. Conversion from GNFR to IIASA sector naming:

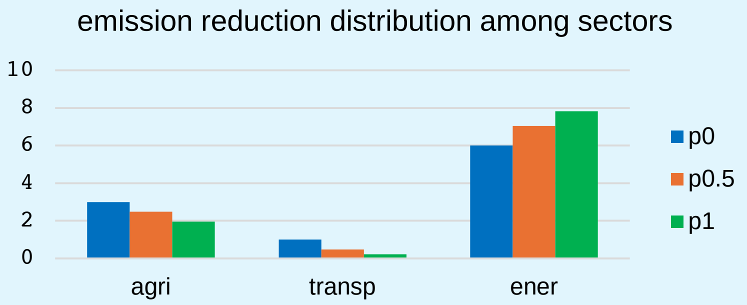
GAINS measures were matched with the 13 GNFR according to conversion table (CEIP, 2019; Bessagnet et al., 2022)
Matrix computed at the country level

2. Rank the technologies *T* from the lowest to the highest removal efficiency η (new list *T**)
3. Starting from the lowest to the highest *h*, move from technique m^0 toward the best technology m^x whatever its unit cost (*cn*) but no change of activity
4. Calculate marginal cost *MC* for each substitution

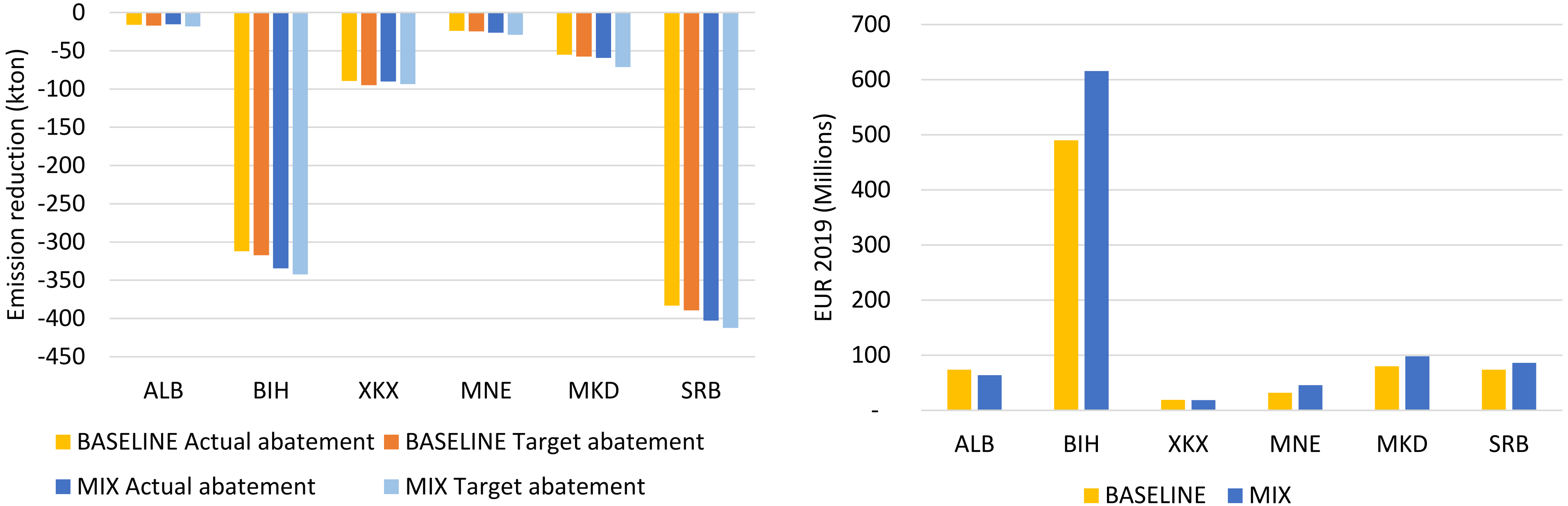
$$MC\left(T^*_{m^o}, T^*_{m^x}\right) = \frac{cn_{m^x} \times \eta_{m^x} - cn_m \times \eta_m}{\eta_{m^x} - \eta_m}$$

5. Sum marginal costs
   - ❑ No double counting if multiple pollutants

Different options were used in the cost calculation algorithm to redistribute the emission abatement of each precursor among the GNFR emission sectors.
The values range from flat reduction (equal proportion in all the relevant emission sectors) p = 0,
to reduction distribution strongly depending on the emissions in each sector, corresponding to a p = 1

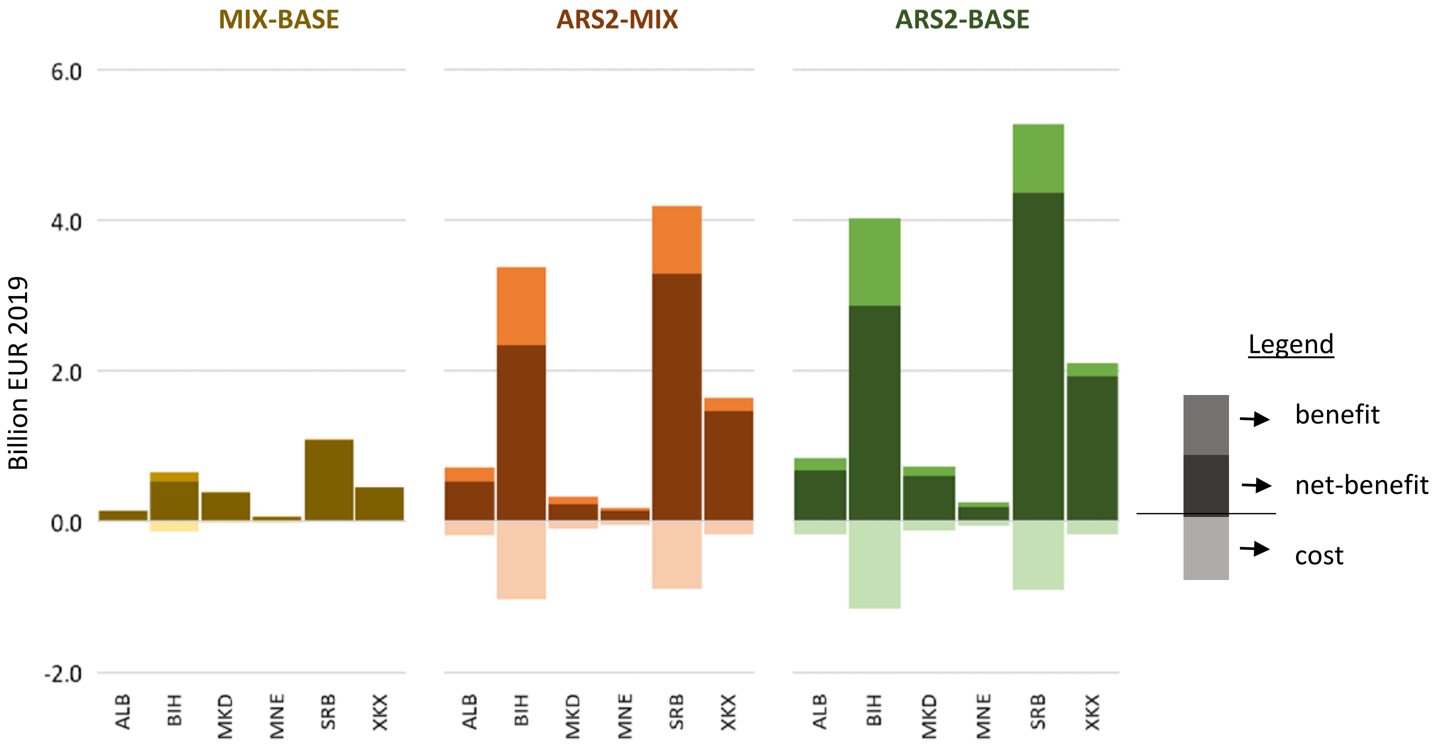


Costs



Reduced emissions in 2030 compared to 2015 in MIX and BASELINE scenarios (left) and estimated costs of measures needed to achieve such abatements (right).

Cost Benefit Analysis



Additional $PM_{2.5}$ benefits, cost and net benefits in 2030 between BASELINE (BASE), MIX and ARS2 scenarios.

The sectors considered in the most efficient emission abatement strategy (ARS2) compared to MIX are:

- **Industry (including energy)**: in ARS2, this sector achieves significant additional reductions in emissions, particularly in SO_2 emissions (ranging from −53 % to −82 %) and NO_x emissions (ranging from −69 % to −78 %).

- **Domestic Combustion**: the scenarios also indicate significant additional reductions in PPM2.5 emissions from this sector (ranging from −20 % to −60 %).

- **Transport**: in ARS2 this sector achieves significant additional emission reductions compared to MIX, particularly in NO_x (ranging from −27 % to −58 %) and NH_3 (ranging from −80 to −84 %).

Conclusions

- A new scenario coherent with the EU Zero Pollution Action Plan was developed by means of a target oriented filter (in terms of mortality reduction)

- The new target oriented (ARS2) to reduce air pollution was obtained in a second step in which reductions were allocated to sectors in a following cost-effective criteria.

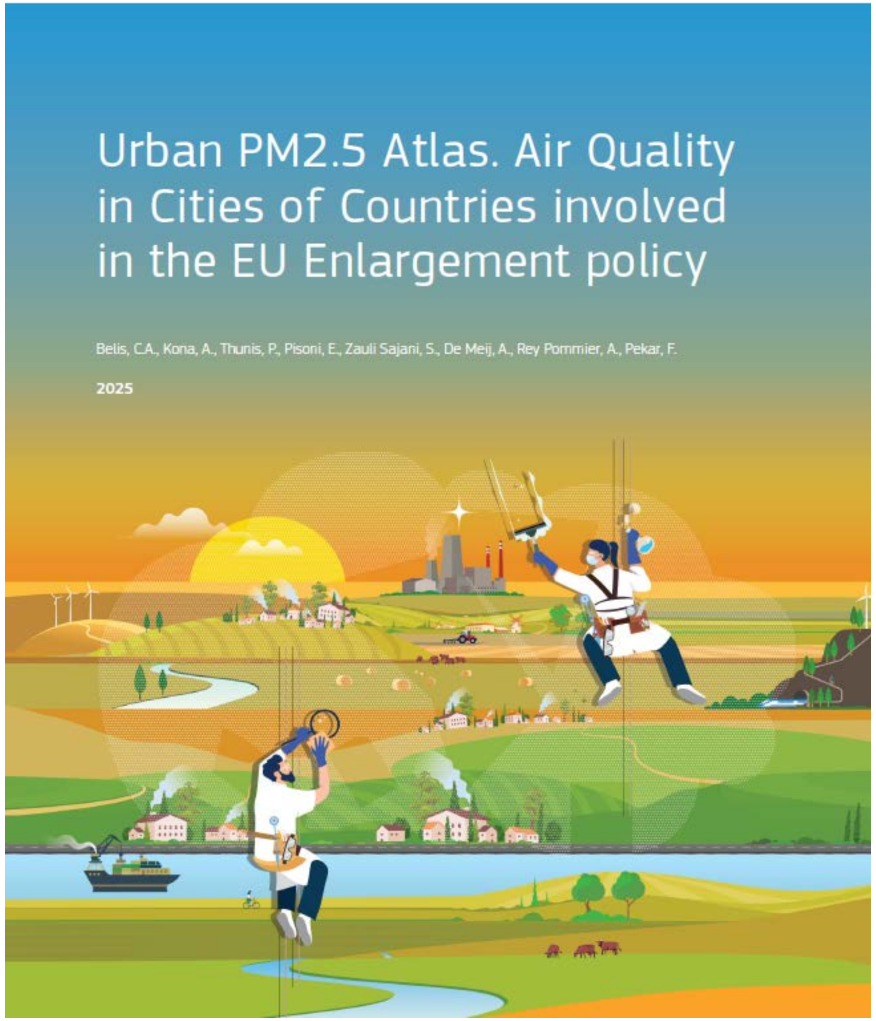
- The ARS2 net benefit is much higher than the pre-existing scenarios BASELINE and MIX although its benefit-cost ratio is lower.

- Achieving further premature mortality reductions in the ARS2 scenario through emission abatement in the WB region implies significantly higher marginal costs, mainly in BIH and SRB.

- In ARS2 main reductions are in power, industry, domestic combustion and transport sectors.

Target oriented scenario analysis of PM2.5 health impacts and costs: A case study in South-East Europe
https://doi.org/10.1016/j.jenvman.2025.126280

Urban $PM_{2.5}$ Atlas



Urban PM2.5 Atlas. Air Quality in Cities of Countries involved in the EU Enlargement policy

Belis, C.A., Kona, A., Thunis, P., Pisoni, E., Zauli Sajani, S., De Meij, A., Rey Pommier, A., Pekar, F.

2025

- Air Quality management is necessary for the alignment of Enlargement countries with the EU Acquis.
- The objective of the Atlas is to quantify the spatial and sectoral contributions from pollution sources, as encoded in the emission inventories, to help finding the right balance between the action by local authorities and the one at higher levels of governance.
- This Atlas was launched at the 5th EU Clean Air Forum in December 2025.

https://publications.jrc.ec.europa.eu/repository/handle/JRC144080

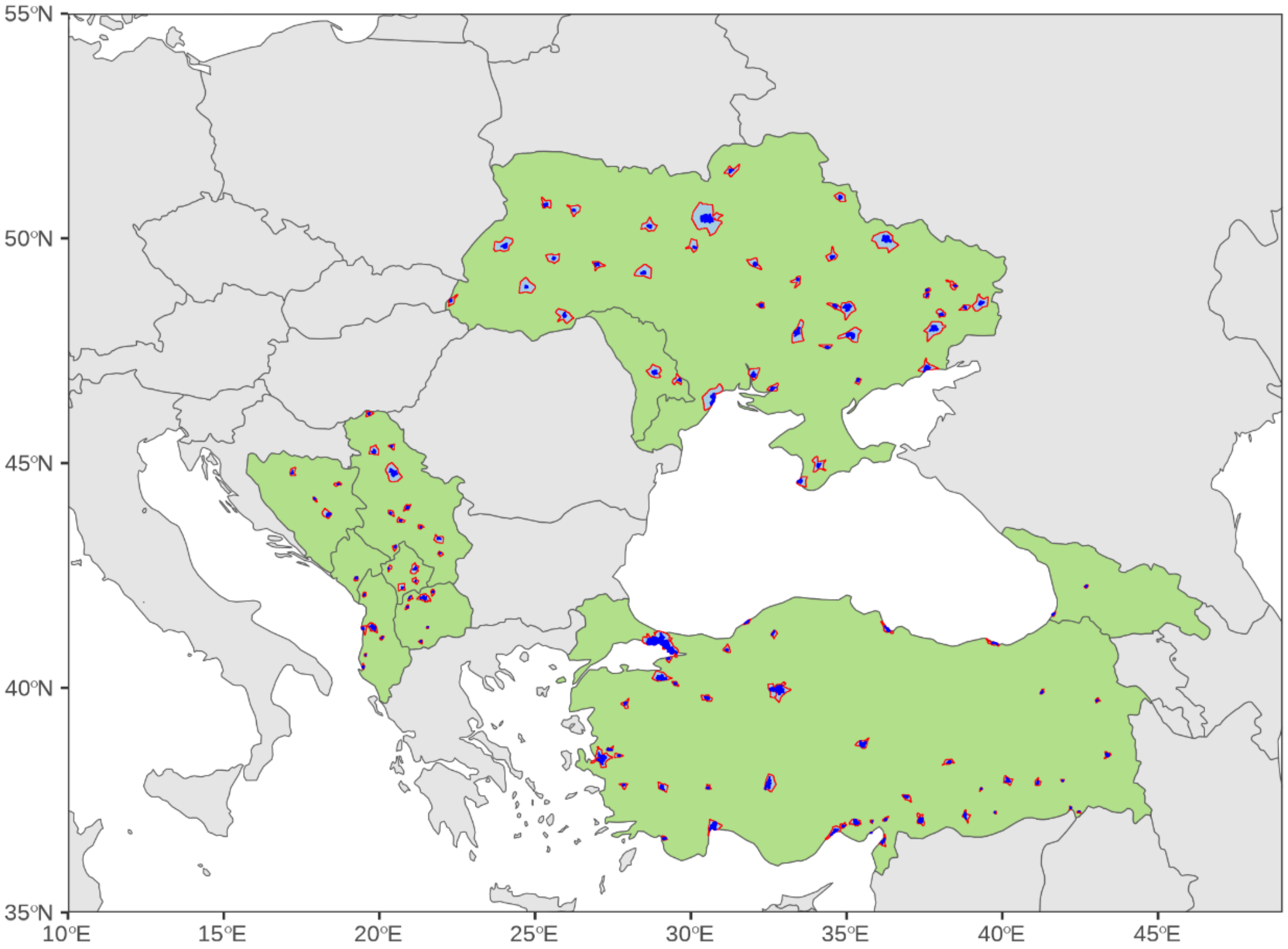
Methodology: the model set up

- SHERPA is based on the **EMEP model** rv4.45 (Simpson et al. 2012) covering the whole of Europe at **0.1 x 0.05 longitude/latitude** (~ 6 x 6 km) spatial resolution. The modelling domain extends from -15 to 45 degrees, longitude wise and from 32.45 to 71.50, latitude wise.
- **Anthropogenic emissions** underlying the model simulations are based on **CAMS** V8.0 emissions (including condensable) per country-pollutant-sector for 2022 based on Denier Van Der Goen et al. (2020) and Kuenen et al. (2022).
- **Meteorological** input data are based on 2021 analysed meteorological fields from the **Integrated Forecast System** (IFS), a global operational forecasting model from the European Centre for Medium-Range Weather Forecasts (ECMWF).

Uncertainties

- SHERPA assumes **linearity** between emissions and concentrations changes and a **bell-shape** function to describe the spatial impact of emissions on concentrations.
- **Spatial resolution** approx. 6 km x 6 km only suitable for greater cities.
- The accuracy depends on the **underlying CTM** model EMEP.
- The **emission inventories** are known to have high uncertainties (Trombetti et al., 2018)
- Due to the **meteorological variability** between years, the meteorology used is valid only for the reference year.
- The impact of sources is estimated at the **location of highest concentration** in the city, this value maybe substantially different in other locations of the city**.**
- the limited information about the influence of **military operations** on emissions in **Ukraine** since 2022 is a non-negligible source of uncertainty in this specific context.

Cities included in this study



City core (in blue) and greater city areas (in red)

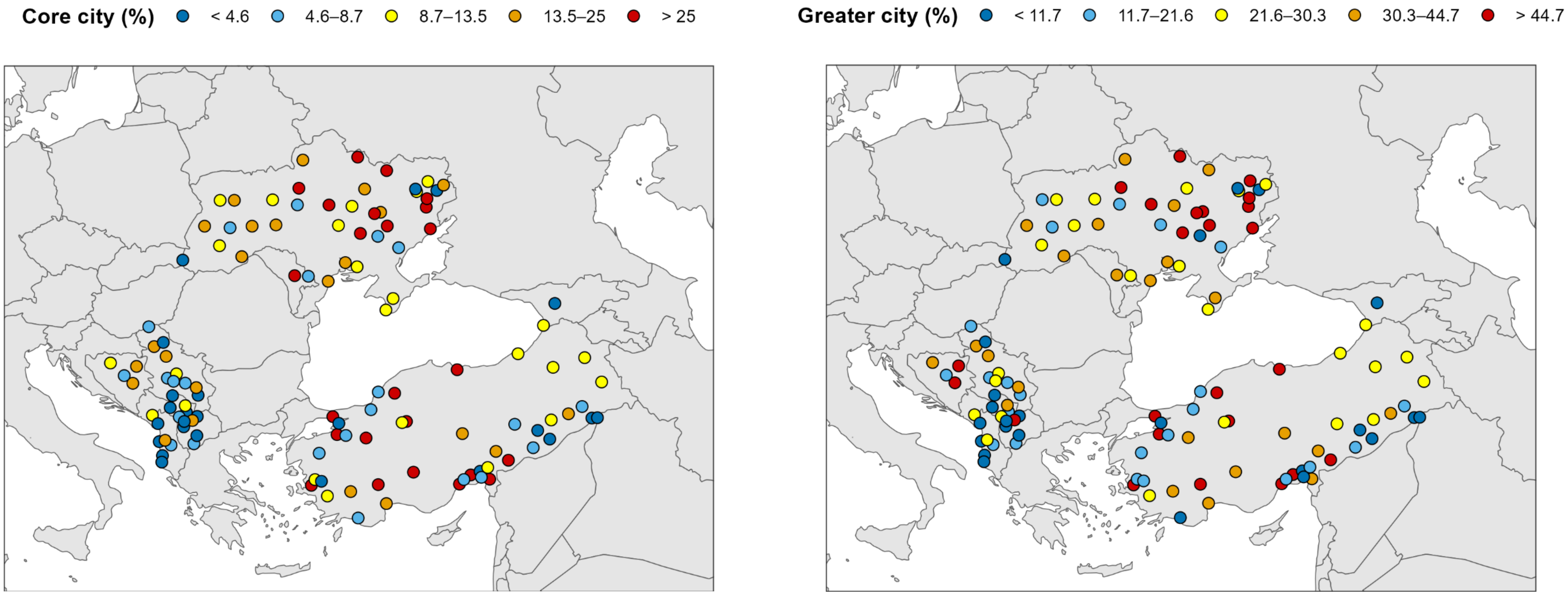
The study covers **118 urban areas** of countries involved in the EU Enlargement policy (Enlargement countries)

Countries are grouped in three regions:

Western Balkans (32) ,
Ukraine and Moldova (40), and
Türkiye and Georgia (46)

Impacts are presented both in terms of **spatial** (city core, greater city, country, transboundary) and **sectoral** (Residential, Road transport Agriculture, Industry, Shipping, Natural, and Others)

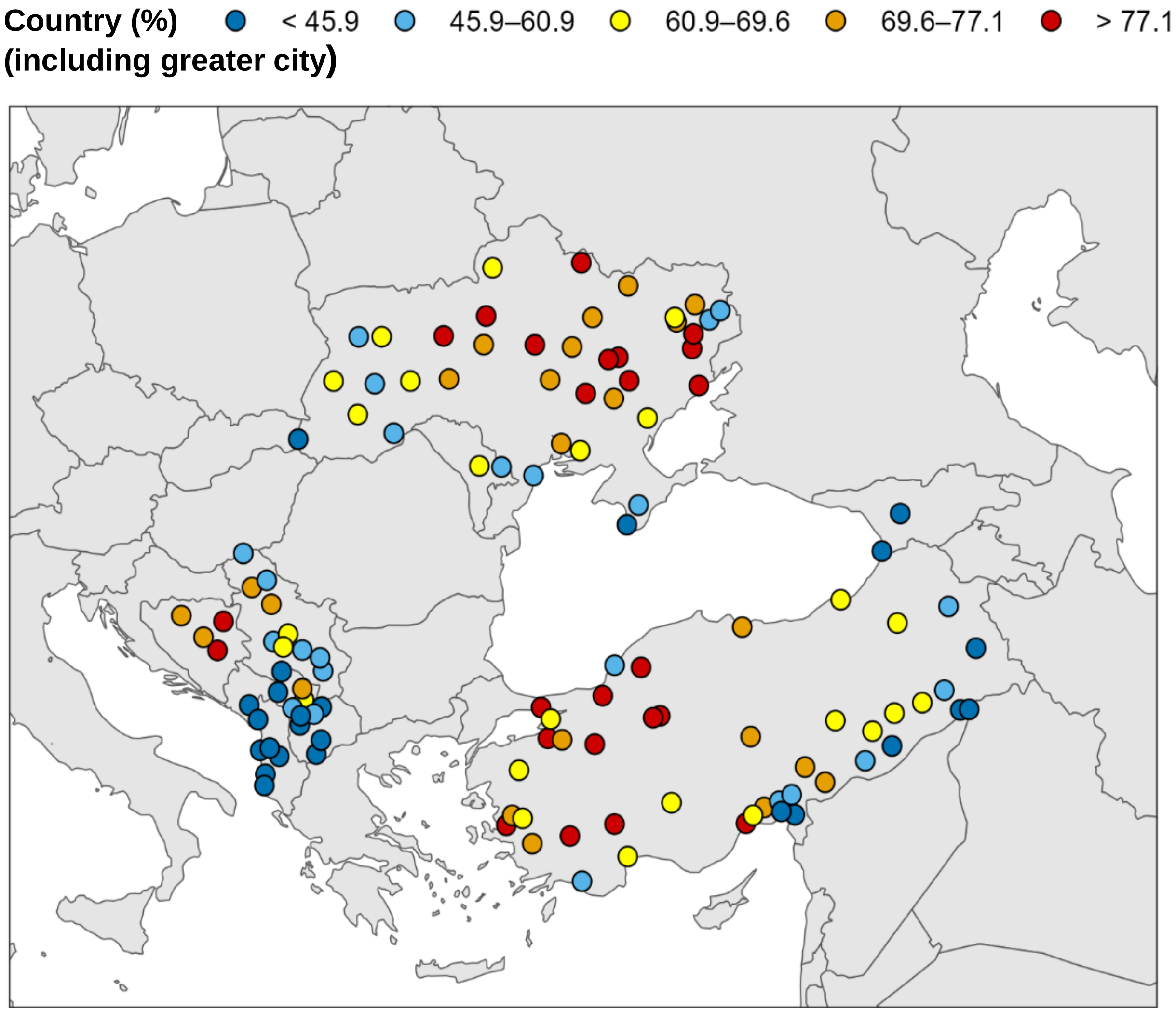
Areas: Core city and Greater city



The core city's own contribution to annual PM$_{2.5}$ concentrations is on average **9%, 21% and 18%** in Western Balkans, Ukraine and Moldova and Türkiye and Georgia, respectively.

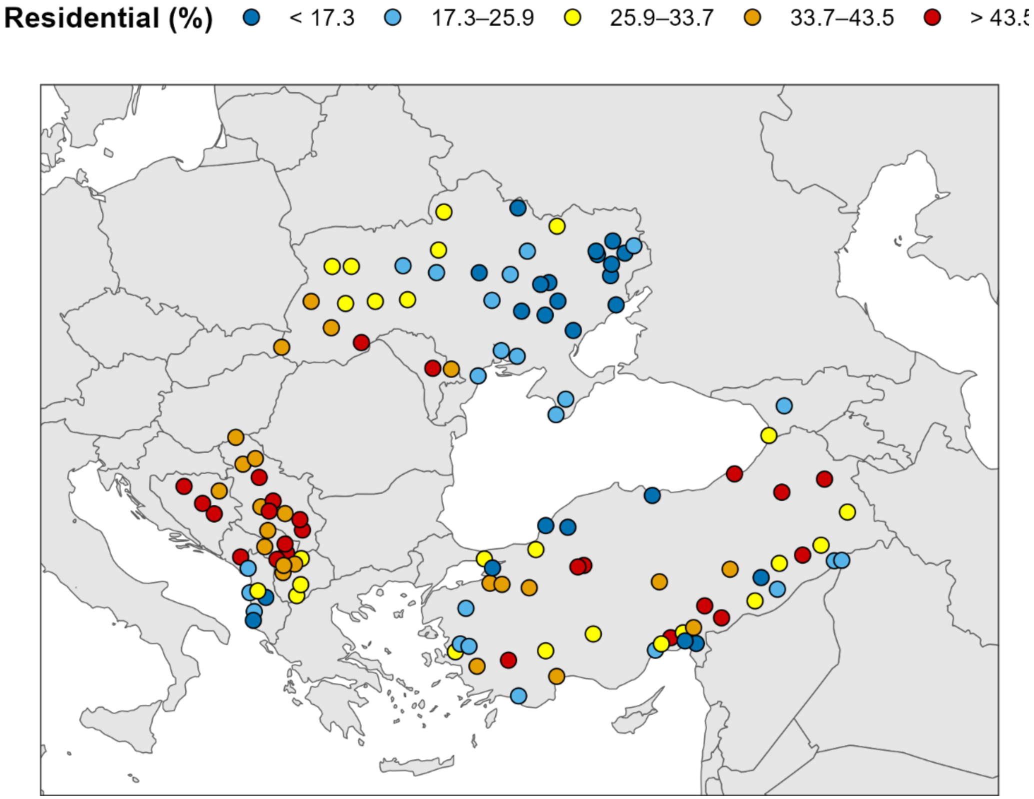
The Greater city contribution is on average around **14%, 17% and 12%** in Western Balkans, Ukraine and Moldova and Türkiye and Georgia, respectively.

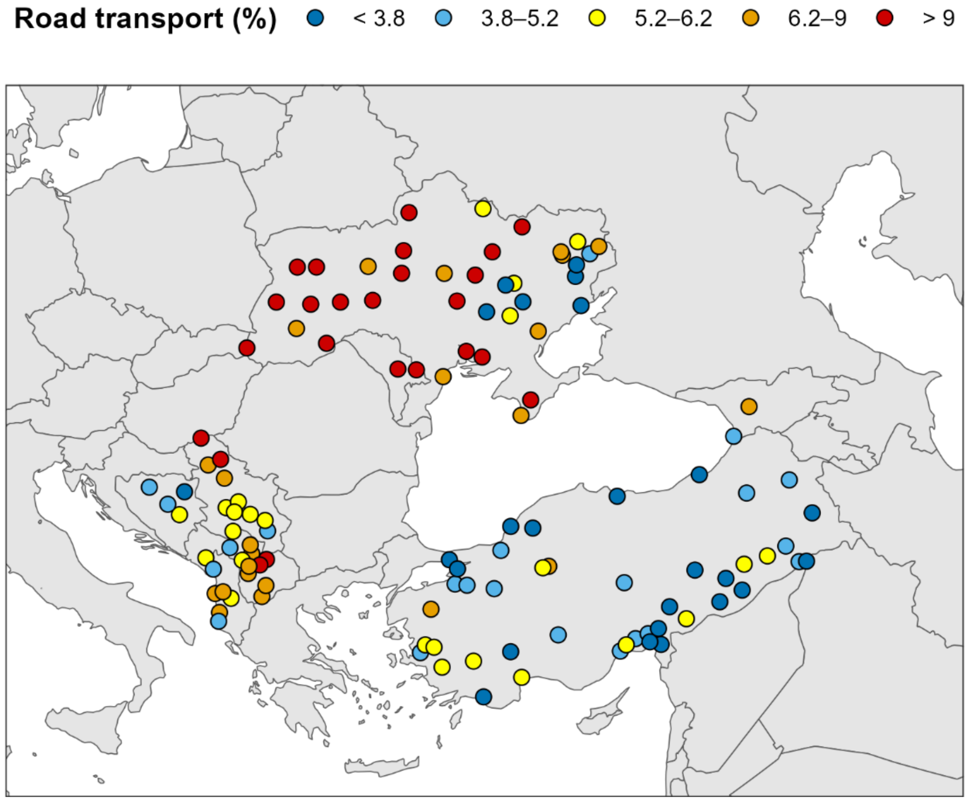
Areas: Country



The country contribution to annual PM$_{2.5}$ concentrations is on average **28%, 32% and 34%** in Western Balkans, Ukraine and Moldova and Türkiye and Georgia, respectively.

Sectors: Residential and Road transport

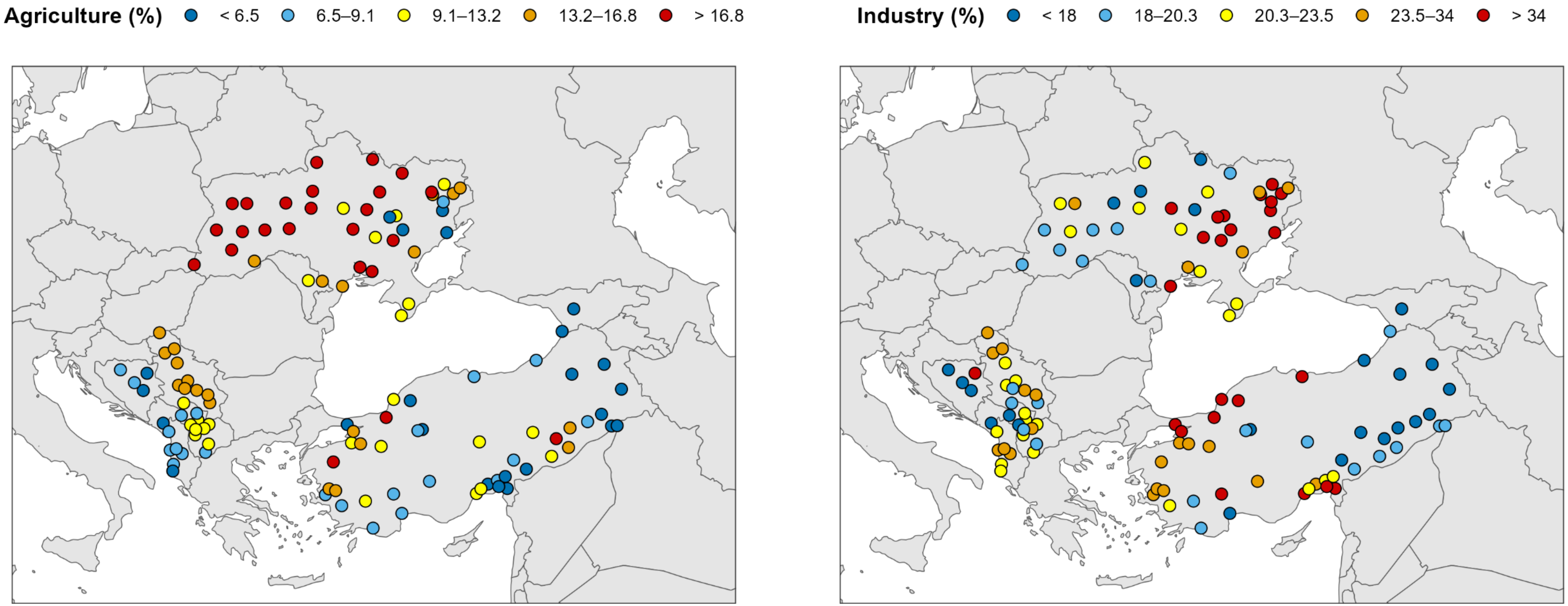




The Residential sector contribution to annual PM$_{2.5}$ concentrations is on average **40%, 23% and 31%** in Western Balkans, Ukraine and Moldova and Türkiye and Georgia, respectively.

The Road transport sector contribution is on average around **7%, 8% and 4%** in Western Balkans, Ukraine and Moldova and Türkiye and Georgia, respectively.

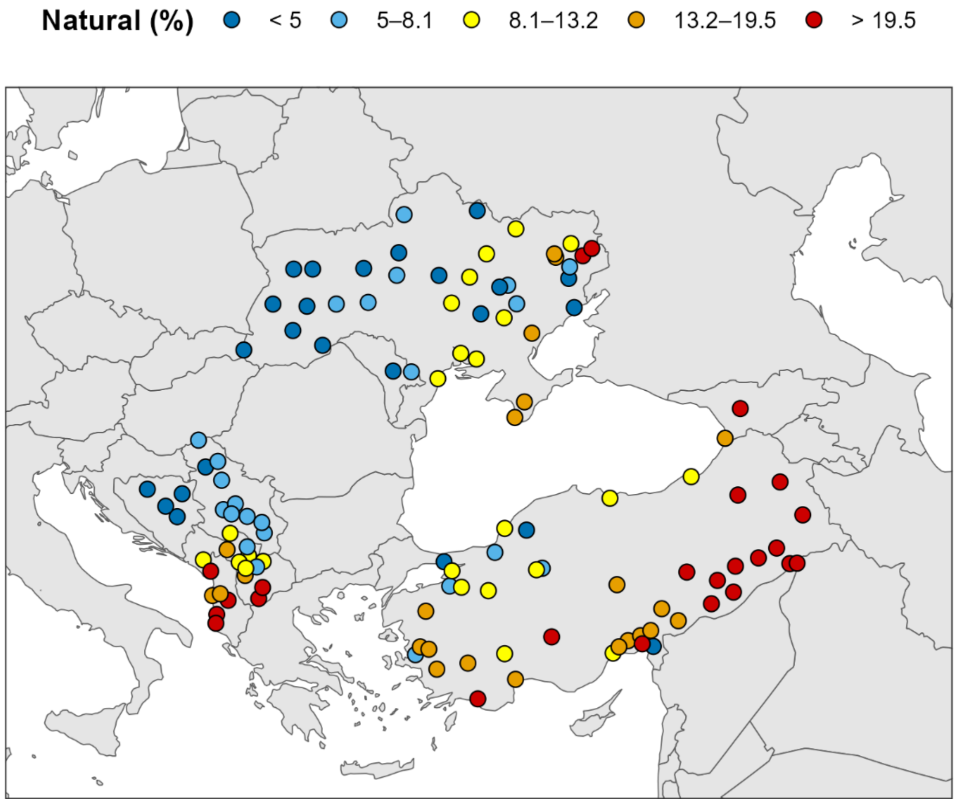
Sectors: Agriculture and Industry

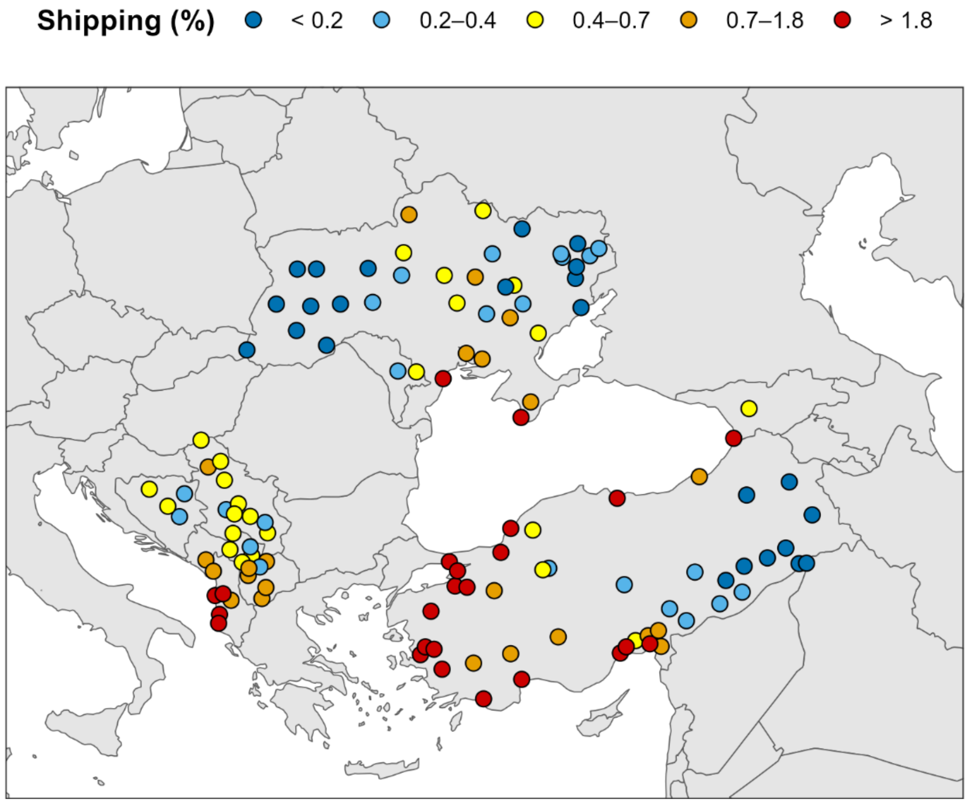


The Agriculture sector contribution to annual $PM_{2.5}$ concentrations is on average **10%, 18% and 10%** in Western Balkans, Ukraine and Moldova and Türkiye and Georgia, respectively.

The Industry sector contribution is on average around **22%, 34% and 27%** in Western Balkans, Ukraine and Moldova and Türkiye and Georgia, respectively.

Sectors: Natural sources and Shipping





The Natural sources contribution to annual $PM_{2.5}$ concentrations is on average **12%, 8% and 18%** in Western Balkans, Ukraine and Moldova and Türkiye and Georgia, respectively.

The Shipping sector contribution is on average around **1%** in all regions.

Recommendations

- This study provides information to **support authorities** in charge for air quality policy in choosing the most efficient actions at the appropriate administrative level and scale.
- An appropriate **balance between local actions** focusing on the urban scale and **actions requiring national/international efforts** is needed.
- **Local actions** (i.e. at greater city scale) are key to improve air quality in that city, but their **strength varies across regions** (relatively low in Western Balkans).
- Target **sectors and scales** to abate air pollution are **city specific**.
- In most cities, sectoral measures addressing **residential** and **industrial** emissions can significantly improve urban air quality, regional specificities also play a role.
- For many cities, sectoral measures addressing **road transport** at multilevel scale and agriculture at country scale would clearly benefit urban air quality.

Thank you