TRANSPHORM

Transport related Air Pollution and Health impacts –

Integrated Methodologies for Assessing Particulate Matter

Collaborative project, Large-scale Integrating Project

SEVENTH FRAMEWORK PROGRAMME

ENV.2009.1.2.2.1 Transport related air pollution and health impacts

Deliverable D5.3.2
Integrated assessment of strategies and recommendations to policy makers

Deliverable D4.4.1
Health impacts evaluation of baseline scenario embedded in software – Core Part

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1. Introduction

According to the Global Burden of Disease (GBD) study, exposure to ambient particulate matter pollution remains among the ten leading risk factors with over 76 million DALYs (disability-adjusted life years) estimated globally in 2010 (ranging from 68 to 85 million DALYs). This document covers the health impact assessment of the baseline scenarios (Deliverable D4.4.1) and the avoided health impacts of potential future transport policies (Deliverable D5.3.2).

We find that in 2005 about 4.8 million DALYs (ranging from 4.5 to 6.2 million DALYs, depending on the atmospheric model used) in the EU, Norway and Switzerland can be attributed to exposure to ambient particulate matter, nitrogen dioxide and ozone. This value is expected to drop by about one third until 2020. Further scope of this deliverable is to assess the potential of future transport policies in reducing the adverse health impacts even further and to assess which policies are cost-efficient. A set of policies and measures were identified, assessed and ranked according to their positive impact on human health earlier in the project (cf. Deliverable D5.3.1). This report will build upon the findings of that assessment and include further aspects into the analysis for an integrated assessment of transport policies regarding not only air quality but also potential synergies for climate change mitigation.

Several improvements have been made to the methodology of assessing health impacts including finer spatial resolution, enhanced assessment of urban increment and incorporating latest scientific findings about concentration-response functions. Previously, an effectiveness analysis of the benefits of isolated measures has been carried out to address questions about the impact of single measures in the future. Thus, it was possible to determine whether the realization of an option would be a worthwhile pursuit in terms of reducing the relative risk of the population to suffer from morbidity and premature mortality due to exposure to outdoor air.

For a more complete view on the impacts of the proposed policies several further analyses were conducted: Climate change impacts have to be considered for integrated assessment to cover synergies among measures or identify potential countervailing effects. To compare the benefits of reduced health impacts and avoided climate impacts, money is used as common measure. It serves another purpose in being the unit to measure the implementation costs of policy options. This allows for an assessment that determines the social welfare optimum by maximizing the overall benefit for society. This allows for drawing conclusions and giving recommendations to decision-makers.

The general integrated assessment methodology is described in section 2, followed by an assessment of the baseline health impacts in section 3, and describing the impacts of future policies in section 4. Concluding remarks and recommendations are given in section 5.

2. Methodology for integrated assessment of air quality and climate

2.1. The EcoSense model and recent improvements of the methodology

The following is a summary of the description of the EcoSense model and recent improvements to the methodology and the model. This is given in more detail in the preceding deliverable D5.3.1. EcoSense is an integrated atmospheric dispersion and exposure assessment model applying the impact pathway approach. It was developed to support the evaluation of impacts on human health, crops and building materials resulting from the exposure to airborne pollutants.

Input for the EcoSense umbrella model are spatially disaggregated emissions of classical airborne pollutants such as SO_2, NO_x, primary particulate matter, NMVOC and NH_3. Chemical transport models are then used to calculate the average annual primary and secondary PM2.5 concentrations, SOMO35 values a.s.o. for predefined grids (in this case 0.5° x 0.25° for Europe). The most recent version of EcoSense uses source-receptor matrices derived from numerous runs of a recent version of the EMEP model. These source-receptor relationships link changes in the emissions of a country to changes in pollutant concentrations on the grid (Bickel and Friedrich, 2005; Friedrich et al., 2011).

For a more precise analysis of health impacts due to primary particulate matter in urban areas, the background concentrations derived from the source-receptor matrices are used for the calculation of a city specific increment. This approach captures higher pollutant levels commonly found within densely populated areas (Torras Ortiz and Friedrich, 2013). The urban increment values are then added to the background concentrations for the assessment of health impacts.

To assess the health effects due to concentration changes of simple pathway pollutants, impact functions, consisting of the concentration-response function (CRF, see e.g. WHO/HRAPIE (2013)), the background rate of disease within the population and the fraction of the population exposed, are applied. Resulting values for the different health endpoints can then be calculated using age-stratified population data along with the concentration delta (Friedrich et al., 2011). For aggregation or comparison of these results, the values derived in the previous step, given in cases or years of life lost (YOLL), have to be converted into a common metric, the DALY (Disability Adjusted Life Years). It combines information on both quality and quantity of life and indicates the number of healthy life years lost. To achieve this, morbidity is weighted for the severity of the disorder and the duration of the disease, mortality with years of life lost. Thus, this metric includes both effects. However, DALYs should be used to estimate the potential order of magnitude of health problems rather than being presented as representative absolute numbers (Friedrich et al., 2011).

To perform a state-of-science assessment several substantial improvements have been incorporated into the integrated assessment methodology that is implemented in the EcoSense model. The most important of these improvements are:

(1) The incorporation of new, more fine-grained source-receptor matrices (SRMs) that were derived from the most recent version of the EMEP model at a resolution of 0.5° x 0.25°. The SRMs act as a parameterized version of the atmospheric model and represent a well-established trade-off

between small losses in accuracy (due to linearization) for marginal changes in emissions and a huge gain in computing-time due to the simplified formulization.

(2) An enhanced representation of generally higher PM and NO_2 concentration levels in urbanized areas by evaluating and updating the urban increment (UI) model. A distinction in activities and emissions into non-urban and urban was made for about 900 cities covered (using the up-scaling method described in Deliverable D5.2.2). The importance of the urban increment is due to the fact that many emissions happen in urban areas and at low release heights, i.e. near surface, and the effect of more than half of the measures heavily depends on adequately representing their effect in cities.

(3) Incorporation of new concentration-response functions (CRFs) as recent findings of the REVIHAAP/HRAPIE projects (see WHO/HARAPIE (2013)). This affects especially the substantial but previously neglected health impacts due to exposure to ambient NO_2 (for which also an urban increment had to be developed).

The metric used to assess the avoided health impacts of measures is Disability-Adjusted Life Year (DALY). The metric and its implications are described in more detail in Deliverable D5.3.1.

2.2. Monetisation of health impacts

The monetary values in Table 1 have been derived during the EU-funded projects INTARESE and HEIMTSA (Friedrich et al., 2011), where pre-existing monetary values have been reassessed and updated based on a meta-analysis of existing work.

Table 1: Summary of Monetary Values relating to specific health end-points (€,2010)

Health End-Point	Monetary value (central)
Medication / bronchodilator Use	80
Cardiac Hospital Admissions	2990
New cases of chronic bronchitis	60000
Increased mortality risk (Infants)	4485731
Lower respiratory symptoms	57
Work loss days (WLD)	441
Life expectancy reduction - Value of Life Years chronic	60000
Cough Days	57
Lower respiratory symptoms excluding cough	57
Increased mortality risk - Value Of Life Years	89715
Minor restricted activity days (MRAD)	57
Respiratory hospital admissions	2990
Restricted activity days (RADs)	194

2.3. The social cost of carbon

Estimates of the damage cost per ton CO_2 equivalent (CO_2eq) vary a lot among several studies. This is due the fact that (i) future costs need to be discounted and the discount rate is highly uncertain, (ii) assumptions on weighing damages differently among different regions, so called equity weighting, vary from study to study, and (iii) general uncertainty is hard to account for (cf. Wille et al. (2012)).

From a review of several existing studies on estimates of long-term damage and avoidance cost estimates of climate change we used a modest $€_{2010}$ 58 per ton CO_2 equivalent to estimate climate change related benefits of a measure (cf. Wille et al. (2012); Kuik et al. (2009)).

3. Health impact assessment of baseline scenarios

In this section the health damages (in disability-adjusted life years) of all anthropogenic emissions in the baseline scenarios that were defined in SP1 are shown. For a detailed descriptions about the European emission baseline (incl. specific transport emissions) and the assumptions of the underlying energy scenarios and future projections on resulting human activities and emissions, the reader is referred to deliverable D1.3.5.

Figures 1 and 2 show the results of the state-of-the-art large-scale models CMAQ, SILAM and LOTOS-EUROS. For both years there is a reasonable agreement between CMAQ and LOTOS-EUROS, with SILAM tending to estimate higher levels of concentration and, thus, higher health damages.

In detail, there is an estimated 4.5 million DALYs for CMAQ and 4.8 million DALYs for LOTOS-EUROS in 2005 (+8%). The result for SILAM are estimated to be about 6.2 million DALYs, corresponding to +39% compared to CMAQ and +28% compared to LOTOS-EUROS.

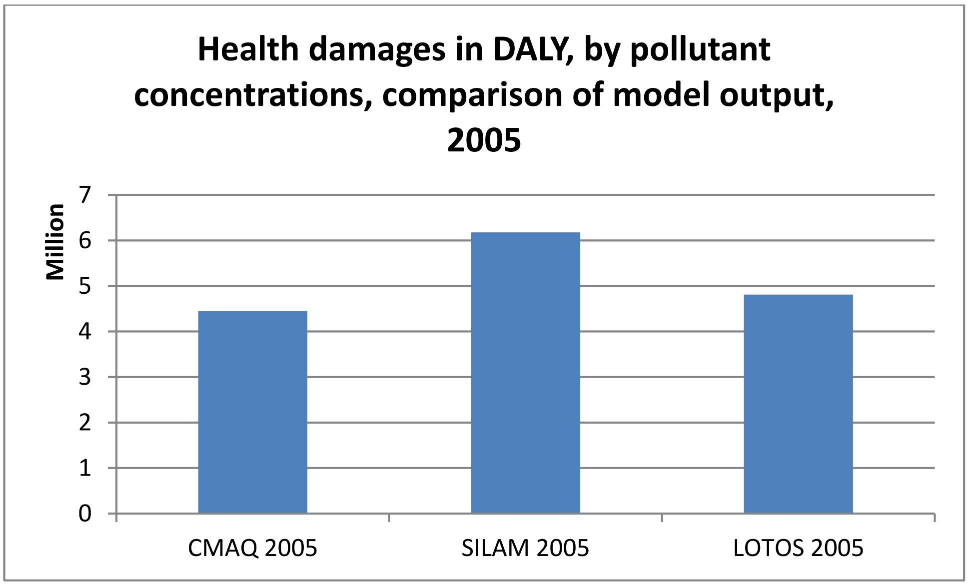

Figure 1: Health damages (in DALYs) estimated for 2005 with three different atmospheric models, namely CMAQ, SILAM and LOTOS-EUROS.

For the future year 2020, the same assessment has been conducted. It is evident that current policies and regulations already agreed on, will show effects in the future. The damages are estimated to decrease by about one third in 2020 compared to 2005 (detailed figures are 31.2% for CMAQ, 31.6% for SILAM and 35.8% for LOTOS-EUROS).

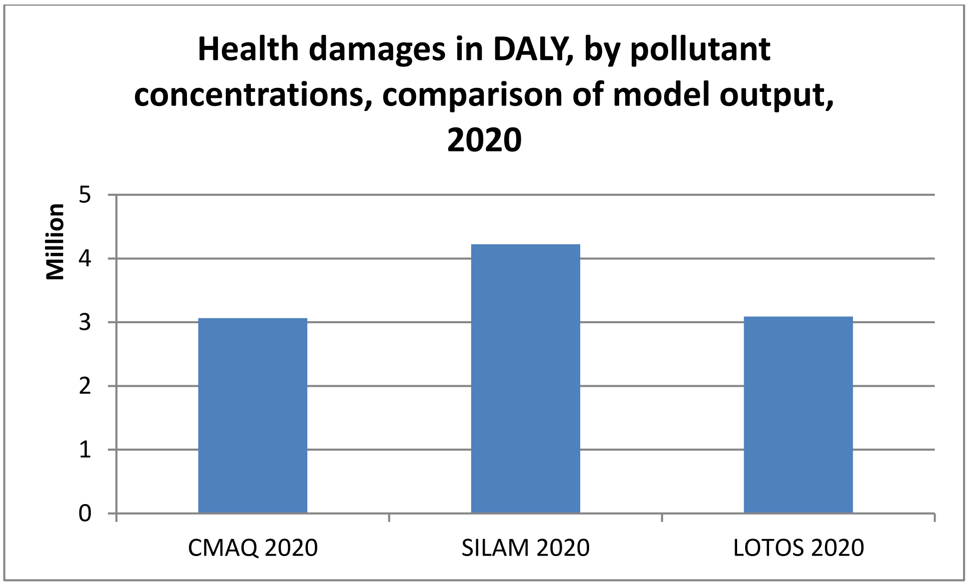

Figure 2: Health damages (in DALYs) estimated for 2005 with three different atmospheric models, namely CMAQ, SILAM and LOTOS-EUROS.

4. Assessment of future policy scenarios

Based on the integrated assessment methodology developed in SP5, an assessment of the combined effect of measures has been carried out. Due to the nature of the project all the measures investigated in TRANSPHORM affect the transport sector, and thus are likely to overlap or interfere. Due to the thorough analysis and model development, these interferences could be identified and appropriately accounted for in the assessment of strategies, i.e. when determining and evaluating bundles of policy measures.

To assess the health effects due to concentration changes of simple pathway pollutants, impact functions, consisting of the concentration-response function, the background rate of disease within the population and the fraction of the population exposed, are applied. Resulting values for the different health endpoints can then be calculated using age-stratified population data along with the concentration delta. For aggregation or comparison of these results, the values derived in the previous step, given in cases or years of life lost (YOLL), have to be converted into a common metric, the disability-adjusted life years (DALYs). It combines information on both quality and quantity of life and indicates the number of healthy life years lost. To achieve this, morbidity is weighted for the severity of the disorder and the duration of the disease, mortality with years of life lost. Thus, this metric includes both effects. However, DALYs should be used to estimate the potential order of magnitude of health problems rather than being presented as representative absolute numbers.

By estimating the investment costs and monetized benefits of measures, it was possible to determine two strategies for 2020 where each can be considered optimal depending on the criterion applied:

(1) The "effectiveness" scenario was determined by evaluating the avoided health impacts but leaving costs out of the equation.

(2) The "efficiency" scenario is the results of a selection of measures by balancing benefits (i.e. monetised avoided health impacts and monetised saved CO_2 emissions) with costs (i.e. private costs, subsidies, utility and time losses).

The scenarios derived by utilizing the source-receptor relationships were then used as input for the atmospheric models for a more detailed analysis and inter-comparison of results

This remainder of this section is organized as follows. First, the source-receptor relationships of the parameterized atmospheric model used in EcoSense are compared to the results of the full atmospheric dispersion models CMAQ (University of Hertfordshire, UK), LOTOS-EUROS (TNO, Netherlands) and SILAM (FMI, Finland). Then, the two scenarios – namely "effectiveness" and "efficiency" – are derived and described in the subsequent section.

4.1. Comparison of parameterized model and full atmospheric models

Calculations of health effects for single measures have been conducted using EcoSense, as a resource-intensive full atmospheric model run for each single measure was not possible during this project. Therefore, the calculations were made using the parameterized atmospheric model implemented in EcoSense, based on EMEP country-to-grid source-receptor matrices (SRM) to calculate the effect of every measure. Obviously, results determined with these matrices rely on simplified assumptions (i.e. linearization) and do not provide the level of detail of a full non-linear model simulation in terms of chemical/physical mechanisms. Hence the trade-off that may occur when balancing accuracy and computing time had to be assessed before it was possible to determine and evaluate the measure bundles.

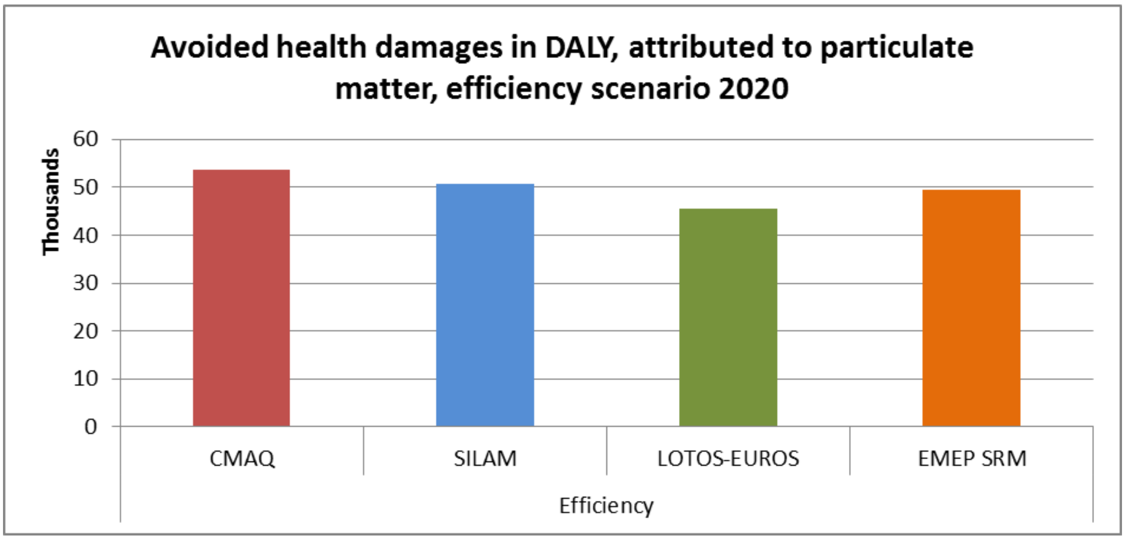

Figure 3: Atmospheric transport model comparison for DALYs attributed to particulate matter, efficiency scenario

A first comparison was conducted with the results for particulates. Figure 3 shows the results for the efficiency scenario for the year 2020. On average, the EMEP SRM results are approximately 1% higher than the full model results. CMAQ and SILAM provide higher outcomes, with values of about 8% and 3%, respectively, higher than the EMEP SRM. On the other hand, the results from LOTOS-EUROS are 8% lower than these provided by the EMEP SRM.

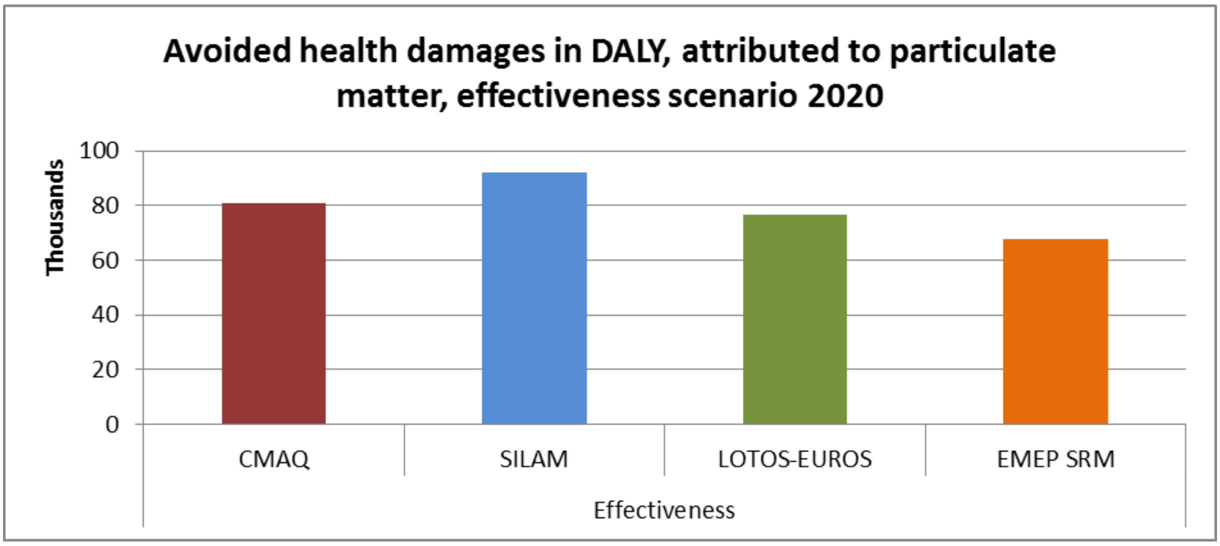

Figure 4: Atmospheric transport model comparison for DALYs attributed to particulate matter, effectiveness scenario

The effectiveness scenario, with less emissions than the efficiency scenario, shows higher variation between the model results, as can be seen in Figure 4. The full models provide values 13% to 36% higher than the EMEP SRM, with an average of 23%. It is worth mentioning that the spread of model outcomes is bigger than the difference between the SRM and LOTOS-EUROS.

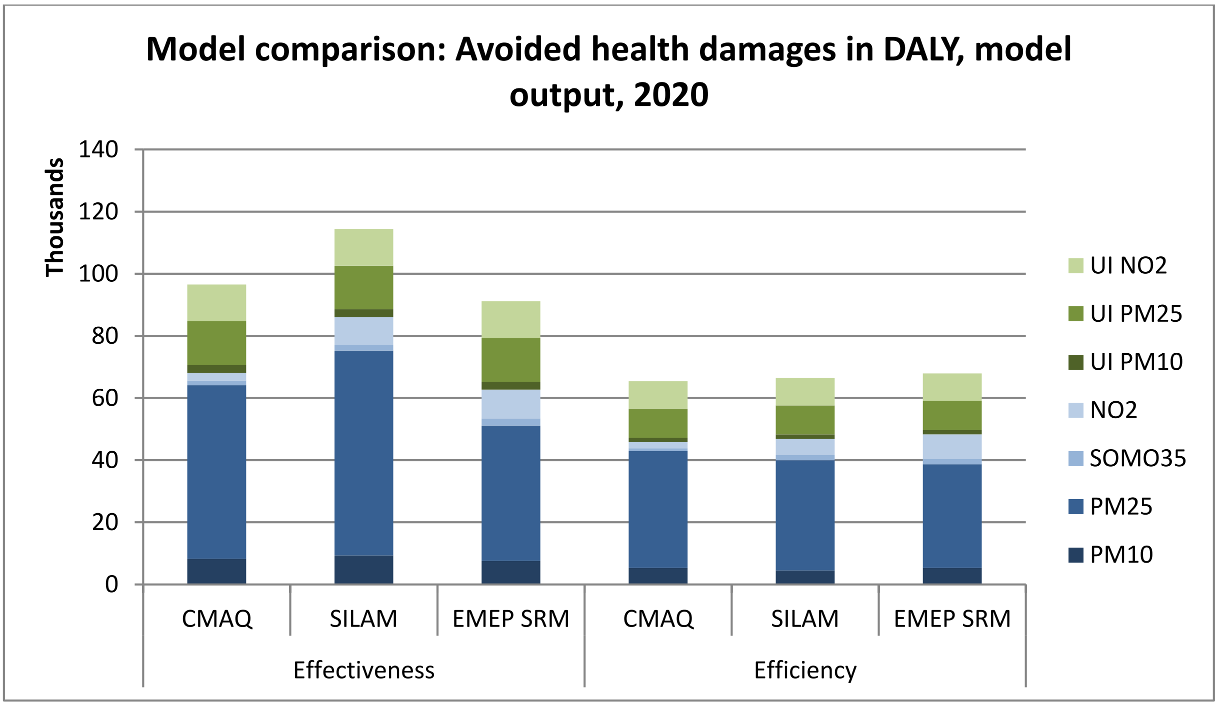

Figure 5: Atmospheric transport model comparison for all considered pollutants

For all pollutants (PM, Ozone, NO_2), including health damages and the urban increment calculations, the efficiency scenario results for the year 2020 calculated with EcoSense, using the source-receptor matrices differ from the results for full atmospheric model runs from CMAQ and SILAM by 2.2% and 3% respectively, with the parameterized model showing slightly higher values than the full model runs. The effectiveness scenario shows a difference of 5% to 20% between the full models and EcoSense, with the latter tending to estimate damages more conservatively.

4.2. Effectiveness scenario and efficiency scenario

The "effectiveness" scenario relies solely on the avoided health impacts. Consequently, neither implementation costs nor saved carbon emissions are considered relevant in this scenario. It is meant to show a potentially achievable gain in health when dismissing cost considerations. The results of the analysis of the single measures was already discussed in deliverable D5.3.1.

Negative effects of increased agricultural activities cause the measure promoting bio-fuel usage to be excluded from the effectiveness scenario. The promotion of e-cars as low emission vehicles is included as a measure. Car-pooling is seen as being part of enhanced utilisation of public transportation in this scenario. Fuel taxes and road pricing schemes follow a similar strategy to reduce mileage. They should not be considered simultaneously as they rely on similar assumptions that might not hold in a combined scenario. We consider the latter measure more interesting as fuel taxes are already applied to a large extent in EU countries.

The "efficiency" scenario takes cost considerations and utility losses into account. As the net benefit for society should be maximised, we would basically select measures resulting in positive net benefit while taking all costs into account (cf. Figure 4). Even though the promotion of bio-fuel usage turns out to have overall positive net benefit due to saved CO_2 emissions, the induced negative health effects caused by additional agricultural activities conflict with the scope of the project aiming at reducing these effects (cf. Figure 6). Therefore, the measure will not be included in the efficiency scenario. Detailed results of both scenarios are given in Table 2.

Table 2: Overview of scenarios. See sections 3.2 for underlying rationale for the effectiveness and the efficiency scenario.

Measure	**included in**	
	effectiveness scenario	**efficiency scenario**
Promote bicycles in cities	Yes	Yes
Promote public transport	Yes	No
Bus fuel switch	Yes	Yes
Car-pooling	No, effects covered by enhanced use of public transport	No
LEVs (e-cars)	Yes	Yes
Traffic management	Yes	Yes

Low emission zones	Yes	
City toll	Yes	No
Parking management	Yes	No
Ban of through-traffic	No, as scale cannot be modelled appropriately	No, as scale cannot be modelled appropriately
Freight consolidation centre	Yes	Yes
Lower speed limit (motorways)	Yes	Yes
Lower speed limit (rural roads)	Yes	Yes
Low emission cars	Yes	Yes
Fuel tax	No, due to relying on the same assumptions as road pricing	No, due to relying on the same assumptions as road pricing
Road pricing	Yes	No
Euro 7	Yes	Yes
Tyres & brakes	Yes	Yes
Bio-fuels	No, due to negative health effects caused by additional agricultural activities	No, due to negative health effects caused by additional agricultural activities
Kerosene tax	Yes	No
Shift from air to rail	Yes	Yes
Tighter emission limits for inland ships	Yes	Yes
Tighter emission limits for maritime ships	Yes	Yes
Shore-based electricity	Yes	Yes

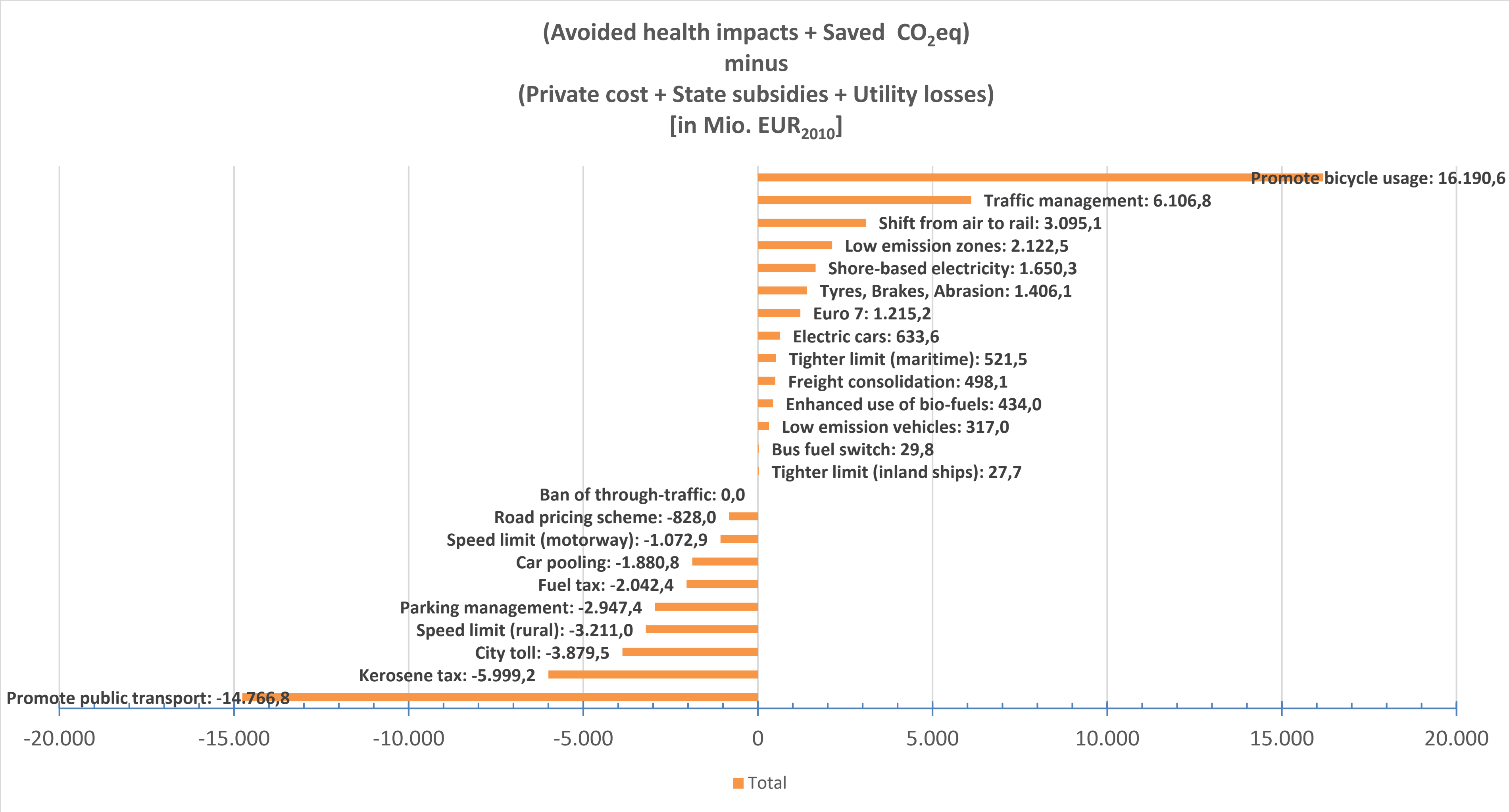

Figure 6: Net benefit in Mio. EUR_{2010} for single measures applied in 2020. Avoided health impacts and saved CO_2 emissions are considered benefits, whereas private costs, state subsidies and utility losses are considered costs

5. Key results and recommendations

A thorough analysis of policy measures has been conducted that comprise both technical measures and non-technical measures, the latter showing big potential in terms of health impact reduction by aiming for behavioural changes as enhanced use of bicycles and/or public transport systems. The assessment was carried out by an innovative up-scaling approach to evaluate EU-wide effects of city-level and regional transport measures. Analysis of policy measures has shown that avoided health impacts can be properly assessed at a high level of detail and that cost-effectiveness as well as cost-efficiency of policy options can be determined.

Even though the focus of the project is on health impacts due to exposure to particulate matter, it turned out than the assessment should not only consider the avoided health impacts but also account for climate change related co-benefits. This is key to evaluate all benefits of a measure when they are compared to its costs (i.e. private cost and subsidies, as well as utility losses and time losses), as they are likely to render a measure cost-efficient even when health benefits alone do not outweigh costs. A good example are measure that deal with air traffic. As emission causing health damages are emitted almost completely at heights below 1000 meters (i.e. during landing, taxiing and take-off), the majority of CO_2 emission of an aircraft are emitted during cruise and cannot be omitted. Also, it is important to account for relevant up-stream emissions, especially when shifts in modal transport are induced. For instance, emissions from power generation cannot be ignored when urban transport shifts from individual car traffic to metro/tram or electric vehicles of car-pooling.

Apart from the specific evaluation of the scenarios described and recommended, a great advance in developing and applying the scientific methodology of integrated assessment with focus on particulate matter and nitrogen oxides has been achieved. A tool was developed that for the first time allows for accounting for the assessment of concurrent implementation of potentially interfering transport measures. Due to the advances in the REVIHAAP/HRAPIE projects it was possible to incorporate state-of-science findings derived from epidemiological studies and use them to enhance the assessment of avoided health impacts due to policy implementation

Policy recommendations have been derived based on the analysis undertaken in this work package. Based on the common approach of selecting the policy measures that maximize the discounted net benefit for society, bundles of measures have been identified for future years using the methodology that was applied in scenario (2) described in Task 5.3.2. For all measures the specific activity data of each city and each region has been determined. Also side-effects on non-transport sectors are covered as far as reasonable in the analysis. Such effects include for instance changes in electricity demand due to more utilisation of electric cars, metros/railcars or the supply of shore-side electricity for ships at berth, as well as changes in agricultural activity levels in the case of bio-fuel usage.

In general, it is suggested to promote bicycle usage in cities for it having great effect on emission reduction and the resulting positive health benefits due to exposure to lower levels of particulate matter, along with co-benefits due to increased sporting activity. Also, traffic management options should be considered in cities to reduce fuel consumption of cars by optimizing traffic flows. Promotion of low-emission vehicles is recommended in general, especially if the tighter emission limits of Euro 7 are met as the reduction in emissions yields substantial health impact reductions. While speed limits on rural roads and motorways might yield benefits in terms of reduced emissions, they do not outweigh the substantial time losses experienced by the operators of a car. While the promotion of bio-fuel causes negative health impacts in regions were agricultural activities are increased due to fuel production, the negative impacts are out-weighed by the potential of climate change mitigation. A similar effect of the importance of climate change mitigation co-benefits is observed in the case of measures that deal with reduction of air traffic via kerosene tax or shifting traffic to rail-bound vehicles. Also, tighter limits for inland and sea-going vessel turned out to be efficient, and the reduction potential is even higher if power for ships at berth is generated shore-based at the ports rather than relying on the internal auxiliary combustion engines.

From a perspective of a social planner that aims towards maximization of welfare, the cost-efficient scenarios should be considered recommendations. However, we felt the need of assessing also the most effective measures that have not turned out to be cost-efficient (or it was not possible to estimate costs) but have a significant potential of decreasing air pollution that originates from transport activities. While measures can be effective in reducing air quality impacts as in the case of EU-wide harmonized speed limits on rural roads and motorways, often time and utility losses are out-weighing the benefits of emission reduction and render the inefficient.

References

Bickel, P. and Friedrich, R. (2005): ExternE Externalities of Energy Methodology - 2005 Update, European Commission 2005.

Friedrich, R., Kuhn, A., Bessagnet, B., Blesl, M., Bruchof, D., Cowie, H. (2011): INTARESE / HEIMTSA D153/D5.3.1/2: Final report of the Common Case Study, 263 pp.

Kuik, O., Brander, L. and Tol, R. S. J. (2009): Marginal abatement costs of greenhouse gas emissions: A meta-analysis, Energy Policy 37, S. 1395–1403.

Torras Ortiz, S. and Friedrich, R. (2013): A modelling approach for estimating background pollutant concentrations in urban areas. Atmospheric Pollution Research 4 (2013): 147-156.

WHO (2013): Health risks of air pollution in Europe – HRAPIE project. Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide. Available online at: http://www.euro.who.int/en/health-topics/environment-and-health/air-quality/publications/2013/health-risks-of-air-pollution-in-europe-hrapie-project.-recommendations-for-concentrationresponse-functions-for-costbenefit-analysis-of-particulate-matter,-ozone-and-nitrogen-dioxide (last checked on 5 June 2014).

Wille, V., Preiss, P. and Friedrich, R. (2012): Sachstandspapier zu Treibhausgase & Klimawandel, Sachstandspapier im Rahmen des Vorhabens „Schätzung Externer Umweltkosten und Vorschläge zur Kosteninternalisierung in ausgewählten Politikfeldern“, Umweltbundesamt, Forschungsprojekte FKZ 3708 14 101, IER, Universität Stuttgart.