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Analysis of Air Pollutant Emission Scenarios for the Danube region

Benefits of modal shifts in transport, climate mitigation and climate-efficient air pollution mitigation in the Danube region

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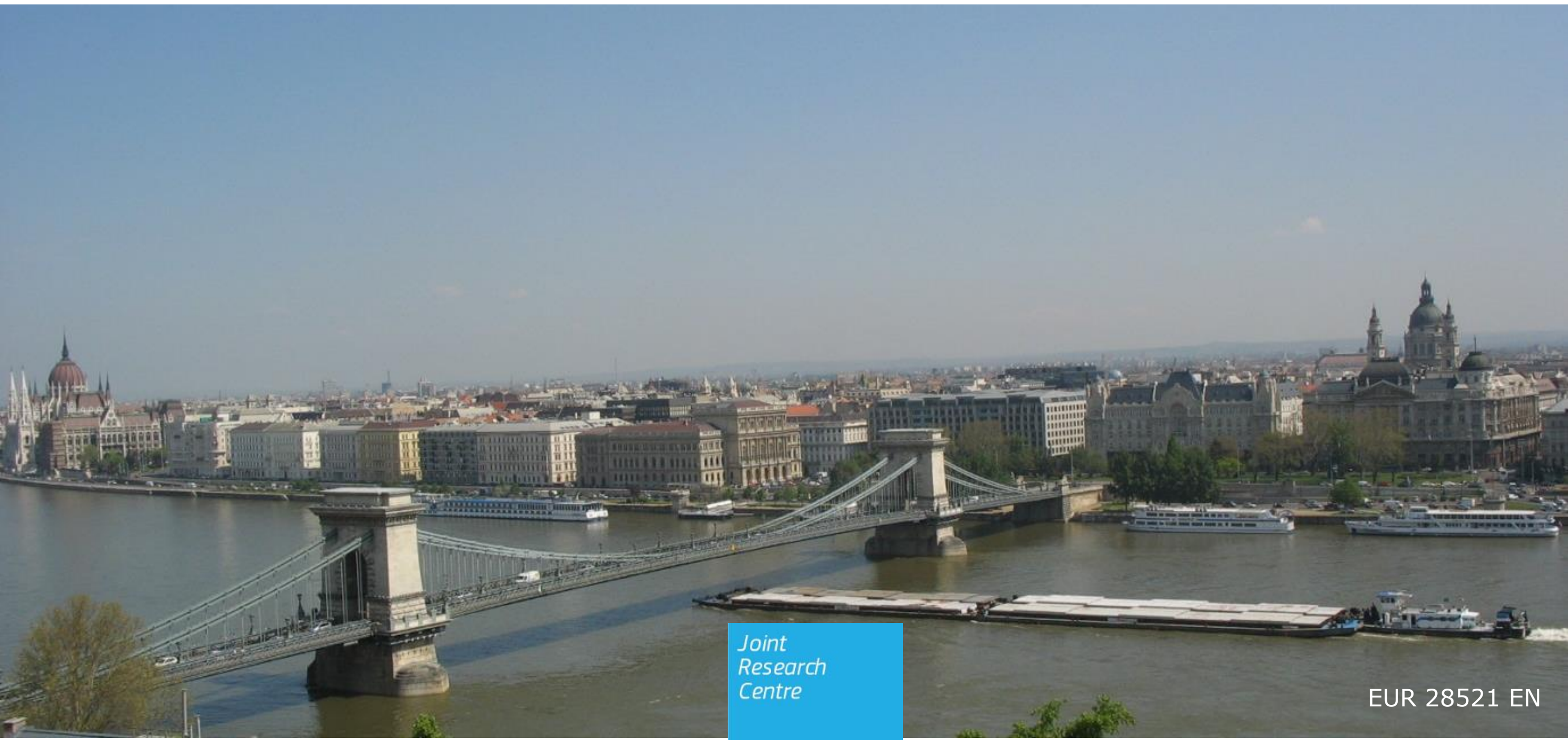

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Abstract

This report investigates air quality, health and crop production impacts in the Danube region for two types of air pollutant emission scenarios:

1. A modal shift in freight transport scenarios for inland waterways and road modes only, which includes a reference scenario and a scenario in which we increase the inland waterways freight transport in the Danube region by 20%; this is complemented by a fictitious modal shift scenario in which 50% of the road freight transport is assumed to shift to inland waterways. The pollutant emissions for these scenarios are based on JRC's global pollutant and greenhouse gas emission database EDGAR.
2. Climate mitigation scenarios, developed in a framework of identifying climate-efficient air quality controls with optimal climate benefits at a global scale focusing on the impact of shorter-lived pollutants which directly or indirectly influence the climate. The pollutant emissions for the latter scenarios are available as a public dataset from the FP5 ECLIPSE research project.

For both analyses, the pollutant emission scenarios are analysed with JRC's global reduced-form air quality model TM5-FASST, which provides pollutant concentrations and their associated impacts on human health and agricultural crop production losses.

The modal shift scenario analysis indicates that a 20% increase of present day inland waterway transport (without a modification in road freight transport) has a negligible impact on air quality in the Danube countries. One extreme scenario case whereby road freight transport is assumed to use modern, low-emission trucks, 50% of which moves to waterway transport with current cargo ships, leads to a net deterioration of air quality with potentially an increase of annual premature mortalities in the Danube region with about 300. The opposite extreme case, assuming the 50% road freight shift to waterways is exclusively with old-type high-emission heavy duty vehicles, leads to a net effect of the same magnitude but opposite sign, i.e. a net improvement of air quality with a decrease in annual premature mortalities of about 300.

The analysis of the ECLIPSE climate mitigation scenarios (both greenhouse gases and short-lived pollutants) focusing on the Danube basin region suggests a maximum potential decrease in annual air pollution-induced mortalities, relative to a current air quality legislation scenario without climate mitigation of 40000 by 2050. The corresponding reduction in crop losses in the area is estimated to be a combined total of 3.7 MTonnes/year in 2050 for wheat, maize, rice and soy beans.

1 Introduction

Air pollution harms human health and the environment. It is a transboundary, multi-effect environmental problem, which knows no national borders. Air pollutants released in one country may contribute to or result in poor air quality elsewhere. In parts of the Danube Region, air pollutant concentrations are relatively high and harm health and ecosystems which the Region depends on. This work supports the EU Strategy for the Danube region by exploring the air quality, health and agricultural crop production impacts of

— modal shift emissions scenarios in transport and

— ECLIPSE[1] project climate mitigation scenarios for both greenhouse gases and short-lived pollutants.

The first set of emissions scenarios on which we focus in this study is based on JRC's Emission Database for Global Atmospheric Research (EDGAR), from which we evaluate impacts of a modal shift in transport. In the European Union (EU), road transport is still an important source of NO_x emissions even though they have decreased by more than half since 1990. In 2014 road transport contributed 39% to the total NO_x emission in EU28 (EEA, 2016) and road transport is an important source of $PM_{2.5}$ (13%) and CO emissions (21%).

The fraction of NO_x emissions from Heavy Duty Vehicles in total NO_x emission from road transport in the EU28 is not negligible. Emissions mitigation from freight transport could be achieved among others by: fleet renewal, retrofitting, fuel quality, reducing congestion and also by a modal shift in transport for which a regional approach would be recommended. The inland waterway network is one of the main freight transport modes in Europe and it has a potential for reducing transport costs, emissions and decongesting roads. However, as mentioned in the European Court of Auditors report (European Court of Auditors, 2015), no significant improvements in modal share conditions since 2001 have been achieved.

Since a modal shift is an option to mitigate emissions, we investigate if there is an impact on air quality (and its impacts on human health and crop production) from the resulting emission pattern (in terms of emitted pollutants and their emission strength) for different emissions scenarios in an approach that covers the entire Danube region. We estimate emissions for three scenarios: S1 is the reference scenario, in S2 we increased freight transport (tkm) on the Danube by 20% and in S3, which is a fictitious modal shift scenario, we considered a shift of 50% of freight (tkm) from roads to inland waterways; these emissions were used as input for the JRC's global air quality assessment tool TM5-FASST tool to evaluate the impacts on air quality and health.

A second and completely different set of pollutant emission scenarios focuses on climate and air pollution mitigation scenarios developed in the framework of the ECLIPSE FP7 project (Stohl et al., 2015). In addition to CO_2, N_2O and CH_4, other anthropogenic emissions, such as short-lived climate pollutants (SLCPs), give strong contributions to climate change. These shorter-lived climate pollutants also have detrimental impacts on air quality, directly or via formation of secondary pollutants. In this study, the air quality impacts were evaluated by using ECLIPSE emissions scenarios as input to TM5-FASST. The ECLIPSE scenarios describe a few possible futures for emissions of short-lived pollutants until 2050:

1. Current legislation (CLE), including the full realisation of currently agreed air quality policies in all countries worldwide over the coming decades
2. Climate mitigation scenario (CLIM), describing a 2°-consistent greenhouse gas mitigation effort out to 2050

(1) Evaluating the CLimate and Air Quality ImPacts of Short-livEd Pollutants

3. SLCP-CLE mitigation scenario (no climate mitigation from greenhouse gases), i.e. reduction measures of (short lived) air pollutants on top of current air quality legislation with a scope of maximizing the near-term climate benefit
4. Combined SLCP-CLIM mitigation scenario

The outcome of the work on the analysis of air pollutant emission scenarios for the Danube region that is presented in this report represents the Deliverable 1/2016 "Benefits of sustainable freight transport" of the "Macro-regions and regions of the future: mainstreaming sustainable regional and neighbourhood policy" (MARREF) project, CONNECTIVITY work package. Chapter 2 briefly describes the methodologies used to develop EDGAR modal shift and ECLIPSE emission scenarios, and presents the TM5-FASST tool. The results are discussed in Chapter 3 and Conclusions are presented in Chapter 4.

2 Methodology

2.1 Definition of the Danube region in this study

The Danube river flows through 10 countries. It stretches from the Black Forest (Germany) to the Black Sea (Romania-Ukraine-Moldova) and is home to 115 million inhabitants. Its drainage basin extends to 9 more countries (Figure 1). This study focuses on pollutant emissions, control measures and their impacts in the Danube region, however the domain considered is different for the 'modal shift' and the ECLIPSE scenarios.

For the modal shift scenarios, we consider emissions and impacts for the countries where waterway freight transport via the Danube river represents a significant share of the countries' total waterway freight transport: Austria, Hungary, Croatia, Serbia, Romania, Romania, and Bulgaria. 'Modal shift' emission scenarios for Germany, Moldova and Ukraine are not included in this part of the study. The ECLIPSE mitigation scenarios on the other hand are evaluated for emissions from and impacts for the whole Danube basin (see Table 4).

Figure 1. Danube basin countries

Source: http://www.danube-region.eu/about/the-danube-region

2.2 Pollutant emissions for Transport Modal Shift scenarios (EDGAR)

Generally, countries estimate their pollutant emissions based on fuel sold methodology described in the EMEP/EEA air pollutant emission inventory guidebook (European Environment Agency, 2016) and report them to the Convention on Long-range Transboundary Air Pollution (CLRTAP). For the road transport sector, the main data sources for emissions calculation are energy balance and vehicle fleet statistics.

The shares of NO_x emissions from Heavy Duty Vehicles in national total NO_x emissions for the countries in the Danube region are high. Table 1 illustrates this for some of the countries in Danube region (EMEP/CEIP, 2014).

Table 1. The shares of NOx emissions from transport subsectors in national total emissions for some countries in the Danube region.

Country	$HDV_{share\ NE}$[1]	$HDV_{share\ NEt}$[2]	$SHIP_{share\ NE}$[3]	
Austria	26.7%	50.5%	0.5%	International inland and national navigation
Hungary	20.8%	52.2%	0.4%	National navigation only
Croatia	16.7%	40.4%	3.0%	National navigation only
Serbia	14.6%	55.3%	0.6%	National navigation only
Romania	23.6%	59.8%	1.3%	National navigation only
Bulgaria	11.9%	40.9%	5.0%	International inland and national navigation
EU28	16.0%	40.6%	3.6%	International inland and national navigation

[1]share of NO_x emissions from Heavy Duty Vehicles including buses in national total emissions.
[2]share of NO_x emissions from Heavy Duty Vehicles including buses in national total road transport emissions.
[3]share of NO_x emissions from inland waterways (freight and passengers transport) in national total emissions.

Source: EMEP/CEIP (2014) and JRC analysis

In the fuel sold methodology emissions are calculated using the equation:

$$E_i = \sum_m \left(FC_m \times EF_{i,m} \right)$$

where E is emission, FC is fuel sold, EF is fuel-specific emission factor, *i* is pollutant, *m* is fuel type; the technology and mitigation measure could also be included.

The downside of the fuel sold methodology is that it can be a source of errors for emissions estimation in particular for the cases where the fuel is purchased in one country and used in another. Since freight transport often has a trans-boundary component, a more advanced methodology such as the fuel used methodology should be considered to improve the accuracy of emissions estimation. For example, the emissions from inland waterways freight transport should be estimated for both international inland and national navigation; even if the shares of these emissions in national totals are low, emissions estimation should be based on fuel used methodology at least for the international inland navigation.

In this study we estimate emissions for three scenarios including a modal shift emissions scenario (from trucks to ships) – see section 2.2.1 for more details. Considering the drawbacks of fuel sold methodology, we have chosen a methodology that uses information on freight movements, which are expressed in tonne-kilometre (tkm), and freight movement-specific emission factors to estimate emissions from freight transport;

the tonne-kilometre (tkm) is a unit of freight that represents the movement of one tonne of payload a distance of one kilometre.

Emissions for these three scenarios were calculated for the following countries in the Danube region: Austria, Slovakia, Hungary, Croatia, Romania, Bulgaria and Serbia.

2.2.1 Definition of emissions scenarios

Scenario 1 is the reference scenario. It includes two extreme cases: S1a comprises emissions from both inland waterways and road freight transport assuming that for road freight transport all vehicles are modern trucks while S1b comprises emissions from both inland waterways and road freight transport assuming that for road freight transport all vehicles are old trucks.

Since "increasing the cargo transport on the river by 20% by 2020 compared to 2010" is one of the targets of the Priority Area 1A[(2)] of the European Union Strategy for the Danube egion, we define scenario 2 (S2a, S2b), as a 20% increase to the reference scenario in inland waterway freight movement per country (tkm) without modifying road freight transport emissions.

Scenario 3 (S3a, S3b) is a fictitious modal shift scenario. It is scenario 1 to which we applied a 50% shift from road freight movement per country (tkm) to inland waterways freight movement per country (tkm).

2.2.2 Data source for freight movements (tkm)

Since the modal shift proposed in this study is from trucks to ships we have collected data on freight movements for both inland waterways and road as following:

(a) from EUROSTAT (2016a) and OECD (2016a, 2016b) road freight moved per country

(b) from EUROSTAT (2016b), OECD (2016a) inland waterway freight moved per country; for Serbia we added data from PBC (2016).

The inland waterways and road freight movements (tkm) data used in this study for S1, S2 and S3 are provided in Annex I.

2.2.3 Data source for emission factors (EFs)

Here we present the emission factors (EFs) for CO_2, NO_x, PM_{10}, SO_2 used in this study; in our approach we assume that particulate matter emitted by the transport sector are all $PM_{2.5}$, consequently the $PM_{2.5}$ EFs are identical to the PM_{10} EFs provided. We also derived EFs for BC and OC assuming: a) for inland waterways freight transport fractions of, respectively, 0.2 and 0.1 in $PM_{2.5}$, and b) for road freight transport fractions of, respectively, 0.6 and 0.32 in $PM_{2.5}$. These fractions are those used by EDGAR4.2 (EC-JRC and PBL, 2011) to derive EFs for BC and OC from $PM_{2.5}$ EFs.

The references and values of the EFs used in this study to calculate emissions from inland waterways freight transport (ILW) are presented in Table 2. The references and values of the EFs used in this study to calculate emissions from road freight transport are presented in Table 3.

[(2)] Priority Area 1A: To improve mobility and intermodality of inland waterways

Table 2. EFs for inland waterways freight transport, g/kg fuel

Pollutant	CO_2	NO_x	PM_{10}	SO_2
ILW	3175	50.75	3.19	2

Source: Denier van der Gon and Hulskotte, 2010, MoveIT! (Schweighofe et al., 2013)

Table 3. EFs for road freight transport (trucks), g/tkm

Pollutant	CO_2	NO_x	PM_{10}	SO_2
Modern truck[1]	51.7	0.141	0.00109	0.00049
Old truck[2]	51.8	0.746	0.04797	0.00049

[1]Model Year 2007-2010+
[2]Model Year 1987-90

Source: WebGIFT (Rochester Institute of Technology, 2014)

The EFs used to calculate emissions from road freight transport are from the Geospatial Intermodal Freight Transportation Modal (GIFT) model, Multi-Modal Energy and Emissions Calculator module (Rochester Institute of Technology, 2014). In this study we used the EFs provided in GIFT model for "Model Year 2007-2010+" and "Model Year 1987-90", hereafter called "Modern truck" and "Old truck" respectively. Given the fact that the EFs in GIFT model are expressed in g/TEU-mile a unit conversion was needed. In order to convert them to g/tkm we assumed a 10 metric tonnes of cargo per TEU (standard intermodal shipping container) as recommended by Corbett et al. (2016).

2.2.4 Emissions estimation: methodology

For road freight transport, we calculated emissions by multiplying freight movements (tkm) data with freight movement-specific emission factors (g/tkm) for each scenario.

For inland waterways freight transport, since the EFs are expressed in g/km fuel, the unit conversion from tkm to g for freight movements was needed. Information on the average fuel consumption for motor-cargo vessels and convoys, which accounts for 8 g diesel per tkm (Viadonau, 2007), was used for this unit conversion. With the freight movement expressed in unit of mass (see annex II) we calculated emissions using the EFs in Table 2.

The emissions for Scenario 1, Scenario 2 and Scenario 3 are presented and discussed in section 3.1.1 of this report.

2.3 Pollutant emissions for Climate and Short-Lived Pollutants mitigation scenarios (ECLIPSEV5a)

In this report we evaluate as well an independent global set of emission scenarios, here specifically applied to the Danube region. The emission scenarios have been developed in the frame of the ECLIPSE FP7 (2011 – 2013) project[(3)] with the GAINS model (IIASA, 2015; Klimont et al., 2016; Stohl et al., 2015). The gridded ECLIPSEV5a (subsequently referred to as ECLIPSE) scenarios are now public domain and available as input to air quality and climate modelling projects. The scenarios were developed in a framework of identifying climate-efficient air quality controls with optimal climate benefits at a global scale. While CO_2 is the most important anthropogenic driver of global warming, with additional significant contributions from CH_4 and N_2O, other anthropogenic emissions give strong contributions to climate change that are excluded from existing climate

(3) http://eclipse.nilu.no/

agreements. We investigate air quality impacts of a number of much shorter-lived components (atmospheric lifetimes of months or less) which directly or indirectly (via formation of other short-lived species) influence the climate (Stohl et al., 2015):

— Methane (CH_4), a greenhouse gas with a warming potential roughly 26 times greater than that of CO2 at current concentrations.

— Black carbon (BC), which causes warming through absorption of sunlight and by reducing surface albedo when deposited on snow and ice-covered surfaces.

— Tropospheric O_3, a greenhouse gas produced by chemical reactions from the emissions of the precursors CH_4, carbon monoxide (CO), non-CH_4 volatile organic compounds (NMVOCs) and nitrogen oxides (NO_x).

— Several polluting components have cooling effects on climate, mainly ammonium sulphate, formed from sulphur dioxide (SO_2) and ammonia (NH_3), ammonium nitrate from NO_x and NH_3, and particulate organic matter (POM) which can be directly emitted or formed from gas-to-particle conversion of NMVOCs. They scatter solar radiation leading to cooling, and may alter the radiative properties of clouds, very likely leading to further cooling.

These substances are called short-lived climate pollutants (SLCPs) as they also have detrimental impacts on air quality, directly or via the formation of secondary pollutants.

For the current study, the following ECLIPSE scenarios were considered which represent possible futures for emissions of short-lived pollutants until 2050:

— Reference scenario: Current legislation (CLE), including current and planned environmental laws, considering known delays and failures up to now but assuming full enforcement in the future. No climate mitigation.

— Climate mitigation scenario (CLIM): developed based on the 2 degree (or 450ppm CO_2) energy pathway of the IEA (International Energy Agency, 2012) which includes beneficial side effects on air quality.

— SLCP mitigation (SLCP-CLE) includes additional selected measures that have both beneficial air quality and climate impact, applied on top of the CLE reference scenario.

— SLCP mitigation as above, applied on top of the climate mitigation scenario (SLCP-CLIM).

The native ECLIPSE gridded emission fields for the selected scenarios cover the global domain. For this study they were aggregated to the 56 FASST source regions + international shipping and aviation, ready to be used as input for JRC's global air quality assessment tool TM5-FASST (see below). We focus specifically on the Danube region in terms of air quality impacts resulting from this set of scenarios.

2.4 From emissions to pollutant concentrations and impacts (TM5-FASST)

TM5-FASST is a reduced-form global air quality model that uses as input annual emissions of relevant precursors (SO_2, NO_x, NH_3, black carbon, organic matter, CH_4, non-methane volatile organic compounds, primary $PM_{2.5}$) and calculates the resulting annual average concentrations of atmospheric pollutants. Furthermore, the model additionally calculates impacts of these pollutant concentrations on human health, crop yield losses and the radiative balance of the atmosphere. An extensive description of the model and its methodology is given by Van Dingenen et al. (2015) and Leitão et al. (2014).

2.4.1 Pollutant concentration

In brief, TM5-FASST calculates the change in pollutant concentrations at the earth's surface, due to a change in emissions of precursors in any of 56 source regions. TM5-FASST is available as a public web-based tool with concentration and impact output aggregated either at the level of the 56 source regions or more aggregated world regions (European Commission, 2016). An extended non-public research version with more features and high resolution output (1°x1° globally) is used for in-depth assessments and scenario analysis. TM5-FASST mimics the complex chemical, meteorological and physical processes in the atmosphere that are resolved in a full chemical transport model like TM5-CTM, by using simple and direct relations between emissions and resulting annual mean concentrations. The emission-concentration dependencies are represented by linear emission-concentration response functions, which allow for a fast (immediate) calculation of the pollutant concentrations in a receptor region from a given emission, without having to run the full TM5-CTM model. These linear emission-concentration relations were obtained "once and for all" by scaling TM5-CTM pre-calculated sets of emission-concentration responses for a 20% emission reduction to the actual emission change in the scenarios considered. This approach is identical to the one described by Amann et al. (2011) and Wild et al. (2012). Validation tests have shown that robust results are also obtained outside the 20% emission perturbations (Van Dingenen et al., 2015).

The emission-concentration response functions are available for the precursors SO_2, NO_x, CO, BC, OC, NMVOC and NH_3 and resulting pollutants ozone (O_3), $PM_{2.5}$ (as a sum of SO_4, NO_3, NH_4, BC, OC and H_2O) and specific (O_3) metrics for crop damage (Van Dingenen et al., 2009), as well as for instantaneous radiative forcing and CO_{2eq} emissions of short-lived climate pollutants (SLCP).

Source-receptor relations were not only calculated for pollutants concentrations, but also for specific metrics like the growing-season mean O_3 daytime concentration, which is needed for the calculation of crop yield losses. The source-receptor relations for $PM_{2.5}$ and O_3 are weighted for population density so that they represent the population exposure to pollutants.

Figure 2 shows the global domain of the TM5-FASST model with the 56 continental source regions. Europe has a relatively high spatial resolution: EU28 is represented by 16 source regions. The FASST regions covering the Danube area are given in Table 4. The regional aggregation of the FASST source regions is the level at which emissions are provided to the model.

2.4.2 Health impacts

Health impacts are calculated both for $PM_{2.5}$ and for O3 exposure, by applying established health impact functions from recent literature, based on epidemiological cohort studies. Recent studies (Burnett et al., 2014 and references therein) have identified $PM_{2.5}$ as a risk factor contributing to premature mortality from 5 specific causes of death: Ischemic Heart Disease (IHD), Stroke, Chronic Obstructive Pulmonary Disease (COPD), Lung Cancer (LC) and Acute Lower Respiratory Infections (ALRI) – the latter mainly for infants below 5 years. The health impact of O_3 is evaluated for long-term mortality from COPD, following the approach in the Global Burden of Disease (GBD) study (Burnett et al., 2014; Forouzanfar et al., 2015; Lim et al., 2012).

The health impact functions express, for each of the death causes, the relative risk (RR) for exposure to a given concentration X of the pollutant (or pollutant exposure metric) of interest, compared to exposure below a non-effect threshold level X_0.

$$RR = \mathrm{f}(X) \text{ with } RR = 1 \text{ when } X \leq X_0$$

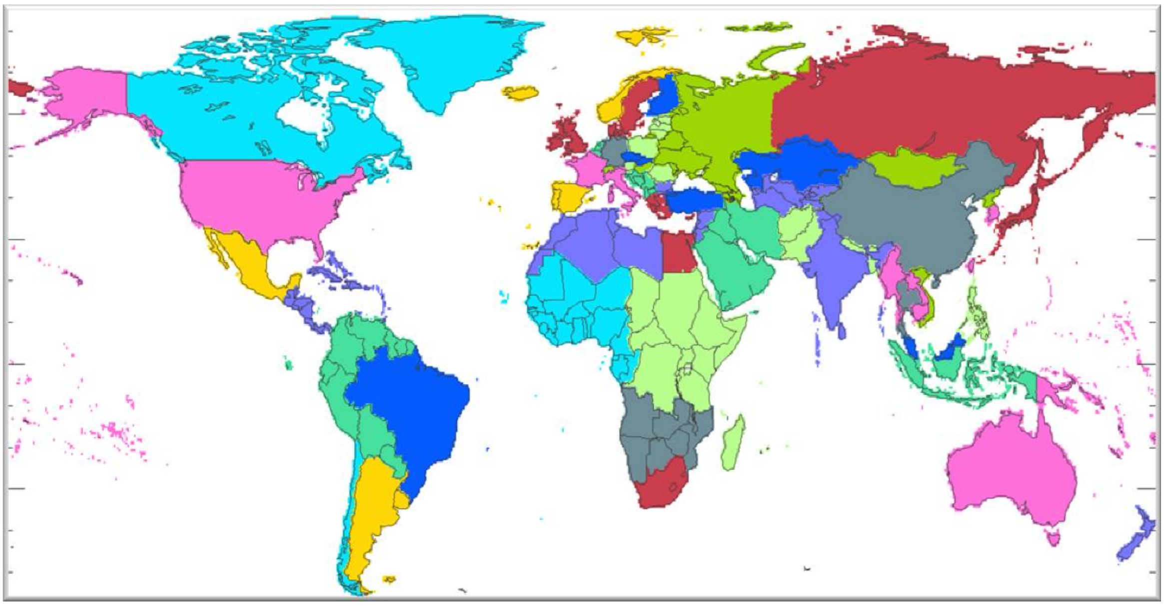
For O_3, the relevant metric consistent with the epidemiological studies is the six-month-average 1-hr daily maximum concentrations for O_3, which we abbreviate to "M6M".

Table 4. List of TM5-FASST source regions covering the Danube basin, and individual countries contained therein

TM5-FASST regions, part of Danube Basin	Countries included in region
AUT	Austria, Slovenia, Liechtenstein
CHE	Switzerland
ITA	Italy, Malta, San Marino, Monaco
GER	Germany
BGR	Bulgaria
HUN	Hungary
POL	Poland, Estonia, Latvia, Lithuania
RCEU (Rest of C. Europe)	Serbia, Montenegro, FYR of Macedonia, Albania
RCZ	Czech Republic, Slovakia
ROM	Romania
UKR	Ukraine, Belarus, Moldova

Source: JRC analysis

Figure 2. Definition of TM5-FASST source regions



Source: JRC analysis

The functional relationship between RR and M6M is calculated from a log-linear relationship (Jerrett et al., 2009):

$$RR(M6M) = e^{\beta(M6M - X_0)} \quad \text{for } M6M > X_0$$
$$RR = 1 \quad \text{for } M6M \leq X_0$$

with X_0 = 33.3 ppbV, i.e. the threshold level below which no effect is observed.

β is the concentration-response factor, i.e. the estimated slope of the log-linear relation between concentration and mortality. From epidemiological studies (Jerrett et al., 2009 and references therein), a 10ppb increase in the seasonal (April-September) average daily 1-hr maximum O_3 (concentration range, 33.3-104.0 ppbV) was associated with a 4% [95% confidence interval 1.3-6.7%] increase in RR of death from respiratory disease. This leads to a central value of β = ln(1.04)/ 10ppbV = 3.92 10^{-3}

For $PM_{2.5}$, the relevant metric is the annual mean $PM_{2.5}$ concentration and RRs are calculated using the following functional relationships (Burnett et al., 2014) which have a more complex mathematical form and depend on 4 parameters:

$$RR(PM) = 1 + \alpha \left[1 - e^{-\gamma(PM - X_0)^{\delta}}\right] \quad \text{for } PM > X_0$$
$$RR = 1 \quad \text{for } PM \leq X_0$$

The values for parameters α, γ, δ and X_0 have been fitted to the Monte-Carlo generated dataset provided by the authors of the original study (IHME, 2011) and are given in Table 5. For simplicity we use the functions provided for the total age group >30 years (except for ALRI: <5 years) rather than age-specific relations.

Table 5. Parameters for the $PM_{2.5}$ health impact functions

	IHD	STROKE	COPD	LC	ALRI
α	0.83	1.03	58.99	54.61	1.98
γ	0.07101	0.02002	0.00031	0.00034	0.00259
δ	0.55	1.07	0.67	0.74	1.24
X_0	6.86	8.80	7.58	6.91	6.79

Source: Original Monte Carlo data: Burnett et al., 2014; IHME, 2011; parameter fitting: JRC

With RR established from modelled or measured exposure estimates, the number of mortalities within a receptor region, for each death cause and each pollutant ($PM_{2.5}$ and O3), is calculated from:

$$\Delta MORT = \frac{RR_i - 1}{RR_i} y_0 \, POP$$

with RR_i being the risk rate, y_0 being the baseline mortality rate (deaths divided by population total) for the respective disease, and POP being the total population. For the years [1990, 1995, 2000, 2005, 2010, 2013] baseline mortalities for all countries (y_0) are obtained from the 2013 GBD study (IHME, 2015). The year 2015 mortalities are estimated from a linear extrapolation of year 2010 and 2013. Projections up to 2030 are calculated as follows: regional projections for 2015 and 2030 for six world regions are obtained from (WHO, 2013). For each region, the ratio $y_0(2030)/\,y_0(2015)$ is used to extrapolate the year 2015 data of the GBD study to 2030, using the ratio of the corresponding world region for each country. For 2050 no data are available from WHO, and we assume the same mortality rates as for 2030 – however multiplied with projected population data for 2050 (see below).

Health impacts are calculated by overlaying gridded population maps with gridded pollutant concentration (or health metric) maps and applying the appropriate RR to each populated grid cell. We use high-resolution population grid maps up till 2100 that were prepared by IIASA for the Global Energy Assessment (GEA, 2012), based on UN population projections (2008 Revision, Medium Fertility Variant) (UN DESA, 2009). Population distribution by age class, which are required to establish the age classes >30 and <5 years for all scenario years, are obtained from the United Nations Population Division (2015 Revision) (both historical data and projections up till 2100). For the projections we use the Medium Fertility Variant. It has to be noted that there is an intrinsic inconsistency in using the same population data and base mortalities for future air quality scenarios that show large differences in air quality levels. Indeed, worse air quality scenarios would be consistent with lower future life expectancy and higher base mortality rates than clean air scenarios. However to our knowledge, a diversification of population trends, consistent with various air quality scenarios is not available.

2.4.3 Crop impacts

Production losses are evaluated for each of the four major crops: wheat, rice, maize and soybeans. This is done by overlaying gridded crop production maps for the respective crops with TM5-FASST calculated grid maps of appropriate ozone metrics. We base our calculations on 2 different approaches, each using a specific metric:

- Based on the seasonal 'accumulated ozone above a 40ppb threshold' (AOT40), unit ppm.hour
- Based on the seasonal mean daytime ozone concentration M7, with daytime period = 7hrs for wheat and rice, or M12 with daytime period =12hrs for maize and soybean, expressed in ppb. We will indicate this very similar metrics with the generic symbol Mi.

The crops relative yield loss (RYL) is calculated using exposure-response functions (ERF) from literature, using the methodology described by (Van Dingenen et al., 2009).

For AOT4, the ERF is linear:

$$RYL[AOT40] = a \times AOT40$$

For the Mi metric, ERF are sigmoid-shaped:

$$RYL[M_i] = 1 - \frac{exp\left\{-\left[\left(\frac{M_i}{a}\right)^b\right]\right\}}{exp\left\{-\left[\left(\frac{c}{a}\right)^b\right]\right\}}$$

The values for the parameters a, b and c are given in Table 6. Note that for Mi = *c, RYL = 0* hence *c* is the lower Mi threshold for visible crop damage.

The calculation of the respective metrics accounts for differences in growing season for different crops over the globe and the actual ozone concentrations during that period. Crop production grid maps and corresponding gridded growing season data are obtained from the Global Agro-ecological Zones (GAeZ) data portal (IIASA and FAO, 2012). We apply a standard growing season length of 3 months to calculate AOT40 and Mi, matching the end of the 3 month period with the end of the growing season from GAeZ.

The absolute crop production loss CPL (metric tonnes) is calculated combining the RYL with the actual reported crop production (CP). This equation takes into account that reported CP already includes a loss due to ozone damage.

$$CPL_i = \frac{RYL_i}{1 - RYL_i} CP_i$$

Because of the unavailability of crop production data for future scenarios that would be consistent (in terms of yield) with the actual air pollutant concentrations implied by the respective scenarios, we estimate crop losses for all scenarios from a standard 'undamaged' crop production set, based on pollutant concentrations and crop production data for the year 2000, from GAeZ V3.0 (IIASA and FAO, 2012):

$$CP_i^* = CP_{i,2000} + CPL_{i,2000} = \frac{CP_{i,2000}}{1 - RYL_{i,2000}}$$

Crop production losses for any scenario *S* are then obtained from:

$$CPL_{i,S} = RYL_{i,S} \times CP_i^*$$

Table 6. Overview of air quality indices used to evaluate crop yield losses. The a, b and c coefficients refer to the exposure-response equations given in the text.

	Wheat			Rice			Soy			Maize		
Index	a	b	c	a	b	c	a	b	c	a	b	c
AOT40 (ppm.h)	0.0163	-	-	0.00415	-	-	0.0113	-	-	0.00356	-	-
Mi (ppbV)	137	2.34	25	202	2.47	25	107	1.58	20	124	2.83	20

Source: Mills et al., 2007; Wang and Mauzerall, 2004

3 Results

3.1 Modal Shift

3.1.1 Emissions

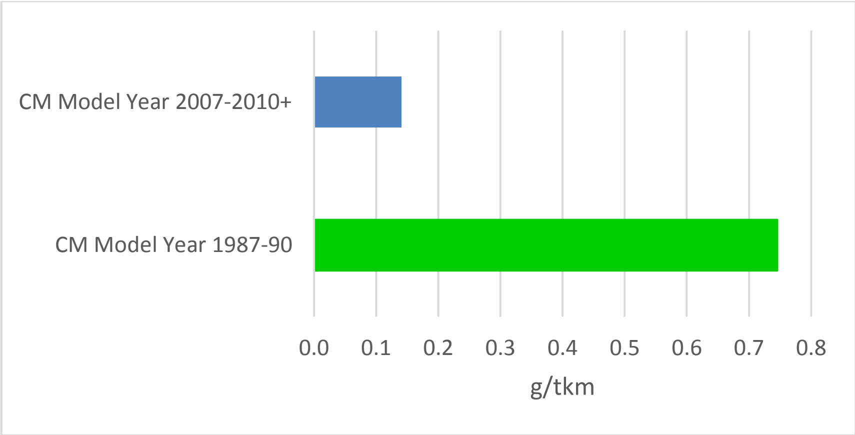
As mentioned in section 2.2, emissions are estimated by multiplying activity data with emission factors. Emissions from road freight transport were calculated by using road freight movements as activity data and freight movement-specific emission factors as emission factors; the road freight movements per country are provided in annex I and the EFs in section 2.2. For each emission scenario we consider two extreme cases by assuming that: a) all trucks transporting goods are modern and b) all trucks transporting goods are old. The definitions for modern and old trucks are provided in section 2.2.; in this analysis they are, respectively, "Model Year 2007-2010+" and "Model Year 1987-90" from the WebGIFT model (Rochester Institute of Technology, 2014). It is worth noting that the emission factors for CO_2 and SO_2 are the same for both modern and old trucks. On the other hand, for NO_x and PM_{10} there are large differences between the EFs as is illustrated in Figure 3 and Figure 4; the actual values for NO_x are: 0.141 g/tkm for modern trucks and 0.746 g/tkm for old trucks, and for PM_{10}: 0.0011 g/tkm for modern trucks and 0.048 g/tkm for old trucks. The EFs of the old truck for NO_x and PM_{10} are, respectively, 5 and 44 times higher than those of the modern truck. Since the EFs for BC and OC are derived from $PM_{2.5}$ EFs, which in our assumption have the same values as PM_{10} EFs, the differences in PM_{10} EFs will also be reflected in the EFs of BC and OC.

The impact on emissions of the different modal shift scenarios (see the description in section 2.2) depends on the quantity of goods transported by each transport mode and on the emission factors for trucks and ships. The CO_2, SO_2, NO_x, PM_{10}, BC and OC emissions for each scenario are represented in Figure 5 to Figure 10. Blue bars represent the emissions of "a" cases where only modern trucks are used and the bars in green represent the emissions of "b" cases where only old trucks are used. Each bar represents the sum of emissions for both road and inland waterways freight transport (ILW) for each scenario.

No significant differences in CO_2 emissions (Figure 5) are found between the reference scenario (S1) and the scenario in which we consider a 20% increase in inland waterways freight transport (S2) due to the relatively small contribution of freight transported y inland waterways in the reference scenario. A decrease of about 24% in CO_2 emissions for S3 (50% shift from road freight to ILW) when compared to S1 shows that the transport of goods on ship is more energy efficient than the transport of goods on trucks.

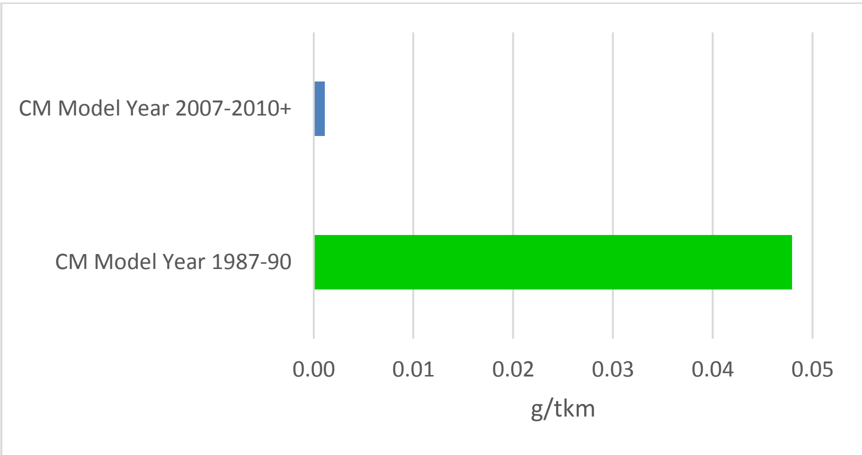
An increase in SO2 emissions (Figure 6) comparable to the increase in inland waterways freight transport for S2 is seen when compared to S1. In the case of S3 (a fictitious scenario) in which we assume that 50% of the road freight is moved to ILW for each country, the SO_2 emissions are four times higher than those in S1. This shows that an increase in the quantity of goods transported on ships results in an equivalent increase in SO_2 emissions.

Figure 3. NOx emission factors for modern and old trucks



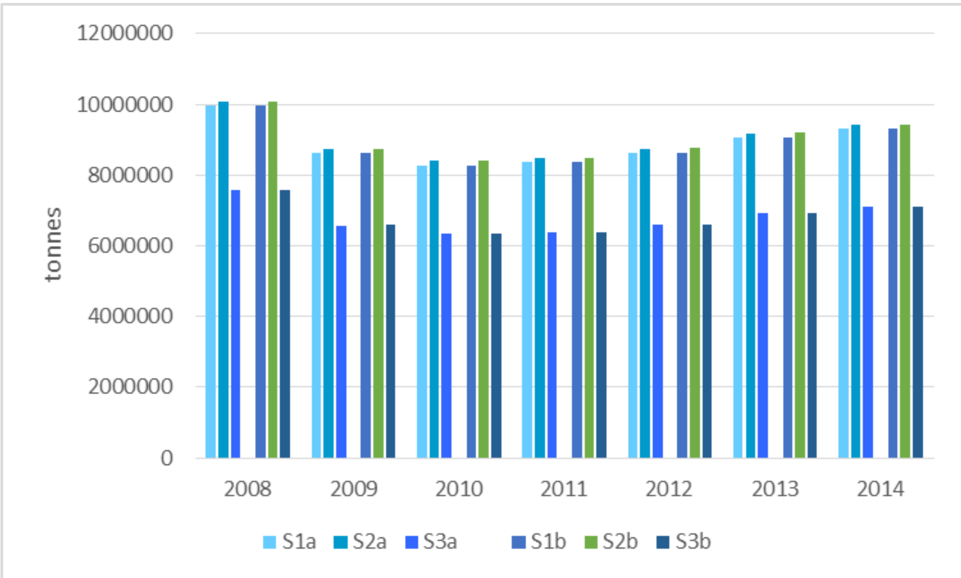
Source: WebGIFT (Rochester Institute of Technology, 2014) and JRC analysis

Figure 4. PM10 emission factors for modern and old trucks



Source: WebGIFT (Rochester Institute of Technology, 2014) and JRC analysis

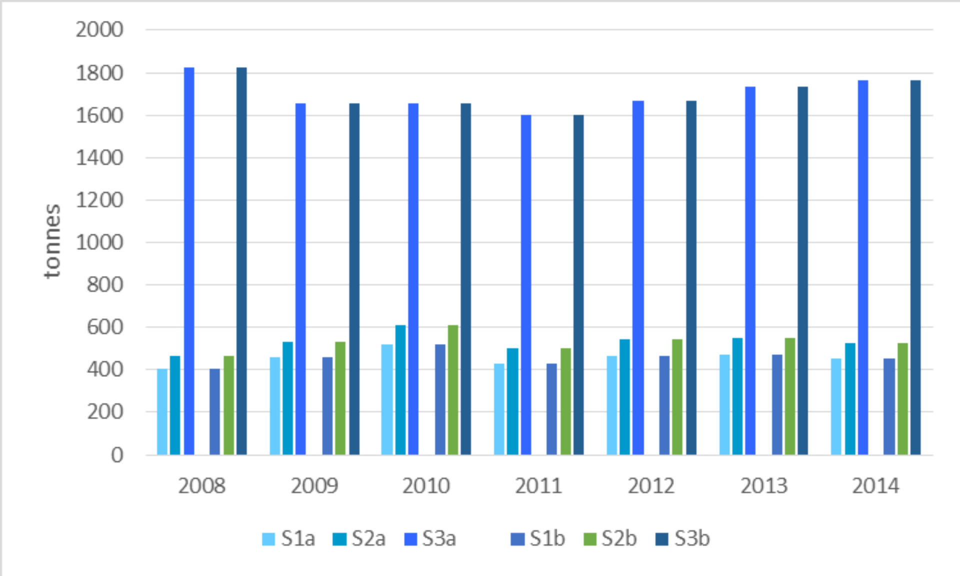
Figure 5. CO2 emissions



Source: JRC analysis

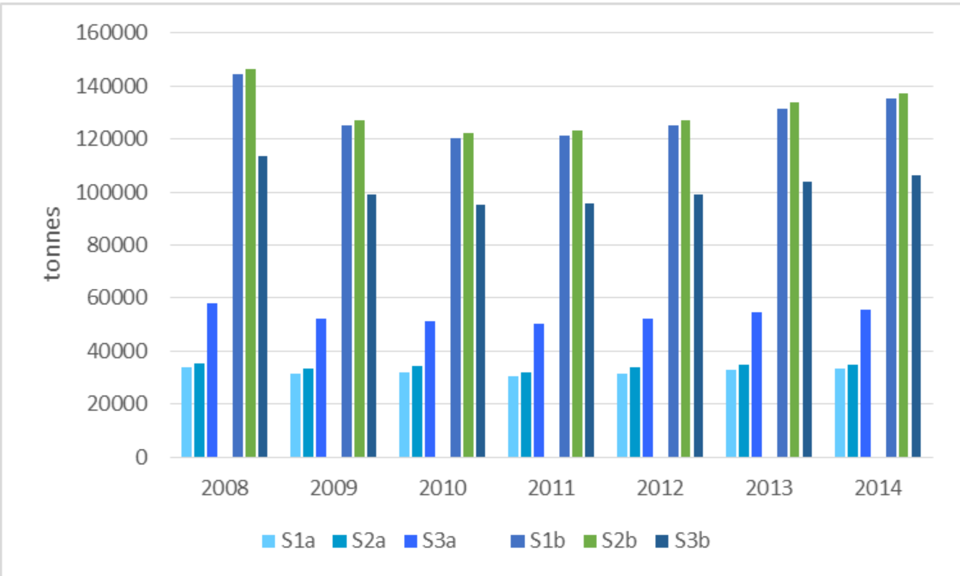
As mentioned, the modern and old trucks have different values for NO_x EFs, therefore, the "a" and "b" cases are discussed here for the three scenarios. NO_x emissions (Figure 7) in S1b, S2b and S3b are, respectively, 4.1, 3.9 and 1.9 times higher than those in S1a, S2a and S3a. This shows that the difference between the impacts produced on NO_x emissions by modern and old trucks are significant. It is to be noted that the "a" case, in which we assume all trucks to be "modern", results in an increase of 68% in NO_x emissions for a shift of 50% of road freight to inland waterways (S3 versus S1), whereas for the "b" case, in which we consider all trucks used to transport goods to be "old", there is a decrease in NOx emissions with 21% for the same shift.

Figure 6. SO2 emissions



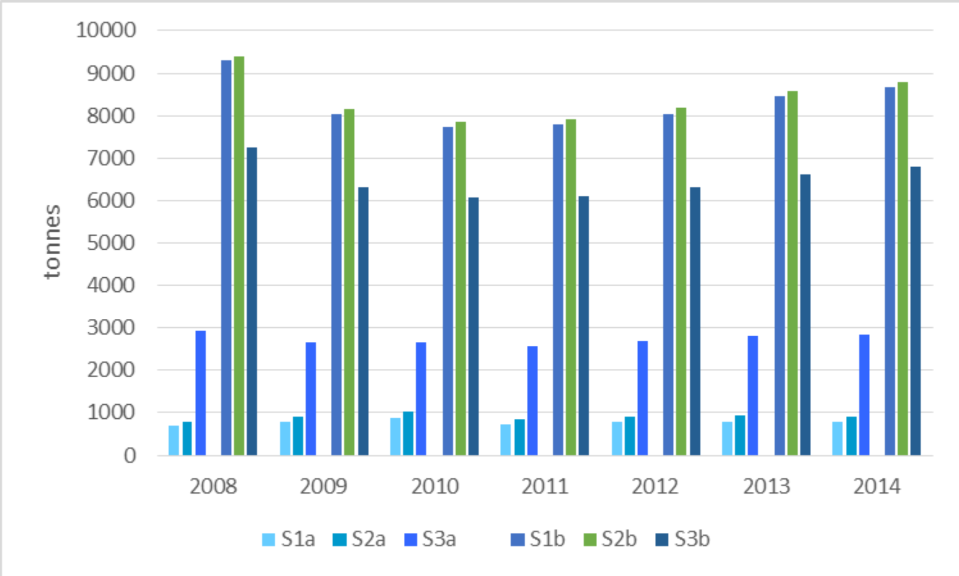
Source: JRC analysis

Figure 7. NOx emissions



Source: JRC analysis

Figure 8. PM10 emissions



Source: JRC analysis

Thus we can conclude that:

— Due to the current relatively low volume of ILW transport, a 20% increase in the latter has only a minor impact on pollutant emissions (scenario S1a)

— If mainly modern trucks are taken out of service, there are no real benefits in NO_x emission reductions for a modal shift to ships, on the contrary, the emissions will increase.

— If mainly old trucks are taken out of service, there are possible benefits in NO_x emission reductions as these high emitters are less used for road freight transport.

However, more precise insights of the benefits require accurate emissions estimates, based on existing fleet composition and technology-specific EFs, for more realistic modal shift scenarios.

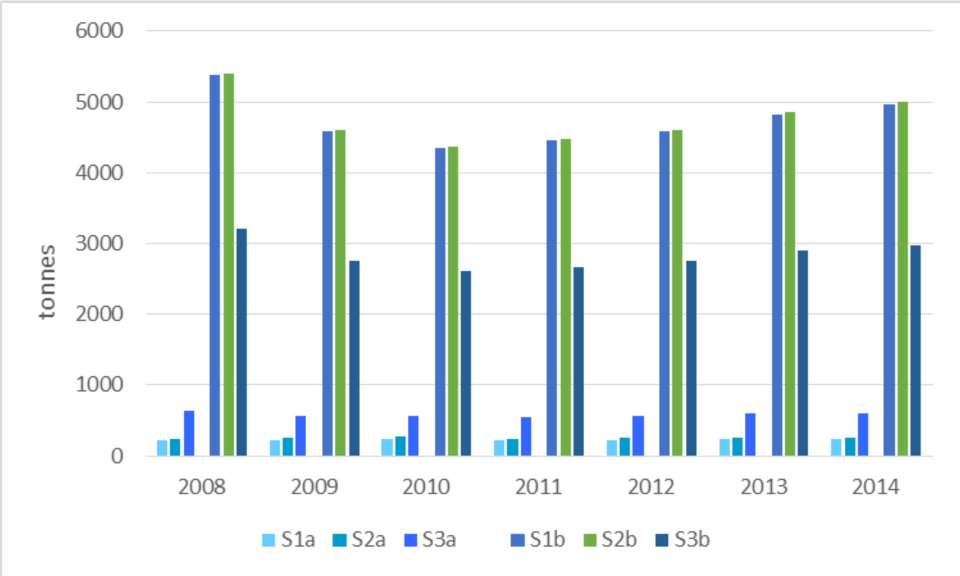
PM_{10} emissions (Figure 8) variations are similar to those of NO_x emissions for the three scenarios. In S1b, S2b and S3b PM_{10} emissions are, respectively, 11.2, 9.8 and 2.4 times higher than those in S1a, S2a and S3a. PM_{10} emissions for "a" situation increase by 265% for S3 when compare to S1, whereas for "b" situation they decrease by 22% for S3 when compared to S1. The findings on the benefits regarding PM_{10} emissions reduction are the same as for NO_x emissions: a shift from road freight transport by modern trucks only to ILW results in increased emissions, whereas a shift from old trucks to ILW produces a net benefit in terms of PM_{10} emissions.

Constant fractions of BC and OC content in PM_{10} have been used to derive emission factors for these pollutants and consequently BC (Figure 9) and OC (Figure 10) emissions follow the same patterns as for PM_{10} and NOx emissions.

The CO_2, SO_2, NO_x, PM_{10}, BC and OC emissions presented in this section for the three scenarios were used as input to TM5-FASST tool to evaluate their impact on air quality and health (see section 3.1.2).

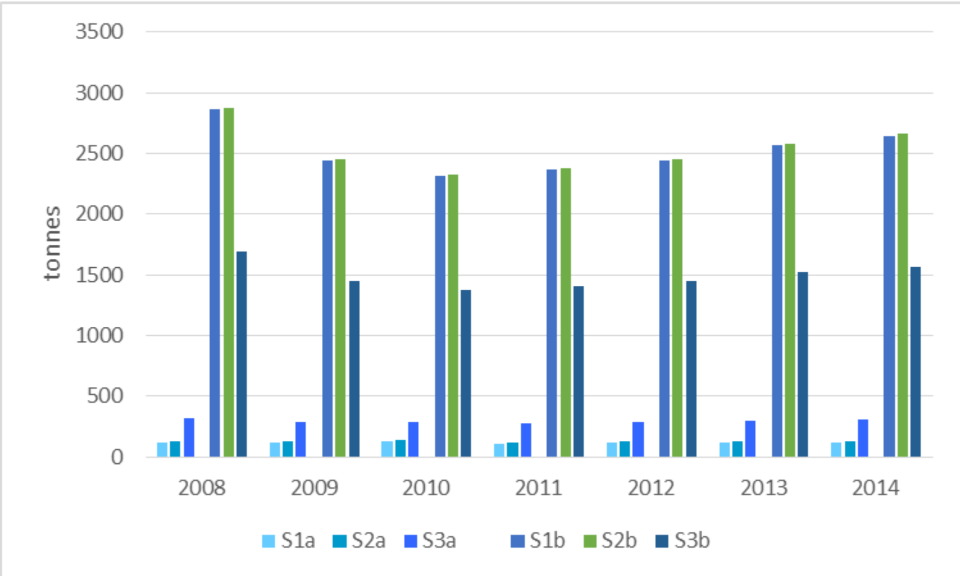
As a continuation of this work, we would recommend that 1) more realistic region-specific emissions scenarios for different policy options be developed by the regional authorities, 2) these more accurate emissions are used as input by chemical transport models such as TM5-FASST to evaluate the impact on air quality, health and crops and further 3) gridded emissions be prepared by using the EDGAR.ms1 Web-based gridding tool (Muntean et al., 2015); these emission gridmaps can be used as input for finer resolution models to investigate on more local issues.

Figure 9. BC emissions



Source: JRC analysis

Figure 10. OC emissions



Source: JRC analysis

3.1.2 Concentrations and impacts in the Danube region

In this section we evaluate the impacts on air quality and human health resulting from the scenarios described above. The emissions from the Danube regions for which data are available are used as input to the TM5-FASST model. Because the input dataset contains only emissions for the transport sources discussed, we cannot make an evaluation of the contribution of the selected transport modes to the total impact from all sectors. Instead, we evaluate the differences between a 'policy' scenario and a 'reference' scenario in the frame of the defined transport mode scenarios. As reference we adopt 2 extreme cases:

(a) emissions from inland waterway transport via ship plus road freight transport assuming all trucks are 'clean/modern'

(b) emissions from inland waterway transport via ship plus road freight transport assuming all trucks are 'dirty/old'

We compare the impacts of increased ILW transport or shift from road to ILW to these two reference case.

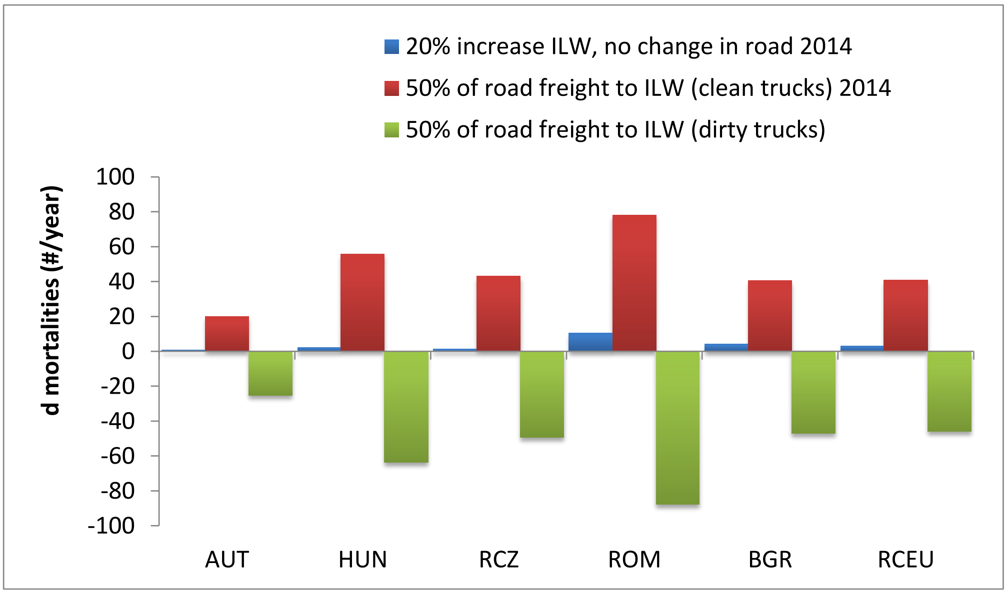
Table 7 shows the estimated change in $PM_{2.5}$ (as population-weighted average over the region) for the scenarios described above. Changes in absolute concentrations are very small. Note that $PM_{2.5}$ values are given in units of ng/m³, i.e. 10^{-3} µg/m³. Despite high pollutant emission factors for inland ships, a 20% increase in the current volume of ILW transport has virtually no impact on air quality – this is a consequence of the fact that the current volume of ILW is very low. The net impact of transferring 50% of road freight transport to ILW transport is a combination of a reduction in road transport emissions and an increase in ILW emissions. The two extreme scenarios considered (in terms of trucks emission factors) lead to opposite impacts of similar magnitude, as could already be inferred from the emissions presented above in Figure 6 to Figure 10.

Table 7. Changes in $PM_{2.5}$ from shifts in transport modes (compared to reference scenario without shifts). See Table 4 for the list of countries included in each region.

TM5-FASST region[1]		$\Delta PM_{2.5}$ (ng/m³)					
		AUT	HUN	RCZ	ROM	BGR	RCEU
20% increase ILW, no change in road	2010	1	3	1	6	6	2
	2014	1	2	1	5	5	2
50% of road freight to ILW (case a: modern trucks)	2010	34	48	30	27	31	19
	2014	32	53	32	36	43	22
50% of road freight to ILW (case b: old trucks)	2010	-43	-55	-34	-31	-37	-21
	2014	-40	-61	-37	-40	-50	-24

Source: JRC analysis

Figure 11. Change in premature mortalities as a result of shifts in transport modes

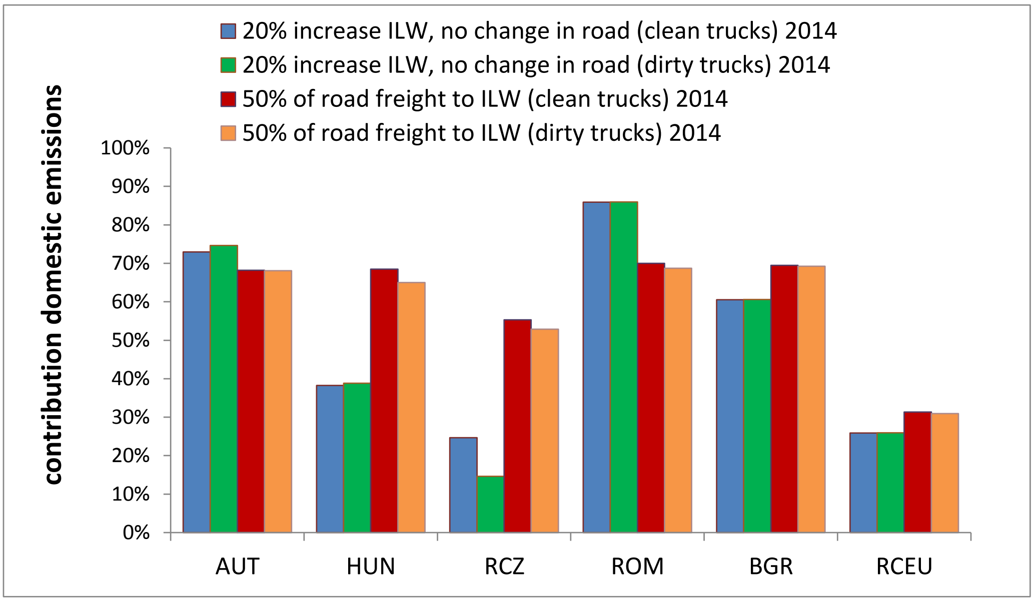


Source: JRC analysis

The health impact on the population of the Danube region is shown in Figure 11. The total change in annual premature mortalities for all included regions varies between +280 for a shift from 50% of clean truck road transport to ILW, and -320 for a similar shift of road transport with dirty trucks.

Impacts of air quality policies applied in a given region also work across boundaries. Figure 12 shows which fraction of the change in $PM_{2.5}$ concentration (shown in Table 7) is due to emissions within the region itself. The domestic share in the resulting impact is linked to the relative importance of the different transport modes compared to neighbouring regions, and to the geographical extend of each region. For instance, a small region with relatively low freight transport intensity is likely to be more affected by long-range transport of pollutants from its neighbouring regions, in particular when emissions in the freight transport sector are higher in the latter. Figure 11 shows that the regions "Rest of Central Europe" (RCEU) and "Czech Republic + Slovakia" (RCZ) have the lowest domestic contribution from the assumed modal shift, hence they are most affected by cross-boundary pollutant transport and by measures implemented in neighbouring regions – whether they be beneficial or not. On the other hand, in Romania the air quality impacts from the assumed measures are 70-80% generated by emissions within the country itself.

Figure 12. Contribution of internal emissions (inside the regions) to the change in $PM_{2.5}$ from the transport scenarios (emissions for the year 2014)



Source: JRC analysis

3.2 Co-benefits of Climate and SLCP Mitigation Scenarios (ECLIPSEV5a scenarios)

The ECLIPSE scenarios have been developed and analysed on a global scale (Stohl et al., 2015) in terms of health and climate impacts. Here we focus on their outcome for the Danube region, in particular the air quality co-benefits resulting from climate mitigation targeting both greenhouse gases and short-lived pollutants. We evaluate the CLE scenario (i.e. full implementation of current legislation), and compare to that the additional benefits of CLIM scenario (i.e. climate mitigation by greenhouse gas emission reduction, to obtain a 2°C target) and the SLCP scenario (i.e. air quality control specifically targeting those pollutants that are contributing to warming).

3.2.1 Emission trends

Figure 13 shows emission trends for the four selected ECLIPSEV5a scenarios, aggregated for the entire Danube region, for four major pollutants (SO_2, NO_x, BC, POM). The CLE scenario realizes most of its reductions in the timespan 2010 – 2030, with virtually no further improvements beyond 2030, because of the time horizon of currently decided legislation on air quality controls. The CLIM scenario shows a slight additional reduction in pollutant emissions compared to CLE, in particular for SO_2 with a continued decrease towards 2050. The SLCP scenario shows strong additional reductions in primary $PM_{2.5}$ (BC and POM), a slight additional decrease in NO_x and no effect on SO_2 compared to CLE. This is a consequence of the selection of additional measures, which target in particular short-lived pollutants with a warming impact, to which BC and O_3 (formed from NO_x) are the major contributors. POM is in general considered a cooling compound, and is not specifically targeted in SLCP measures. However, it is mostly co-emitted with BC; hence measures targeting BC will also affect POM. The SLCP measures however have been selected in such a way that in the combined BC-POM reductions, there is a net climate benefit. A more detailed description of the procedure for the selection of the specific SLCP measures is given in The World Bank, The International Cryosphere Climate Initiative (2013).

3.2.2 Concentrations and impacts in the Danube region

3.2.2.1 Concentration and impacts trends for the CLE Baseline

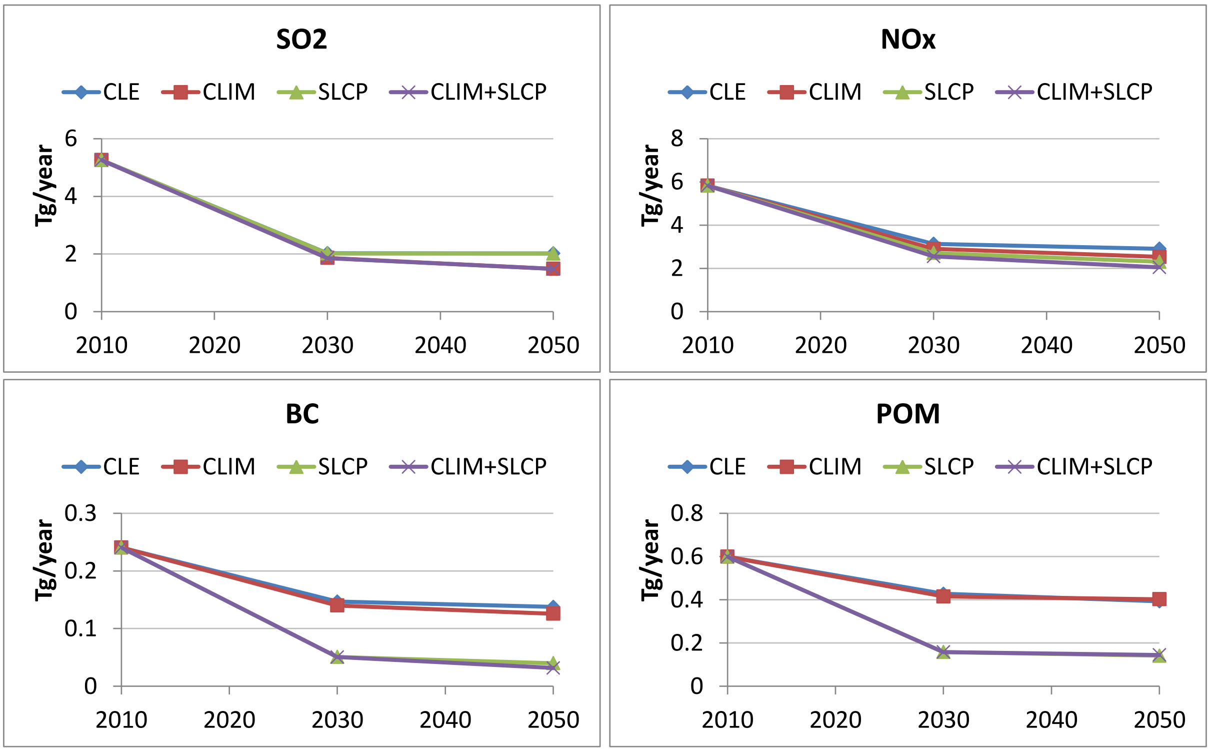
3.2.2.1.1 Health impacts

Figure 14 shows, for all countries of the Danube region, trends in $PM_{2.5}$ under the current legislation (CLE) scenario for the years 2010, 2030 and 2050. As could already be inferred from the overall pollutant emission trends, the CLE baseline gives a significant improvement in $PM_{2.5}$ levels in EU28 countries between 2010 and 2030. After that, no further improvement is projected (under CLE) – in some cases a slight deterioration is even expected. A similar trend is also seen for Albania and TFYR of Macedonia. For Moldova and Ukraine, current legislation does not lead to significant improvements in $PM_{2.5}$ levels by 2050.

The projected changes in the M6M ozone exposure metric under CLE are less pronounced, for both EU28 and non EU countries within the Danube basin (Figure 15). For the year 2050, the ozone health metric shows a slight increase, despite constant or slight further reduction of NO_x emissions. A possible reason is the long-range hemispheric transport of ozone produced in Asia, and an increased contribution from background ozone produced by CH_4.

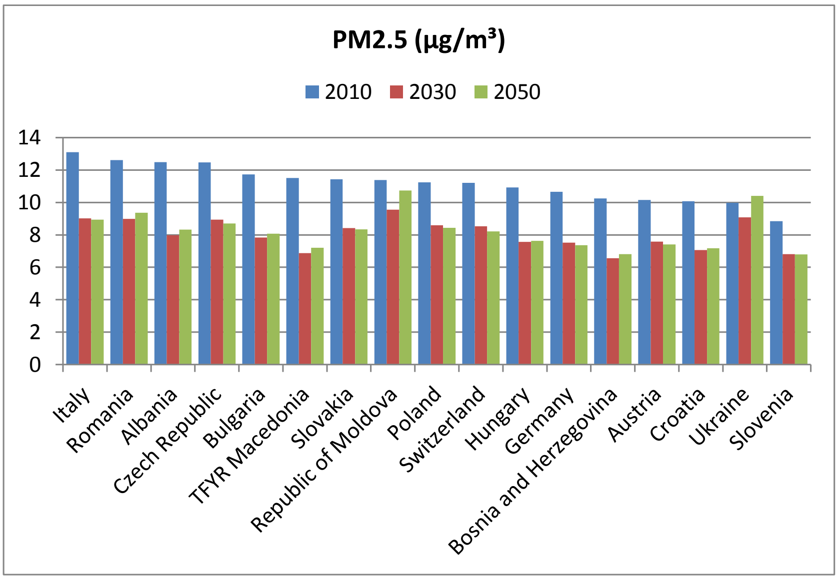
Figure 16 shows premature mortalities from five death causes (population aged > 30 year for IHD, Stroke, COPD and LC, and < 5 years for ALRI) attributable to $PM_{2.5}$ and O_3 for the coming decades under CLE. The trends within each country roughly reflect the trends in $PM_{2.5}$ which is responsible for >90% of the mortality burden, however population and baseline mortality changes for 2030 and 2050 also play a role.

Figure 13. Emission trends for major pollutants in the Danube Basin Area, for the four scenarios considered in this study



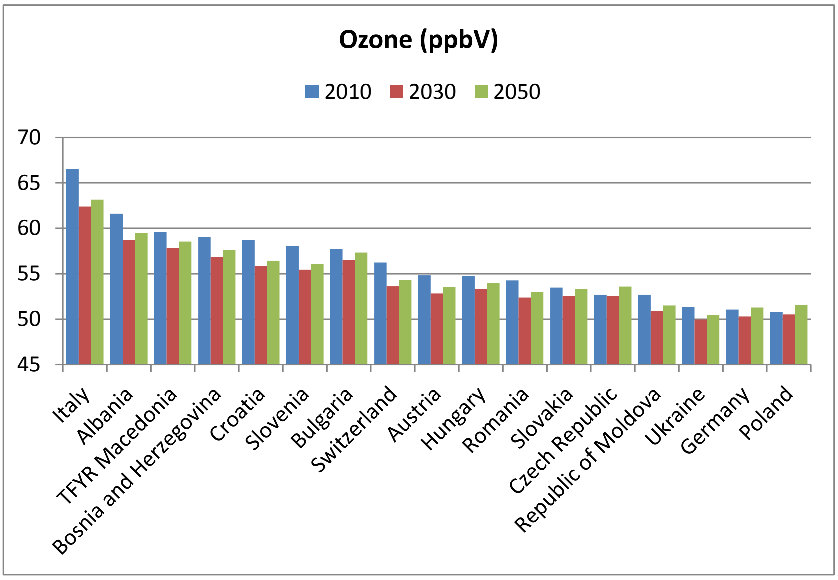
Source: JRC elaboration of ECLIPSEV5a emission scenarios (IIASA, 2015)

Figure 14. Country-averaged anthropogenic $PM_{2.5}$ concentration in the Danube region for CLE scenario, years 2010 (blue), 2030 (red) and 2050 (green). Countries have been ranked from high to low by $PM_{2.5}$ levels in 2010.



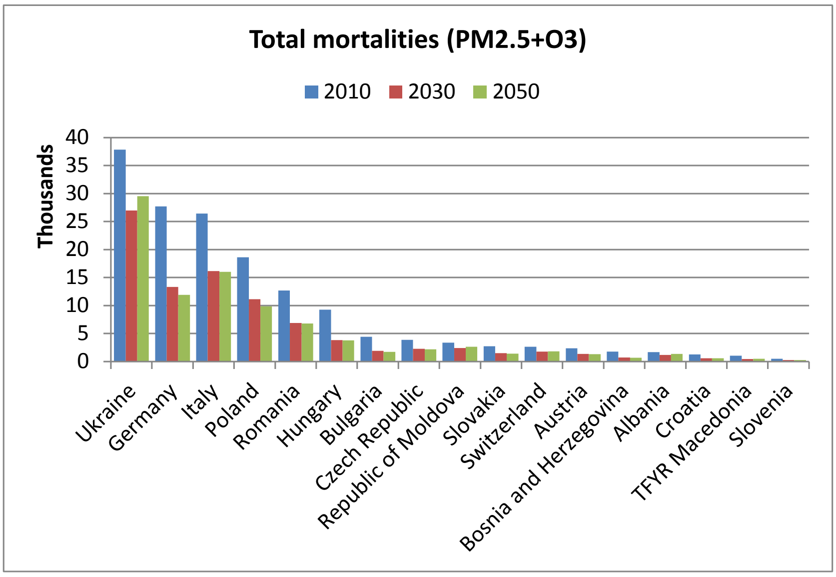
Source: JRC analysis

Figure 15. Country-averaged M6M metric (average ozone exposure during 6 highest months) in the Danube region for the CLE scenario. Countries have been ranked from high to low by M6M level in 2010.



Source:JRC analysis

Figure 16. Premature mortalities from air pollution under CLE for 2010, 2030, 2050. Countries have been ranked from high to low by the number of mortalities in 2010.



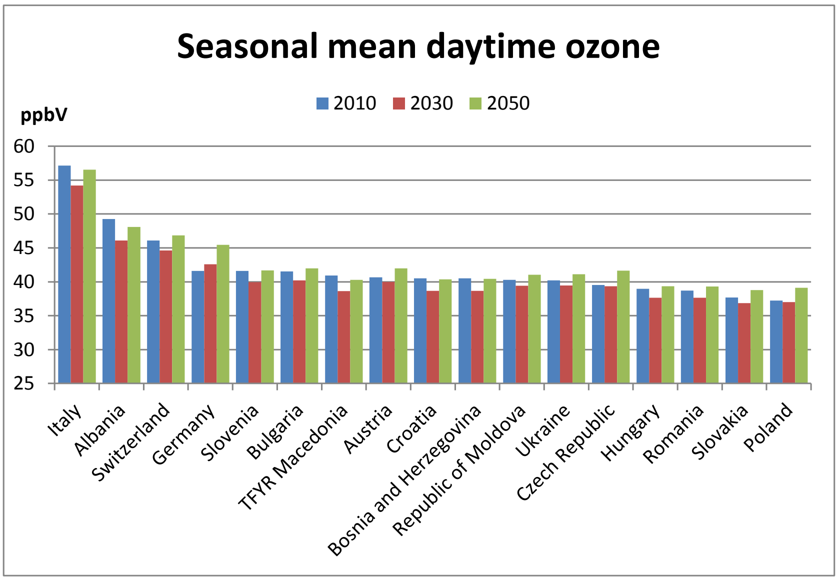
Source:JRC analysis

3.2.2.1.2 Crop impacts

Figure 17 shows the trend in the ozone metric used for the crop yield loss (growing season-mean of daytime ozone). As observed for the ozone health metric, the ozone crop metric increases consistently for all countries between 2030 and 2050 under CLE.

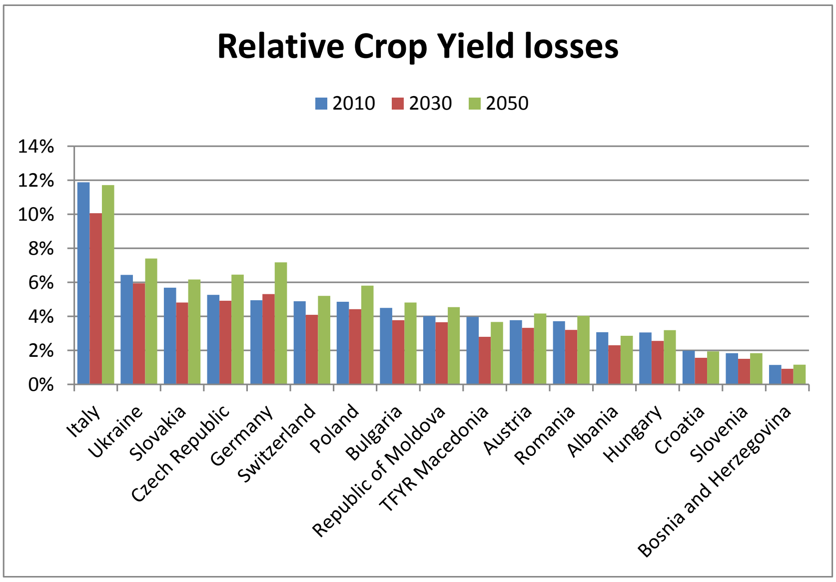
Relative crop losses (4 crops) are shown in Figure 18. Highest losses are observed in Italy (12% in 2010 and 2050, 10% in 200). Most other countries of the Danube region observe losses round 5%. Table 8 shows absolute numbers of crop losses. Italy, Germany and Ukraine account for 67% of the crop losses in the Danube region in 2010 and 68% in 2030 and 2050.

Figure 17. Growing-season mean daytime concentration (shown for wheat only) for CLE years 2010 - 2030 - 2050. Values are shown above the 25ppb threshold. Countries ranked from high to low by Mi concentration in 2010.



Source: JRC analysis

Figure 18. Estimated relative yield losses (four crops) for CLE 2010 - 2030 - 2050 in the Danube regions. Ranking according to losses in 2010.



Source: JRC analysis

Table 8. Crop production losses from four considered crops (ktonnes) under CLE scenario for the years 2010, 2030 and 2050.

	2010	2030	2050
Italy	1765	1495	1741
Germany	977	1045	1413
Ukraine	630	581	724
Romania	347	299	376
Poland	292	266	349
Hungary	250	210	262
Bulgaria	237	199	254
Czech Republic	183	171	224
Austria	109	96	121
Slovakia	62	53	67
Croatia	50	40	49
Republic of Moldova	49	45	55
Switzerland	36	30	38
TFYR Macedonia	14	10	13
Bosnia and Herzegovina	13	10	13
Albania	9	7	8
Slovenia	7	6	7

Source: JRC analysis

In the following sections we will evaluate changes in impacts for each of the mitigation scenarios relative to the CLE baseline, by comparing each scenario with the CLE projections for the same year (i.e. 2030 and 2050). We evaluate the benefit of reduced air pollutant emissions from mitigation scenarios targetting greenhouse gases, as well as mitigation scenarios targetting short-lived climate-relevant pollutants (SLCPs), and the combination of both.

3.2.2.2 Health co-benefits from climate mitigation scenarios

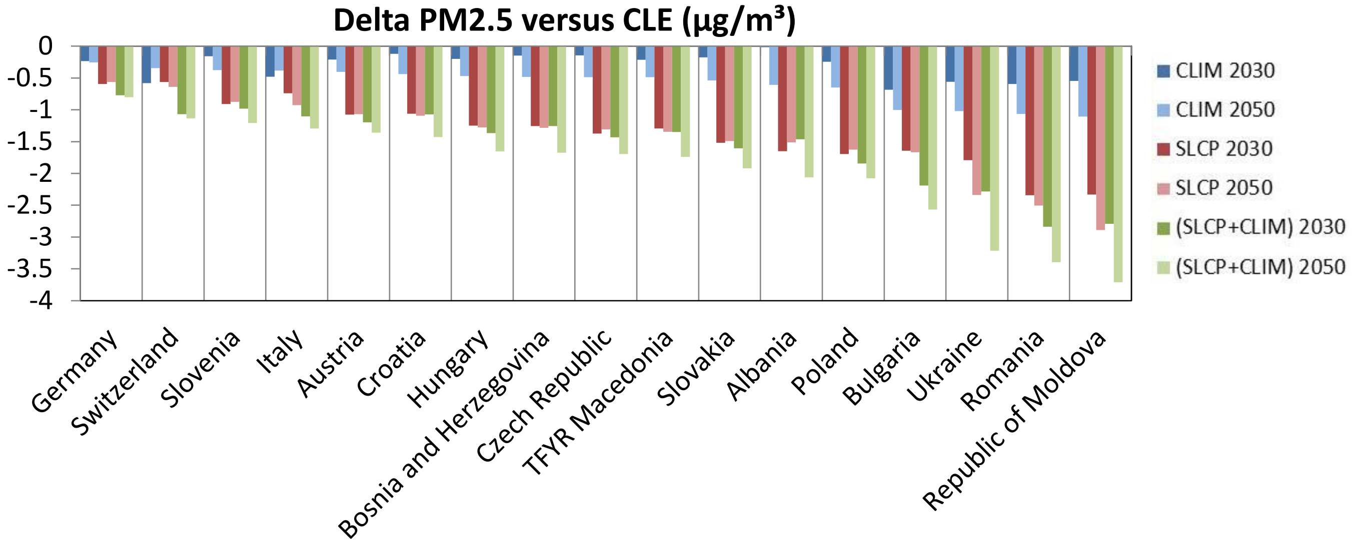
The implementation of climate policies mitigating greenhouse gases happens at the level of energy production, fuel mix and energy consumption. Effectively reducing the use of fossil fuels does not only mitigate CO_2 emissions, but has the additional benefit of reducing emissions of combustion-related pollutants (mainly primary $PM_{2.5}$, see Figure 13). The resulting concentration benefits for $PM_{2.5}$ and the ozone exposure metric M6M for the years 2030 and 2050, relative to a reference scenario without climate mitigation measures, are shown in Figure 19. Climate mitigation measures only (blue bars) have a relatively small impact by 2030 for most countries. The lowest $PM_{2.5}$ co-benefits in 2050 (<0.4µg/m³) are found in Germany, Slovenia, Austria and Hungary. By 2050, the population-weighted $PM_{2.5}$ concentration under the CLIM scenario decreases with about 1µg/m³ in Bulgaria, Romania, Ukraine and the Republic of Moldava. A similar behaviour is observed for ozone, except that SLCP measures continue to improve O_3 levels beyond 2030, thanks to reductions in CH_4 which affects the hemispheric background levels. For both $PM_{2.5}$ and O_3, continued climate mitigation efforts troughout 2050 are leading to continued improvements in air quality beyond 2030 in all cases, except for Switzerland, Italy and Germany. For Albania, virtually all of the co-benefits are realized between 2030 and 2050. Targeted SLCP measures, focusing on BC and O_3 (red bars) obviously lead to a more substantial improvement in air quality. However as technical (end-of-pipe) solutions are expected to be exhausted by 2030, little further improvement is observed beyond 2030. The combination of both policies (CLIM+SLCP) leads to a total air quality benefit which is slightly lower than the sum of both separately because of partly overlap in the targeted sectors. Particularly in Eastern-European countries, the contribution of the continued climate mitigation effort to 2050 pushes forward the boundaries of air quality control that could be reached by (SLCP targetted) technical measures only.

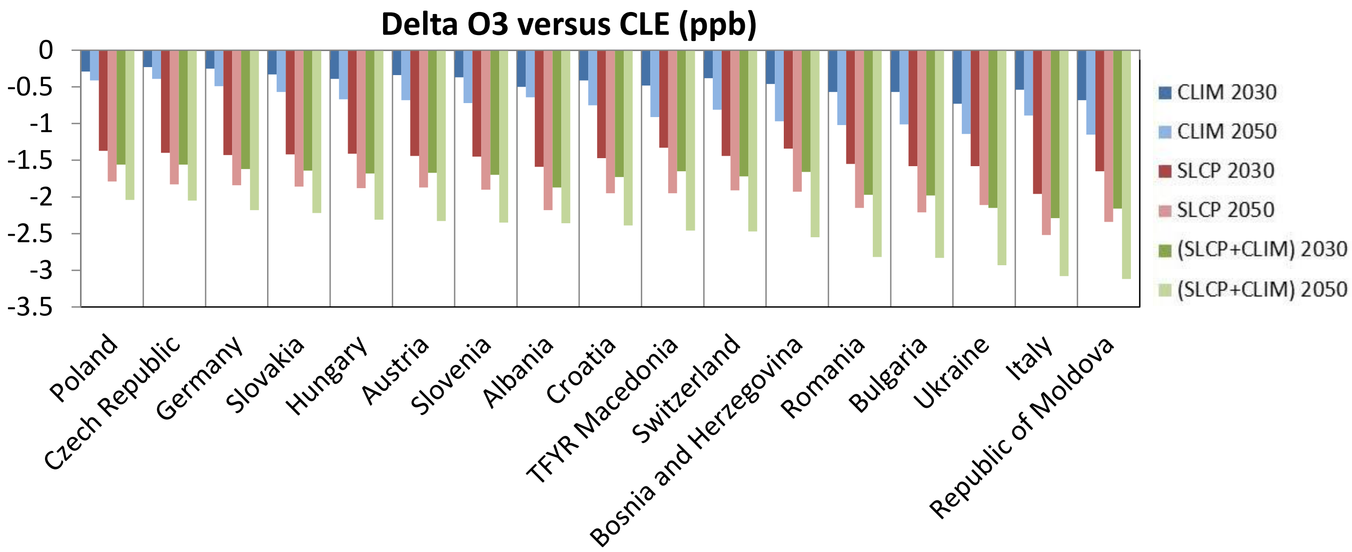
The corresponding impact on premature mortalities is summarized in Table 9. For the whole Danube basin, climate mitigation leads to an estimated decrease in air pollution-induced mortalities of 8000 by 2030 and 12000 by 2050, taking into account both the changing demography and changing pollutant emissions. Note that in our model meteorology is kept constant and all impacts are attributed to emission changes only.

3.2.2.3 Crop co-benefits from climate mitigation scenarios

The co-benefit on ozone levels also has a beneficial impact on agricultural crop yields. The fraction of crop yield lost is independent on the actual absolute production numbers and can be calculated from the appropriate O_3 metrics, as described in the methods section. Figure 20 shows the percentage avoided crop loss (i.e. yield gain compared to CLE) as a total for four major crops (wheat, maize, rice, soy beans of which only Italy produces the latter two) that can be expected from the associated reduction in ozone precursors compared to a reference policy without climate mitigation measures. Again, climate policies superimposed on air quality policies (SLCP) add substantially to the total benefit. The absolute increase in production (ktonnes/year) depends on the actual crop production in the future scenarios which is highly uncertain. Using present-day crop production numbers for the Danube region as a reference for all scenarios and all years, we estimate an increase of 0.6 Mtonnes by 2030 and 1.4 Mtonnes by 2050. A combined greenhouse gas – SLCP mitigation effort would lead to an estimated aggregated crop benefit of 3.7 MTonnes per year for the Danube region. Yield gains for all countries inside the Danube region are reported in Table 10.

Figure 19. Change in $PM_{2.5}$ (top) and ozone (as M6M metric, bottom) concentrations for greenhouse gas and SLCP mitigation scenarios in 2030 and 2050, relative to the reference CLE scenario for the same years.





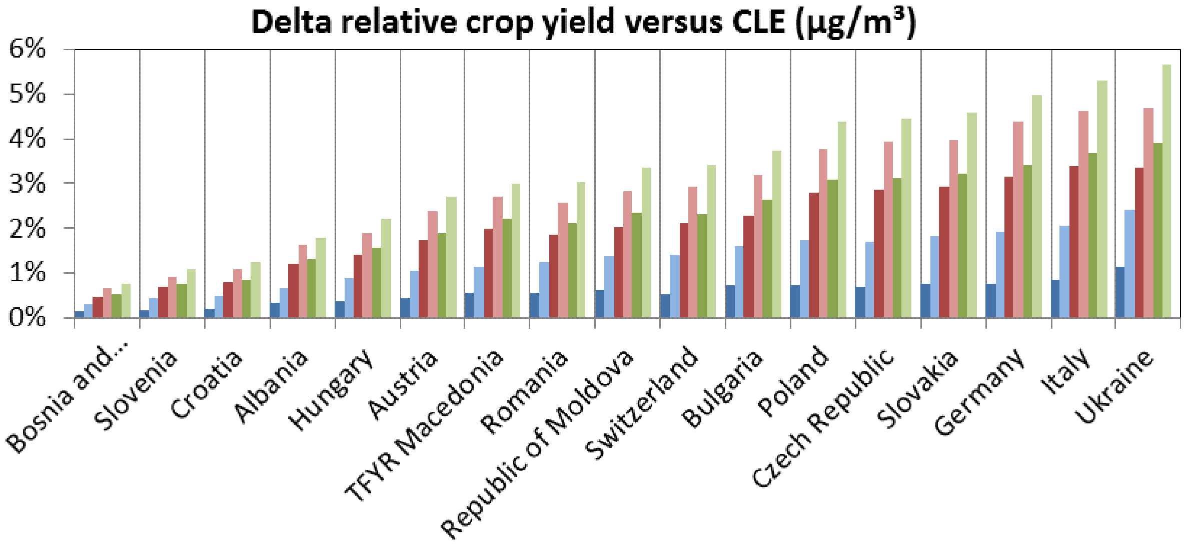
Source: JRC analysis

Table 9. Co-benefits on mortalities from air pollution under various scenarios, compared to currently decided legislation, in the Danube region for 2030 and 2050

	Change in MORTALITIES ($PM_{2.5}$ + O_3) relative to CLE (CLE same year as scenario)					
	CLIM		SLCP		Combined CLIM & SLCP	
	2030	2050	2030	2050	2030	2050
Slovenia	-19	-41	-116	-116	-123	-149
Austria	-96	-186	-492	-503	-546	-661
Bulgaria	-334	-458	-789	-691	-1096	-1109
Switzerland	-237	-308	-249	-284	-467	-547
Hungary	-268	-503	-2194	-2253	-2492	-2937
Italy	-1146	-1276	-1870	-2317	-2799	-3465
Poland	-679	-1585	-4741	-3930	-5151	-5313
Albania	-6	-124	-421	-445	-375	-561
Bosnia and Herzegovina	-47	-124	-440	-346	-437	-526
Croatia	-25	-78	-249	-237	-262	-326
TFYR Macedonia	-35	-83	-209	-204	-214	-265
Czech Republic	-79	-235	-717	-683	-750	-879
Slovakia	-77	-201	-703	-660	-745	-840
Germany	-834	-966	-2453	-2559	-3173	-3176
Romania	-862	-1411	-3528	-3398	-4182	-4421
Republic of Moldova	-240	-370	-1058	-1145	-1270	-1486
Ukraine	-3033	-4446	-9973	-10685	-12999	-15118
TOTAL all regions:	-8017	-12394	-30202	-30457	-37081	-41779

Source: JRC analysis

Figure 20. Change in relative crop yield for GHG and SLCP mitigation scenarios relative to the reference CLE scenario for the same years (bar colour legend as in Figure 19)



Source: JRC analysis

Table 10. Change in crop production (ktonnes/year) for four major crops (wheat, maize, rice, soy beans) as a co-benefit of reduced O_3 damage from GHG and SLCP mitigation scenarios in 2030 and 2050, compared to the reference CLE scenario for the same year. Estimates are based assuming a constant potential 'undamaged' crop production throughout the scenarios. Positive numbers refer to a gain in crop yield relative to CLE.

	Change in crop yield, ktonnes/year relative to CLE (CLE same year as scenario)					
	CLIM		SLCP		Combined (SLCP+CLIM)	
	2030	2050	2030	2050	2030	2050
Slovenia	0.7	1.7	2.7	3.7	2.9	4.2
Albania	1.0	2.0	3.5	4.8	3.9	5.3
Bosnia and Herzegovina	1.5	3.4	5.4	7.5	6.0	8.6
TFYR Macedonia	2.0	4.0	7.0	10	7.7	11
Switzerland	4.0	10	16	22	17	25
Croatia	5.3	13	20	27	22	31
Republic of Moldova	7.7	17	25	34	28	41
Slovakia	8.3	20	32	43	35	50
Austria	12	31	50	69	55	78
Czech Republic	24	59	100	137	109	155
Hungary	30	72	115	156	128	181
Bulgaria	38	84	121	168	138	198
Poland	43	103	168	228	185	264
Romania	52	116	174	240	198	283
Ukraine	112	235	328	458	384	553
Italy	129	306	501	688	548	786
Germany	147	379	622	864	675	981
TOTAL all regions:	**618**	**1457**	**2291**	**3158**	**2543**	**3654**

Source: JRC analysis

4 Conclusions and outlook

The analysis presented in this report is a continuation of the "Preliminary exploratory impact assessment of short-lived pollutants over the Danube Basin" report (Van Dingenen et al., 2015). Where the earlier study addressed the apportionment of various pollutant sources (in terms of economic sectors) to the PM2.5 concentration in the Danube region, here we focus on the impacts of policy interventions at the level of freight transport modes and climate mitigation respectively on pollutant emissions, pollutant concentrations and their associated impact on public health and on crop production. These scenarios do not represent the current air quality legislation, but are evaluated as 'add-ons' to the latter. Indeed, policies at the level of transport modes and greenhouse gas mitigation are likely to impact on air quality levels. Linkages between air quality – climate - transport policies go beyond the mentioned co-benefits from climate policies, considering that many air pollutants interact with radiation and affect climate through cooling (e.g. sulphate) or warming (e.g. BC, ozone) and that NO_x, which is one of the ozone precursors, is still emitted in high quantities from transport sector, heavy duty vehicles in particular. A sustainable transport policy could promote solutions and produce gains for climate and for air quality.

In the first part of this report we investigated possible air quality benefits from a modal shift in freight transport. We used JRC tools and expertise to assess various impacts produced by a modal shift in freight transport (from trucks to ships) in the Danube region. Since "increasing the cargo transport on the river by 20% by 2020 compared to 2010" is one of the targets of the Priority Area 1A[(4)] of the Danube Strategy, we developed EDGAR modal shift freight transport scenarios for inland waterways and road modes only. This includes the reference scenario and a scenario in which we increase the inland waterways freight transport in the Danube region by 20%; this was complemented by a fictitious modal shift scenario in which two extreme cases of a 50% transfer of road freight transport to inland waterways were evaluated.

The main findings/achievements are:

— Methodology development to evaluate emissions from road and inland waterways freight transport.

— Emissions estimation for fictitious emissions scenarios based on the info and data available. We did not treat the aspect of increasing the real freight weight in the future on the road and on the rivers and their corresponding fuel consumption increase; however, we can conclude that policies on replacement of old diesel vehicles could be beneficial for air quality and human health in the region. In addition, a progressive fleet renewal in inland waterways would keep the emissions comparable with those of the modern trucks.

— Scenario evaluation with the TM5-FASST tool shows that a 20% increase in the current volume of inland waterways freight transport has virtually no impact on air quality; this is because the current volume of inland waterways is low.

Various global and regional assessments have demonstrated that climate mitigation of greenhouse gases yield significant beneficial side effects for air quality (Lee et al., 2016; Maione et al., 2016; Mittal et al., 2015; Rao et al., 2016; Zhang et al., 2016). Such analysis has however not been performed so far for the Danube region. Here we analysed an available set of pollutant emission scenarios (ECLIPSE) consistent with climate mitigation within a 2°C target, and evaluated the co-benefit for air quality in the Danube region from underlying greenhouse gas reduction measures. We also evaluated the potential of additional climate-friendly air quality measures on top of currently decided legislation, as well as the combination of both. The set of ECLIPSE scenarios used in this study, includes possible futures for emissions of short-lived pollutants until 2050.

(4) Priority Area 1A: To improve mobility and intermodality of inland waterways

Major findings from the ECLIPSE scenario analysis are:

— climate mitigation scenarios (both greenhouse gases and short-lived pollutants) with a focus on the Danube basin region show an estimated potential decrease in annual air pollution-induced mortalities of 40000 by 2050, relative to a current air quality legislation scenario without climate mitigation.

— The corresponding benefit of combined policies for crop production in the area is estimated to be 3.7 MTon/year in 2050 for wheat, maize, rice and soy beans.

With the JRC tools, TM5-FASST model in particular, and the findings from these studies we demonstrated that the effectiveness of future regional policies on economic development, which are likely to produce impact on air emissions, can be evaluated.

As an alternative, instead of e.g. EDGAR modal shift/ECLIPSE emission scenarios, region-specific scenarios for different policy options can be developed by the regional authorities; these accurate emissions can be used as input for chemical and transport models such as TM5-FASST to evaluate the impact on air quality, health and crops. Regarding transport sector, gridded emissions can be prepared by using the EDGAR.ms1 Web-based gridding tool; these emission gridmaps can be used as input for finer resolution models to investigate on more local issues.

The JRC tools used in this study are available to interested users:

— TM5-FASST: http://tm5-fasst.jrc.ec.europa.eu/

— EDGAR.ms1 Web-based gridding tool for emissions from road transport is available upon request.

JRC organized activities in support to this work:

— Clean growth in freight transport: emissions and impact assessment workshop (Oct. 2016)

— Training: Introduction to the web-based Fast Scenario Screening Tool (TM5-FASST) (Oct. 2016).

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List of abbreviations and definitions

ECLIPSE	Evaluating the CLimate and Air Quality ImPacts of Short-livEd Pollutants
ALRI	Acute Lower Respiratory Infections
AOT40	accumulated ozone above a 40ppb threshold (crop ozone exposure metric)
BC	Black Carbon (here used as a component of airborne fine particulate matter)
CEIP	Centre on Emission Inventories and Projections
CLE	Current Legislation emission scenario (in this study)
CLIM	Climate mitigation emission scenario (in this study)
CLRTAP	Convention on Long-range Transboundary Air Pollution
COPD	Chronic Obstructive Pulmonary Disease
CP	Crop production (annual, ktonnes)
CPL	Crop Production Loss
CTM	Chemistry Transport model
EDGAR	Emissions Database for Global Atmospheric Research
EEA	European Environment Agency
EF	Emission factor
EMEP	European Monitoring and Evaluation Programme
FP7	7th Framework programme
GAeZ	Global Agro-Ecological Zones
GAINS	Greenhouse Gas - Air Pollution Interactions and Synergies, model developed by IIASA
GBD	Global Burden of Disease
GEA	Global Energy Assessment
GIFT	Geospatial Intermodal Freight Transportation
HDV	Heavy Duty Vehicles
IEA	International Energy Agency
IHD	Ischaemic heart disease
IHME	Institute for Health Metrics and Evaluation
IIASA	International Institute for Applied System Analysis
ILW	Inland Waterways freight transport
LC	Lung Cancer
M12	3-monthly growing season mean of daytime ozone (averaged over 12 daytime hours)
M6M	Maximal 6-monthly running mean of the daily maximum 1-hourly O3 concentration (public health ozone exposure metric)
M7	3-monthly growing season mean of daytime ozone (averaged over 7 daytime hours)
MARREF	Macro-regions and regions of the future: mainstreaming sustainable regional and neighbourhood policy

Mi	Generic term for both M7 and M12
NMVOC	Non-methane volatile organic compounds
OC	Organic Carbon (here used as a component of airborne fine particulate matter)
OECD	Organisation for Economic Co-operation and Development
PBL	Planbureau voor de Leefomgeving - Netherlands Environmental Assessment Agency
PEGASOS	Pan-European Gas-Aerosols-Climate Interaction Study
PM10	Airborne particulate matter with an aerodynamic diameter up to 10 μm
PM2.5	Airborne particulate matter with an aerodynamic diameter up to 2.5 μm
POM	Particulate Organic Matter, includes carbon and hetero-atoms associated with the organic compounds
POP	Population (number)
RR	Relative Risk
RYL	Relative Yield Loss (for crops)
SLCP	Short Lived Climate Pollutants
tkm	tonne-kilometre: unit of payload-distance. 1 tkm represents the service of moving one tonne of payload over a distance of 1 km.
TM5-FASST	Fast Scenario Screening Tool, based on the chemical transport model TM5
UN	United Nations
UN-DESA	United Nations Department of Ecinomic and Social Affairs
WHO	World Health Organisation

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Annex I

Freight movements (tkm) for S1, S2 and S3

S1: existing freight transport for inland waterways (ILW) and road transport

UNIT Million tonne-kilometre

ILW

Country	2008	2009	2010	2011	2012	2013	2014
Austria	2359	2003	2375	2123	2191	2353	2177
Bulgaria	2890	5436	6048	4310	5349	5374	5074
Croatia	842	727	940	692	772	771	716
Hungary	2250	1831	2393	1840	1982	1924	1811
Romania	8687	11765	14317	11409	12520	12242	11760
Slovakia	1101	899	1189	931	986	1006	905
Serbia and Montenegro	1369	1114	875	963	605	701	759

UNIT Million tonne-kilometre

Road

Country	2008	2009	2010	2011	2012	2013	2014
Austria	34313	29075	28659	28542	26089	24213	24299
Bulgaria	15322	17742	19433	21214	24372	27097	27854
Croatia	11042	9426	8780	8926	8649	9133	9381
Hungary	35759	35373	33721	34529	33736	35818	37517
Romania	56386	34269	25889	26349	29662	34026	35136
Slovakia	29276	27705	27575	29179	29693	30147	31358
Serbia and Montenegro	1249	1364	1856	2009	2550	2891	3081

S2 - increase only the freight movement of ILW of S1 by 20%

UNIT Million tonne-kilometre

ILW

Country	2008	2009	2010	2011	2012	2013	2014
Austria	2831	2404	2850	2548	2629	2824	2612
Bulgaria	3468	6523	7258	5172	6419	6449	6089
Croatia	1010	872	1128	830	926	925	859
Hungary	2700	2197	2872	2208	2378	2309	2173
Romania	10424	14118	17180	13691	15024	14690	14112
Slovakia	1321	1079	1427	1117	1183	1207	1086
Serbia and Montenegro	1643	1337	1050	1156	726	841	911

Road unchanged

S3 - shift of 50% freight movement from road transport to ILW

UNIT Million tonne-kilometre

ILW

Country	2008	2009	2010	2011	2012	2013	2014
Austria	19516	16541	16705	16394	15236	14460	14327
Bulgaria	10551	14307	15765	14917	17535	18923	19001
Croatia	6363	5440	5330	5155	5097	5338	5407
Hungary	20130	19518	19254	19105	18850	19833	20570
Romania	36880	28900	27262	24584	27351	29255	29328
Slovakia	15739	14752	14977	15521	15833	16080	16584
Serbia and Montenegro	1994	1796	1803	1968	1880	2147	2300

UNIT Million tonne-kilometre

Road

Country	2008	2009	2010	2011	2012	2013	2014
Austria	17157	14538	14330	14271	13045	12107	12150
Bulgaria	7661	8871	9717	10607	12186	13549	13927
Croatia	5521	4713	4390	4463	4325	4567	4691
Hungary	17880	17687	16861	17265	16868	17909	18759
Romania	28193	17135	12945	13175	14831	17013	17568
Slovakia	14638	13853	13788	14590	14847	15074	15679
Serbia and Montenegro	625	682	928	1005	1275	1446	1541

Annex II

Fuel consumption (t) for inland waterways: S1, S2, S3

S1: existing freight transport for inland waterways (ILW) and road transport

Unit tonne

ILW

Country	2008	2009	2010	2011	2012	2013	2014
Austria	18872	16024	19000	16984	17528	18824	17416
Bulgaria	23120	43488	48384	34480	42792	42992	40592
Croatia	6736	5816	7520	5536	6176	6168	5728
Hungary	18000	14648	19144	14720	15856	15392	14488
Romania	69496	94120	114536	91272	100160	97936	94080
Slovakia	8808	7192	9512	7448	7888	8048	7240
Serbia and Montenegro	10952	8912	7000	7704	4840	5608	6072

S2 - increase only the freight movement of ILW of S1 by 20%

Unit tonne

ILW

Country	2008	2009	2010	2011	2012	2013	2014
Austria	22646	19229	22800	20381	21034	22589	20899
Bulgaria	27744	52186	58061	41376	51350	51590	48710
Croatia	8083	6979	9024	6643	7411	7402	6874
Hungary	21600	17578	22973	17664	19027	18470	17386
Romania	83395	112944	137443	109526	120192	117523	112896
Slovakia	10570	8630	11414	8938	9466	9658	8688
Serbia and Montenegro	13142	10694	8400	9245	5808	6730	7286

S3 - shift of 50% freight movement from road transport to ILW

Unit tonne

ILW

Country	2008	2009	2010	2011	2012	2013	2014
Austria	156124	132324	133636	131152	121884	115676	114612
Bulgaria	84408	114456	126116	119336	140280	151380	152008
Croatia	50904	43520	42640	41240	40772	42700	43252
Hungary	161036	156140	154028	152836	150800	158664	164556
Romania	295040	231196	218092	196668	218808	234040	234624
Slovakia	125912	118012	119812	124164	126660	128636	132672
Serbia and Montenegro	15948	14368	14424	15740	15040	17172	18396

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