Land Use Relationships
in Rural-Urban Regions

Module 2

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STRATEGIES AND SUSTAINABILITY
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Response functions for energy consumption and air pollution

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SIXTH FRAMEWORK PROGRAMME

Contents

Classification of results/outputs:

For the purpose of integrating the results of this deliverable into the PLUREL Explorer dissemination platform as fact sheets and associated documentation please classify the results in relation to spatial scale; DPSIR framework; land use issues; output indicators and knowledge type.

Spatial scale for results: Regional, national, European	EUROPEAN at NUTSx level
DPSIR framework: Driver, Pressure, State, Impact, Response	Pressure
Land use issues covered: Housing, Traffic, Agriculture, Natural area, Water, Tourism/recreation	Housing, Traffic: Air pollution related to allocation of human activities
Scenario sensitivity: Are the products/outputs sensitive to Module 1 scenarios?	yes
Output indicators: Socio-economic & environmental external constraints; Land Use structure; RUR Metabolism; ECO-system integrity; Ecosystem Services; Socio-economic assessment Criteria; Decisions	Statistical relationships between air pollution and land use Response functions to estimate effect of land use change on air pollution patterns and volume addressing the urban, peri-urban and rural compartments of the NUTSx regions
Knowledge type: Narrative storylines; Response functions; GIS-based maps; Tables or charts; Handbooks	Response functions; tables, diagrams, maps; interpretations and conclusions

How many fact sheets will be derived from this deliverable?	2

Abstract

The objective of this task described in this deliverable is

(a) to compile a spatially-explicit reference framework to identify and assess land use relationships in Rural-Urban Regions (RURs) and finally in the NUTSx regions (as part of the RURs) referring to energy demand and primary air pollution (emissions) due to activities from housing, traffic and commerce,

(b) to develop response functions for air pollution related to the NUTSx regions, taking into account the indicators which describe the development trends in the urban, peri-urban and rural sub-regions in Europe

(c) to apply the response functions to the NUTSx regions of entire EU 27 to show the effects of different peri-urbanisation trends on air pollution to be expected for the 4 PLUREL scenarios.

The output for the PLUREL scenarios' are amounts of air pollutant emissions for target years 2015 and 2025 per NUTSx regions for selected emission source categories and respective relevant key pollutants: NOx (nitrogen oxide) emissions from road traffic, NOx and CO (carbon monoxide) emissions from small combustion sources (e.g. residential, commercial and institutional heating), and NMVOC (non-methane volatile compound) emissions from industrial combustion, production and solvent use.

The selection of sources and pollutants was based on the availability of reliable data on the spatial distribution of emissions that can be explained through local emission-generating activities. The results are delivered for NUTSx regions in tables and maps.

The overall approach is based on the fact that air pollutant emissions are a principal cause of air pollution, and that emission density patterns in Europe mirror the patterns of regions with air pollution problems. As air pollutant emissions are a result of emission-generating human activities, their extent and spatial dimension may be explained with human activity proxy data.

- Future air pollutant emission patterns were modeled with **response functions** that were developed through a statistical analysis considering appropriate spatially resolved data to reflect current and future pressure on air quality. However, changes of emissions in major point sources (e.g. power generators or large industrial plants) which are – in terms of statistics – "singular events" that cannot be estimated through those functions and are therefore excluded.
- The response functions refer to a limited set of variables which are available for the PLUREL scenarios and consider only **effects of land use** reflecting human activities and to some extent economic development releasing partly more, partly less pollutant emissions.
- **The effect of emission reduction technologies** have been indirectly considered through trends in GDP that reflect economic development. However, technical emission reduction efforts that are not (only) related to GDP (such as implementation of EU-wide new motor vehicle exhaust standards) could not be considered in the response functions. They are based on spatially explicit explanatory data as available for today thus as these describe a static relation between explanatory variables and emission data. Nevertheless we tried to generate such response functions whose (EU-wide) results show the same direction as the EU-wide emission trends which take into account also the direct effects of technology- and energy price development.

- The **final results** contain air pollutant emission data for 4 sets of pollutants in defined source categories on the level of NUTSx regions, reflecting the impacts of land use change and economic development on the release of air pollution through anthropogenic emission-generating activities. The additional potential emission reductions induced by technological standards and legislation (e.g. energy efficiency standards, motor vehicle standards, industrial release norms, product standards) are not considered explicitly within these functions.

The overall trends of air pollutant emissions in Europe are expected to decline. However, the trends are quite different for the pollutants and source categories selected, and for different regions.

- NOx emissions from small combustion sources are expected to increase. This is an effect of more activities (more heating) and trends towards use of higher energy efficiency through use of high-efficiency heating systems from which more NOx is released.
- CO emissions from small combustion sources are expected to decline. This is an effect of change from old low-efficiency heating technologies (e.g. open furnaces) and fuel types (e.g. brown coal) towards efficient systems and fuels, somehow boosted by peri-urbanisation due to applying new technologies when building new houses.
- NOx emissions from road transportation are expected to decline. New relative rapid changes of the composition vehicle fleets will quickly introduce new emissions concepts and engine technologies.
- NMVOC emissions from industrial combustion, production and solvent use are expected to decline. These emissions are only loosely related to changes in settlement patterns. With increasing GDP, households and small production sites will increase their solvent-related activities, such as coating, painting, cleaning. On the other hand, emissions will be reduced because of improved technologies and new low-NMVOC solvent products.

Looking at the entire EU-27, the differences between the varying peri-urbanisation trends as depicted by the 4 PLUREL scenarios are rather small for NOx and CO emissions from small combustion, and for NMVOC emissions from industry and households. NOx emissions from road traffic exhibit more distinct differences which let assume a higher relationship between traffic emission and urbanization than between emissions from “static” source groups (like heating).

All 4 PLUREL scenarios follow the general European trends. The less distinct growth or decline rates show that the settlement distribution has little effect on the spatial pattern of emission changes. The “A”-scenarios show more changes (either increase of reduction) than the “B”-scenarios, probably because of less GDP growth, which influences emission changes more than the changing spatial distribution of human activities.

1 Introduction

This paper describes the theoretical, methodological and empirical basis to assess the spatial patterns of air pollution emission data, to allocate annual emissions to different land use types, and to estimate response functions for air pollution related to RUR sub-regions, namely to urban, peri-urban and rural areas.

Urbanized areas host the major sources of air pollution. Urban activities have major impacts on emissions and air pollution levels emissions in peri-urban and rural areas. Energy sources for urban supply (refineries, power plants, district heating etc.) are frequently located in the peri-urban and rural regions, which means that environmental consequences of urban-caused activities (such as air pollutant emissions, and ambient air pollution) are "outsourced" into neighbouring regions.

Air pollutants that are released from energy consumption activities in urban and peri-urban areas contain a variety of toxic and environmentally damaging substances:

- Directly toxic compounds include carbon monoxide (CO), nitrogen oxides (NOx), fine particulate matter (PM), non-methane volatile organic compounds (NMVOC) and different toxic substances, which all may cause significant health impacts on the population.
- Non-toxic compounds such as carbon dioxide (CO_2), chloro-fluoro-carbons (CFC) and methane (CH_4) that are of general environmental concern because of their contribution to global warming and stratospheric ozone depletion are of global concern and less important in the urban/peri-urban/rural relationship context.

While all energy major conversion processes cause air pollutant emissions, the extent of releases and the compounds in the emissions depend on the processes and technologies. Thus it is necessary to distinguish emission-generating activities from different energy sources which have different effects and different spatial extent on local environmental pollution.

1.1 Air pollution as a spatial reflection of human activities

The underlying cause of ambient air pollution is the release of air pollutants into the atmosphere. The extent of poor ambient air quality depends on emissions source strength, and on many meteorological factors that influence dispersion of pollutants, above the vertical temperature distribution in the atmosphere, wind strength and direction, and precipitation.

While a small share of air pollutants may be released from natural sources (e.g. plants, lightning, volcanoes) the major releases of air pollutants (emissions) are caused by anthropogenic sources (e.g. energy conversion processes, uses of volatile compounds, dust generation). Thus, the spatial patterns of emissions reflect the spatial distribution of human activities (e.g. housing, thermal power plants, industry, traffic).

If the relation of current air emissions to current emission-generating activities can quantified, and if emission-generating activities can be allocated to predominant land, response functions can be developed that allow to assess effects of land use changes on air pollution and further on air pollution impact.

To allocate emissions, several assumptions are usually made (c.f. Orthofer & Loibl, 1993, Loibl & Orthofer, 2001):

1) Emissions of air pollutants is a response of human activities,
2) The spatial patterns of emissions reflect spatial patterns of human activities,
3) If data about emission-generating activities are not available, proxy data that reflect emission generating activities can be used to relate activities and emissions,
4) If proxy data can be related to spatial entities, spatial emission patterns may be estimated and spatially explicit driver–pressure–impact relations may be analysed.

1.2 Air pollution emission data

The quantities and properties (e.g. location, stack height, source strengths) of emissions of air pollutants from different sources are usually compiled in emission inventories. The spatial resolution of these inventories depends on the overall purpose. In some countries regions, the spatial resolution is high but often the overall source coverage might be limited. On the other hand, all EU countries produce “full” nationwide emission inventories, but often the spatial resolution is low.

For the purpose of this project it was necessary to rely on methodologically comparable and complete emission data sets on a Europe-wide level.

The major harmonized collection of spatially disaggregated data at European level comes from the CORINAIR (CORe INventory of AIR emissions) project. CORINAIR has been maintained since 1995 by the European Topic Centre on Air Emissions under contract to the European Environment Agency (EEA). The main objective is to collect, manage and publish information on emissions into the air by means of a European air emission inventory and database system. This concerns air emissions from all sources relevant to the environmental problems of climate change, acidification, eutrophication, tropospheric ozone, air quality and dispersion of hazardous substances.

For the most important pollutants, the CORINAIR dataset is available in spatially disaggregated form, namely in the 50x50km grid format of the European Monitoring and Evaluation Programme (EMEP, 2007, EEA, 2007a, b). The EMEP CORINAIR dataset contains annual total emissions (comprising both large point sources and diffuse sources) for

- Main Pollutants (NOx, SO2, CO, NMVOC, NH3)
- Particulate Matter (PM2.5, PM10, TSP)
- Heavy Metals (Pb, Cd, Hg, As, Cr, Cu, Ni, Se, Zn)
- Persistent Organic Pollutants (POPs)

Data are reported annually for all years from 1990 to the year before the reporting year: e.g. current (2009) emission data include data for all years from 1990 to 2007. Data for countrywide emission totals (in the NFR category system) and for the 50x50 km grid are available through the EMEP Centre on Emission Inventories and Projections (CEIP) at Umweltbundesamt Wien. The EMEP Centre on Emission Inventories and Projections also provides guidelines.

CEIP also maintains a ‘gap-filled’ emission dataset used by air quality modellers, which is available at an aggregate level of 11 source categories and for country totals as well as for the EMEP 50x50 km grid and a 0.5°x0.5° grid. The 0.5°x0.5° grid is equivalent to about a grid system in the range of 50x70 km to 30-70 km.

In principle, the EMEP data base contains pollutant data for the EU27 and most other European countries (Belarus, Croatia, Georgia, Iceland, Monaco, Norway, Moldova, Russian Federation, Serbia, Switzerland, FYROM Macedonia and Ukraine). However, not all countries have reported all pollutants, so that considerable data gaps must be expected when producing a full data set for the E-PRTR. Once the data gaps have been analyzed, a decision will have to be made together with the DG Environment how to deal with data gaps: this will depend on the priorities of the Commission, whether they prefer a complete dataset for fewer substances or if they prefer incomplete datasets for more countries.

The CORINAIR data are grouped by emission sources (“sectors”) and substances (“components”). The main spatially disaggregated substances are listed in table 1.

Table 1: Important air pollutants (CORINAIR)

Main pollutants	
NO_x	Nitrogen Oxides (NO and NO2, overall amount is expressed as NO2)
CO	Carbon Monoxide
NMVOs	Non-Methane Volatile Organic Compounds
SO_2	Sulphur Dioxide
NH_3	Ammonia
Particulate Matter (PM)	
TSP	Total suspended particulate matter
PM_{10}	Particulate matter with diameter of 10 µm or less ("fine particles", subgroup of TSP)
$PM_{2.5}$	Particulate matter with diameter of 2.5 µm or less ("ultra-fine particles", subgroup of PM_{10})

1.3 Emission source categories

The most important driving forces for air pollutant emissions are human emission-generating activities, mainly energy consumption, industrial activities, transportation and agriculture. The level of these emission-generating activities determines the amount of emissions. However, apart from the activity level, the amount of emissions also depends on technologies used and the applicable legal framework. For instance, the shift from coal and heavy fuel oil to cleaner fuels such as light fuel oil use and gas has lead to decreasing emissions.

Between 1990 and 2004, although population in Europe was almost constant, the number of households increased by about 11%. At the same time, gross domestic product (GDP, the most commonly used overall indicator for the intensity of (commercial) human activities) has increased by 33% at constant price index but total energy consumption has increased by about only 12%; this indicates a substantial improvement of energy efficiency in production and services sectors (EEA, 2007a).

Transportation accounts for 31% of final energy consumption (2004 data), the industrial sector for 28%, and households for 27%. Road passenger transport (passenger-kilometres) and goods transport (tonne-kilometres) on European roads has increased faster than GDP growth (EEA, 2007a).

Two other sectors will not be considered within the context of this task: shipping will not be considered because emissions occur mostly on the open seas, and the agricultural sector that contributes significantly to ammonia (NH3) emissions which is addressed in a further PLUREL task.

Different emission categories are related to different land use classes. Thus the differentiation of source categories allows to some extent an allocation of emissions to land use.

There are several nomenclatures for the many different emission sources.

The most detailed nomenclature system is the NAPSEA (Nomenclature for Air Pollution Socio-Economic Activity) system. The system is divided into three groups: NAPACT refers to emission-generating activities, NAPTECH refers to technologies applied, and NAPFUE refers to fuels used (http://esl.jrc.it/envind/sip/in/Sip_in05.htm).

The older, but widely used nomenclature standard in national and international emission inventories is the CORINAIR SNAP system (Selected Activities for Air Pollution, http://www.eea.europa.eu-/publications/EMEPCORINAIR5). It defines categories defined from a technological viewpoint (such as "processes with contact to combustion" and "processes without contact to combustion") but not according to the socio-economic context. which is a disadvantage for relating emission driving forces to environmental pressures. The SNAP-system is differentiated into 11 major SNAP sectors. Some of them are well specified (such as SNAP 02 that includes essentially heating activities for small district heating plans, households and commercial and institutional installations; or SNAP 07 that refers exclusively to road transport sources). Other SNAP Categories, however, are very heterogeneous and cannot be allocated to any single human activity type (an example is SNAP 08 “Other mobile sources and machinery” that encompasses very heterogeneous emission sources that range from military operation, railways, aircraft, inland waterways, agricultural, forestry and industrial machinery, and even includes household machines).

Table 2 summarizes the top level of the SNAP emission source category system as used for the PLUREL methodology development.

Table 2: SNAP emission source categories

SNAP 01	Combustion during transformation of energy (power plants, refineries)
SNAP 02	Combustion for energy consumption (district heating, commercial & residential heating)
SNAP 03	Combustion processes in industry
SNAP 04	Production processes
SNAP 05	Extraction and distribution of fossil fuels (solid, liquid, gaseous)
SNAP 06	Use of solvents (NMVOC only)
SNAP 07	Road transport
SNAP 08	Other mobile sources/machines (military, railways, aircraft, industry, households)
SNAP 09	Waste management (solid waste combustion & landfills, wastewater processing)
SNAP 10	Agriculture & forestry
SNAP 11	Other Sources (incl. nature)

Some of these categories can be directly related to land use classes.

- Emissions from fuel-fired power plants or from petroleum refineries (SNAP 01) are large point sources in single isolated sites. Such installations satisfy energy demands from urban centres, but are often located outside large cities in low-density populated peri-urban or even rural areas. If they are located in the vicinity of urban centres, they tend to be in areas that are close to areas of fuel availability – e.g. near coal mines or harbours. Only dedicated large combined heat & power plants and waste combustion plants are often located in urban areas, but changes in emission volume due to construction of new sites cannot be projected in a spatially explicit way.
- Emissions from stationary combustion for heating (SNAP 02) are expected to be highly correlated with population, household and housing densities. This sector includes commercial & institutional sources (offices, shops, hospitals, universities, test centres, etc) as well as residential sources and district heating plants. Urban and peri-urban emissions are mostly due to combustion from heating where the mix and amount of pollutants depends on fuel type, energy efficiency, dwelling structure and thermal insulation of buildings.
- Emissions from industrial processes (SNAP 03 and 04) come from a variety of sources, notably iron- and steel production, metal industry, chemical industry, car manufacturing etc. Such emissions originate from industrial areas mostly located in the peri-urban regions, but mineral and ore-related industries might also be located near the mining sites. Such mining areas often develop to peri-urban regions. Amount and type of emissions depend on the type of products, technologies applied.
- Emissions from the fossil fuel cycle (SNAP 05) contain a variety of sources ranging from coal mines to gas network leaks to petrol stations; the category cannot be allocated to any typical areas. The majority of emissions are expected to originate in areas in which fuels are mined (coal mines, oil & gas fields) or processed (e.g. refineries). Such areas might be anywhere – either in peri-urban sites that have developed around the mining areas or in isolates spots. Changes in emission volume refer to changes in extraction sites, which cannot be projected at NUTSx level in a spatially explicit way.
- Emissions from use of solvents or solvent-based products (SNAP 06) come from a large extent from the manufacturing sector, but partly also from solvent use in the household sector. As with industrial processes, the industrial emission sources are mostly located in the peri-urban regions, and the household emissions in the urban regions.

- Emissions from road transport (SNAP 07) relate to local traffic in settlements as well as to large distance traffic along inter-urban and inter-regional highways. Emissions depend on population, number of cars, trips along road segments, and short distance and long distance transportation requirements between the various origins and destinations. A major influence for emissions comes from technology used and on the driving behaviour. This is reflected in the average emission factors for different car types, engine technologies, fuel types, road conditions, traffic flow. Such emission factors report the amount of pollutant emitted per activity unit, such as grams of NOx per km travelled) as an average value for given assumptions about the respective fleet composition and the predominant driving patterns.
- Emissions from the "Other mobile sources and machines" (SNAP 08) come from a variety of sources that may not be related to particular areas. A certain part of these emissions may occur from activities in the periphery of urban centres and in the peri-urban sectors (e.g. airports, industrial machinery, military) but another part might be directly related to population densities (households) and another part might be directly related to rural areas (agricultural & forestry machinery).
- Emissions from waste management (SNAP 09) come to a large extent from solid waste incineration, landfills and wastewater plants. These are usually located at the periphery of urban centres. But on the other hand, this sector also includes emissions from agricultural burning which of course do not relate to urban activities. The pollutants generated depend on the type of activity: while incineration processes are expected to yield SO_2, NOx and particle emissions, landfills and wastewater treatment plants generate NMVOC and CH_4 emissions.
- Emissions from agricultural activities (SNAP 10) and nature (SNAP 11) relate almost exclusively to rural areas and will not be considered in this task.

1.4 Emission sources and pollutants considered in PLUREL

Not all source categories are relevant for being integrated into PLUREL investigations. We concentrate on emission patterns where data on spatial distribution are available and reliable, and which can be explained through local activities. (Emissions released through sources which are – in terms of statistics – "singular events" (e.g. allocation of power generators or large industrial plants) cannot be estimated through those functions and are therefore excluded. Thus only those sectors are considered that allow a spatially explicit relation with driving forces and for which sufficient data were available at the European scale and at NUTS 3 level. (This is e.g. not the case for CO_2!)

The most important pollution sources for PLUREL are: emissions from residential, institutional and commercial heating (SNAP 02), from production processes and solvent use (SNAP 03, SNAP 04, SNAP 06), and from road transport (SNAP 07).

All other SNAP emission categories will not be considered in this methodological study. Emissions from agricultural activities (SNAP 10), notably from forestry, manure management, and fertiliser application refer to a different PLUREL task. Emissions from the "other mobile" (SNAP 08) sector are too heterogeneous and not related to general land use development (aircraft, railways, shipping, military machinery etc) to be considered. Emissions from large point sources (including power plants, refineries, extraction of fossil fuels, and waste processing) are also excluded from the estimations as they occur out as singular events, which cannot be spatially allocated through generic response functions, based on statistics considering driver – pressure relations reflected by general land use at European scale.

Emissions from residential, institutional and commercial heating (SNAP 02)
Pollution sources summarized in the SNAP 02 category include households, small to medium business, and institutions that are be located mostly in the populated areas. The amount of emission depends on the heating requirements (e.g. population, heated volumes/areas, and ambient temperatures), the energy sources (e.g. fuel types), applied technologies (traditional furnaces, advanced central heating etc.) and lifestyle (comfort levels). The majority of emissions will occur in urban areas. Peri-urban areas are also important: although the emission loads are generally lower because of a lower housing density, the per-capita emissions are usually higher than in densely packed urban areas, because the energy demand of the large and detached housing structure is much higher than of the densely packed urban housing structure (c.f. Orthofer & Loibl, 1996).

Emissions from production processes and solvent use (SNAP 03, SNAP 04, SNAP 06)

Pollution sources in the SNAP 03, 04 and 06 categories include a variety of industrial processes that are not directly connected to energy conversion for heating: metal/steel production processes including coke furnaces, chemical processes, wood fibre processing, food processing. For NMVOC, this sector also includes NMVOC emissions from the use of solvents, paints, glues, and from other NMVOC-containing products. The amount of emission depends on the size and production of the industrial plants (as measured by throughput or number of employees) and on the technologies applied. It is reasonable to assume that the majority of emissions stem from the vicinity of urban centres due to availability of work force, and vicinity of and accessibility to consumers (cf. Orthofer & Loibl, 1996). Unfortunately, the probably most useful proxy data set, namely employment data, cannot be used to quantify the spatial extent of driving forces, because such data all relate to NUTS 2 regions only. Thus these data reflect a residence-related employment distribution instead of workplace-related distribution. Here certain assumptions based on empirical data of some national emission inventories (Loibl et al., 1993, Orthofer & Loibl, 1996) have to be introduced.

Emissions from road transport (SNAP 07)
Pollution sources in the SNAP 07 category exclusively relate to motor vehicles, including (light passenger vehicles), small and heavy lorries, buses, mopeds and motorcycles. The amount of emission depends on the actual use of vehicles (km driven), on the average technology of the motor vehicle fleet, and on the traffic situation (urban stop & go; motorways, etc.) and driving patterns. Naturally, emissions from road transport occur along the road network, so most emissions are expected to occur in urban plus their peri-urban areas, and in the traffic corridors. The average share of public transport is much higher in urban areas, and thus the vehicle use per person is often lower. On the other hand, the use of vehicles is also connected to lifestyle and grows rapidly with a higher income. It is hardly possible to differentiate between local or regional traffic that is related to population densities (c.f. Orthofer & Loibl, 1996) and the inter-regional traffic that is related to the road network in traffic corridors.

Emissions which are not considered

All other SNAP emission categories will not be considered in this methodological study. Emissions from agricultural activities (SNAP 10), notably from forestry, manure management, and fertiliser application refer to a different PLUREL task. Emissions from the "other mobile" (SNAP 08) sector are too heterogeneous and not related to general land use development (aircraft, railways, shipping, military machinery etc) to be considered. Emissions from large point sources (including power plants, refineries, extraction of fossil fuels, and waste processing) are also excluded from the estimations as they occur out as singular events, which cannot be spatially allocated through generic response functions, based on statistics considering driver – pressure relations reflected by general land use at European scale.

Overview: finally considered air pollution by emission source categories

Fehler! Verweisquelle konnte nicht gefunden werden. and figure 1 show the contribution of emission source categories used for the land use related air pollution allocation.

Air pollutant emissions in 2005 by source sectors for EU-25 Europe (Data from EEA, 2007b)

Emission sectors	CO Mio t	NOX Mio t	SO2 Mio t	NMVOC Mio t	NH3 Mio t	PM Mio t
Residential, commercial, institutional heating	7851	808	713	904	6	609
Production processes and solvent use	6087	1734	1456	4597	65	596
Road transport	12180	4251	42	1835	78	337
Emission sectors considered in PLUREL	26118	6793	2211	7336	149	1542
Agriculture	77	174	0	344	3583	269
Other sectors not included for PLUREL disaggregation	3983	3661	4310	1481	75	441
Total EU Emissions	30178	10628	6521	9161	3807	2252
% of total emissions considered in PLUREL	87%	64%	34%	80%	4%	68%

The emission sectors used for the PLUREL emission projection include almost 90% of CO emissions, nearly 65% of NOx emissions, and 80% of NMVOC emissions. Particulate matter (PM) for which the PLUREL sectors account to nearly 70% of all emissions, were not considered appropriate to be applied, because of high uncertainties regarding the allocation of the PM data (i.e. sources considered, PM specification considered, inventory methodologies etc); thus the data are insufficiently apt to identify spatial relations with land use. Of the other two pollutants, SO2 emissions are considered of less importance: first, they come mostly from single large point sources that are not connected with urban/non-urban spatial characteristics and only a small part of all emissions stem from PLUREL-relevant emission sources; furthermore, emissions are relatively low and subject to continue declining because of decreasing sulphur content in the fuels and advanced cleaning technologies. NH3 that is mostly emitted by agricultural activities is not taken into account in this task.

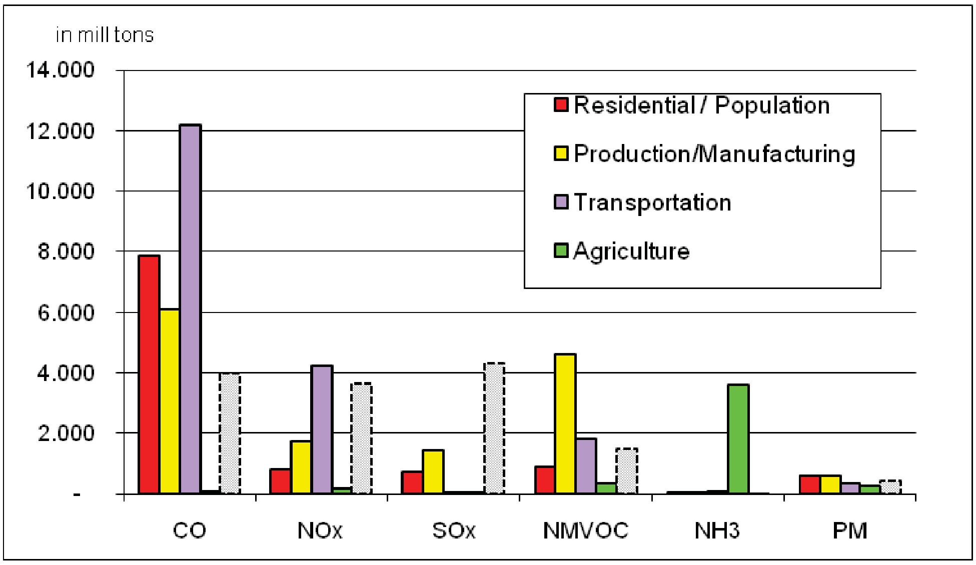

Fig. 1: Emitted pollutants in million tons per year (2005) by sectors (Data from EEA, 2007b)

So, finally, three pollutants were considered for further investigation: CO, NOx and NMVOC (Non methane volatile organic compounds, later simple called hydro-carbon or HC emissions). These three pollutants are expected to have a distinct relation to land use categories reflecting allocation of emission sources and the technologies applied.

- CO emissions result mainly from incomplete combustion, as it is often the case with residential heating devices and motor vehicle engines.
- NOx emissions come from efficient high-temperature combustion processes, such as district heating and natural gas combustion.
- NMVOC emissions come from two major sources: on the one hand they are an effect of incomplete combustion such as in residential heating devices and motor vehicle engines, and on the other hand they are released during use of solvent-containing products (painting, degreasing, dry cleaning etc.).

Both NOx and NMVOC contribute as precursor components to formation of ozone (O3) – a highly reactive secondary air pollutant (Loibl et al, 1993). While there are several significant hot-spots for different pollutants, three pollutants (NOx, PM10 and O3) are a major problem in all of Europe, as air quality target values are often exceeded in most countries. As mentioned above, spatially explicit emission data for particulate matter (TSP, PM10) are currently highly uncertain; similarly, the monitoring network is fragmentary and only few countries provide reliable long-term monitoring data. Therefore a European-wide usage of PM emission data for local scale applications is not appropriate and not included in the PLUREL emission projection study.

Not all activities lead to air pollution. The spatial interrelation between air pollutant emissions and the emission-generating activities in sub-regions within the rural-urban regions can be summarised as follows:

- SNAP 02 emissions include households, small to medium business, and institutions. These are located mostly in the populated areas. The majority of emissions will occur in urban areas. Peri-urban areas are also important: although the emission loads are generally lower because of a lower housing density, the per-capita emissions are usually higher than in densely packed urban areas, because the energy demand of the large and detached housing structure is much higher than of the densely packed urban housing structure. NMVOC and CO emissions – that occur during incomplete combustion processes –are likely to come from peri-urban or rural areas, or generally, from areas with less developed technology, with old heating equipment, or with a high share of solid fuel use. On the other hand, NOx emissions – that occur during high temperature and efficient combustion processes – are likely to come from areas with highly developed residential combustion technologies and with a high share of gaseous fuel use.

- The majority of emissions from production processes and solvent use (SNAP 03, 04, 06) occur in the industrial areas that are frequently located in the urban fringe and in peri-urban areas, or in some cases in the vicinity of the production resources (harbours, mines). Thus the analysis of the relation between emissions and the areas in which the emissions are generated is highly uncertain. Furthermore. NMVOC emissions in this sector also include NMVOC from the use of solvents, paints, glues, and from other NMVOC-containing products, not only by industry but also in the daily life of the population. Thus a significant share of NMVOC emissions occur also in populated areas, following the overall population densities. CO emissions are mostly connected to the locations of iron & steel industry. NOx comes to a major extent from the chemical and mineral (cement) industry. NMVOC emissions come (as stated above) from solvent product use in the overall population and solvent-using industries (chemical, food, metal etc.).
- Emissions from road traffic (SNAP 07) occur along roads and other motor vehicle relevant areas (parking installations), so most emissions are expected to occur in urban plus their peri-urban areas, and in the traffic corridors between urban centres. Emissions depend a very highly on the average technology status of the fleet, and on the predominant fuel type. CO emissions are particularly high in exhaust from old engines, while very low in new vehicles. NOx emissions are relatively high in Diesel-powered vehicles, particularly in vehicles following the pre-EURO5 standards. The majority of NMVOC emissions occur through fuel evaporation in older Petrol-powered vehicles.

Table 3 shows the relevant substances and emission sources that are taken into account for the development of the PLUREL air pollutant emission response functions in the three different regions.

Table 3: Proposed set of air pollution response functions

Emission sectors	Pollutants
SNAP 02 Residential, commercial, institutional combustion (heating)	CO, NOx
SNAPs 03, 40, 06 Combustion, Production processes and solvent use	NMVOC
SNAP 07 Road transport	NOx

2 Overall air pollutant emission trends

Air pollution refers mostly to human activities which drive – and are triggered by - economic development and wealth, demanding energy consumption. Mantzos & Capros (2006) have estimated the EU wide trends for energy and transport for the year 2030, based on the GDP projections from the PRIMES scenarios of the EC Directorate General for Economic and Financial Affairs from April 2005.

According to Mantzos & Capros (2006), EU-25 total energy consumption continues to increase. In 2030 energy consumption is about 15% higher than it was 2000; however, the growth rates become smaller after 2010 with consumption virtually stabilising between 2020 and 2030, caused by lower economic growth and stagnating population (Fig. 2).

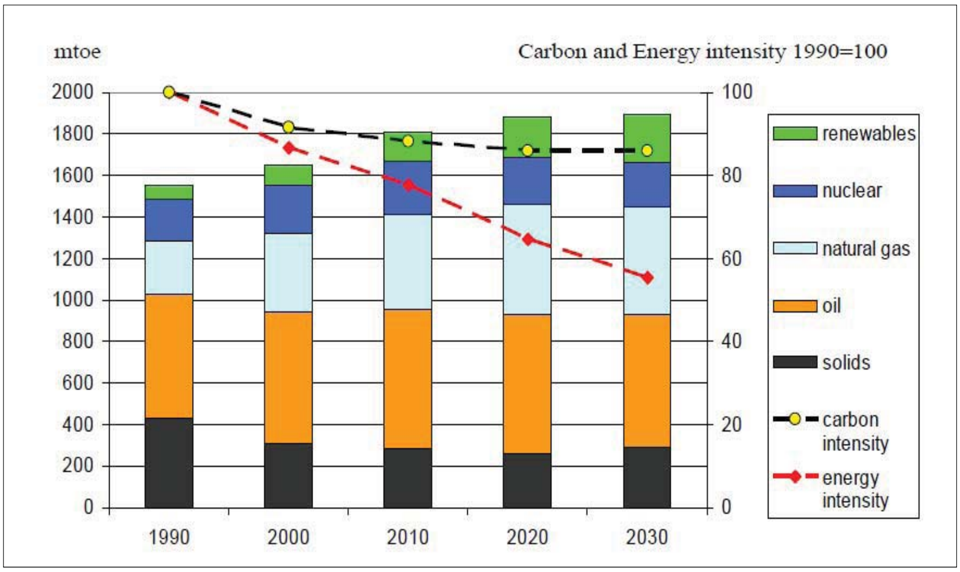

Fig. 2: Development of primary energy consumption by fuel (in Mio t Oil equivalent, left scale), and relative carbon and energy intensity trends (1990 = 100, right scale) in the EU-25 (Mantzos & Capros, 2006)

The 15 % increase of energy consumption between 2000 and 2030 is much lower than the about 80% growth of GDP so that energy intensity (= ratio between energy consumption and GDP) decreases (i.e. improves) by 1.5 % per year up to 2030. Between 2000 and 2010 the improvement of energy intensity was somewhat lower than in the previous decade (1.1% per year): this was caused by a lower economic growth and concurrent lower investments in energy-efficient equipment.

The fuel mix is expected to rather remain stable between 1010 and 2030: after a sharp drop between 1990 and 2010, solid fuels (i.e. coal) will remain at about 15% of total consumption up to 2030. The contribution of fuel oil and natural gas together is expected to remain at about slightly above 60% between 2010 and 2030, nuclear power will decline slowly while the share of renewables will grow from 8% in 2010 to 12% in 2030 (Mantzos & Capros, 2006). Carbon intensity, which is the ration between non-renewable carbon used (and released as CO2) for primary energy production, has considerably decreased between 1990 and 2010, but is expected to decrease only slightly more in the period between 2010 and 2030.

2.1 Economic sectors, energy efficiency and emissions

Mantzos & Capros (2006) identify the following general trends for energy use patterns:

- Mantzos & Capros (2006) identify the following general trends for energy use patterns:

In the final energy demand sector, electricity will experience the largest growth (almost 60% between 2000 and 2030). In the same period, the use of district heating will grow by about 40% and the use of natural gas for heating by almost 30%. The use of oil will increase only moderately due to replacement by gas and electricity for heating. Solid fuels use will decline significantly, with dominant usage sectors mainly in heavy industry. Renewables (ranging from wood combustion to solar water heating and bio-fuels in transport) will almost double their contribution (Mantzos & Capros, 2006).

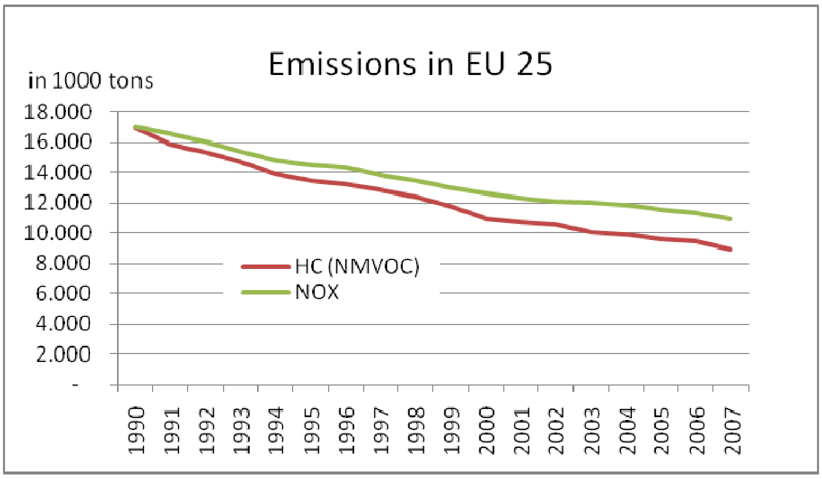

Fig. 3: Development of NMVOC, and NOx emissions in the EU-25 (Data from EEA 2007)

The Baseline economic outlook of EU-25 as projected in the PRIMES scenarios is dominated by the development of the economy in the EU-15 "old" member states. This is because the contribution of "new" member states (NMS), despite their much faster growth over the projection period (about 4% per year in 2000-2030 compared to only about 2% in EU-15), contributes a relatively small share to the overall EU-25 GDP. By 2030, the contribution of GDP in NMS will reach about 7% of the total GDP in the EU-25, economic activity - compared to only 4% in 2000. After 2030, overall economic growth will be similar in old and new member states.

The following figure 4 illustrates the relationships between GDP, primary energy demand and CO2 emission growth from 1995 to 2030 (with energy and carbon intensity plotted against the secondary axis).

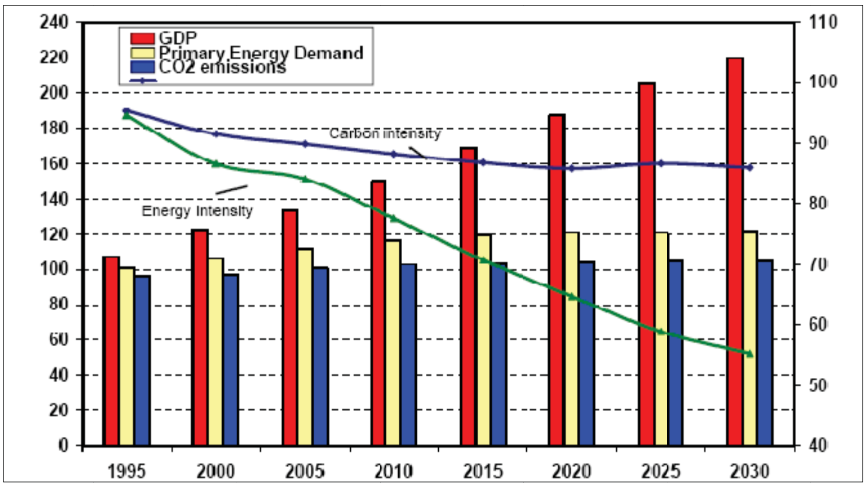

Fig. 4: Development of GDP, primary energy demand and CO2 emissions for EU-25 (Figure taken from Mantzos & Capros, 2006)

The baseline trends in energy consumption and economic growth show certain differences between the old EU-15 and new Member States (NMS). The NMS energy system is characterised by an economic restructuring process driven by the progressive implementation of EU policies that reduces energyintensive activities and improves energy efficiency. GDP per capita that was about 5 times higher in the EU-15 than in the NMS is expected converge in both categories, so that by 2030, the GDP per capita will be only about 2.4 times higher in the EU-15 than in the NMS. Despite the significant improvements in the new Member States convergence with the EU-15 might not be completed by 2030 (Mantzos & Capros, 2006).

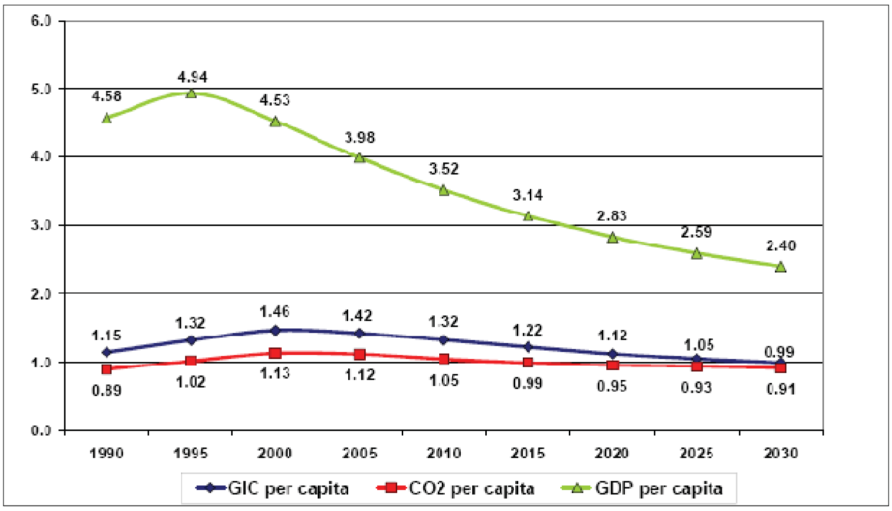

Fig. 5: Convergence indicators ratios between the old and new member states: ratios of situation in EU-15 on situation in NMS (GIC = gross inland consumption in t oil equiv; Figure taken from Mantzos & Capros, 2006)

2.2 Considered emission trends by sectors and countries

Emission trends for NOx have been published recently (EEA, 2010). Between 1990 and 2005 NO_x emissions have decreased by more than 30%. Almost all of the reductions come from three emission source sectors: "road transport" contributed more than 50% of the total reduction, "energy industries" about 30%, and "industry" about 15%. Residential combustion contributed only about 7% to total reductions. On the other hand, the non-energy source categories (industrial processes), emissions have increased by about 8%. These overall changes are very different in the various countries.

As an example for the high variability, Figure 6 shows the variability of relative trends of NOx emissions from road traffic between 1990 and 2005 in the EU-27 countries, taken from the EDGAR database (Emissions Database for Global Atmospheric Research). The relative trends range from a reduction of about 40% (UK; Germany) to an increase of more than 50% (in the Czech Republic). Consistent with overall trends in the EU-27, the majority of countries show a NOx-reduction.

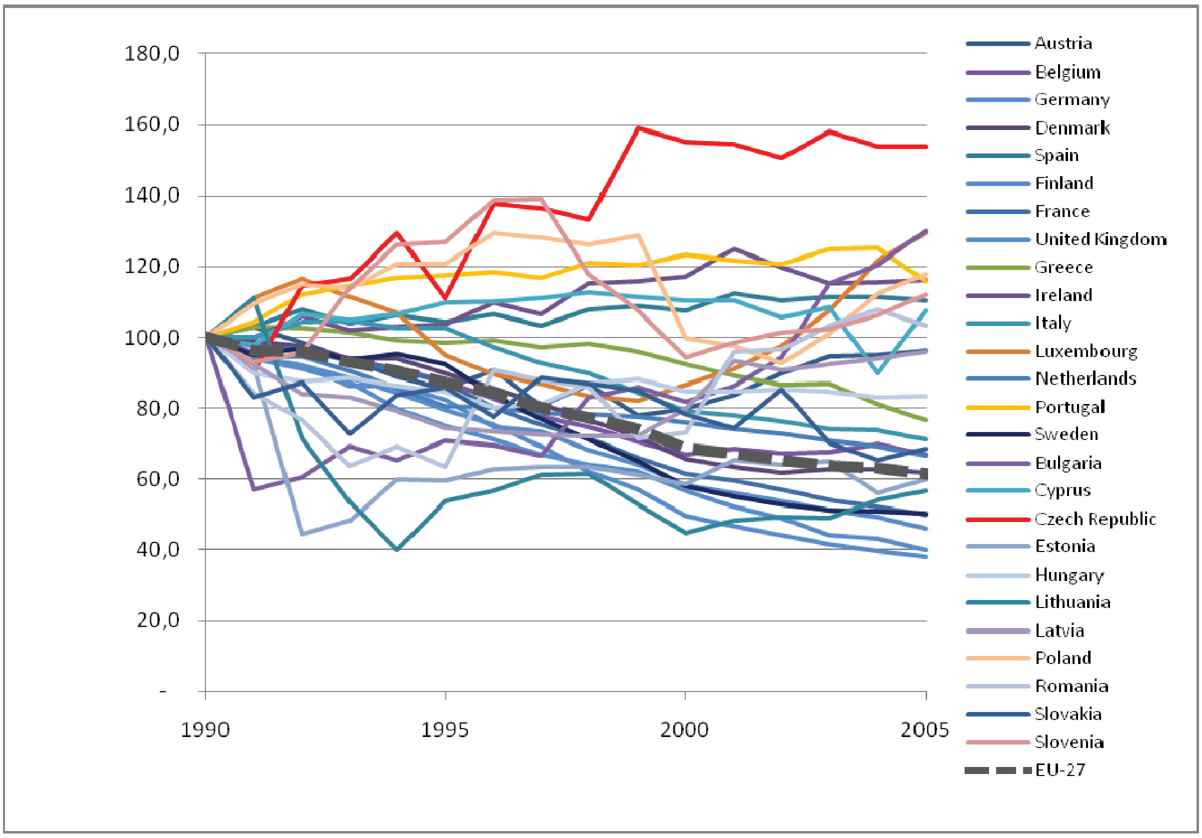

Fig. 6: Relative trends of NOx emissions from road traffic inEU-27 countries (year 1990 = 100) (Data from JRC EDGAR database, 2010).

The European Union has established a comprehensive legislative framework that allows achieving a sustainable air quality. A large number of directives specify minimum requirements for emission controls from specific sources, such as large combustion plants, vehicles, solvents use etc. IIASA has synthesized scenarios on air pollutant emissions (Amann et al., 2005) simulate the effects of the EU's Clean Air For Europe (CAFÉ) Programme. Figure 7 shows the expected reduction for NOx and VOC emissions (volatile organic compound) from 2000 to 2020.

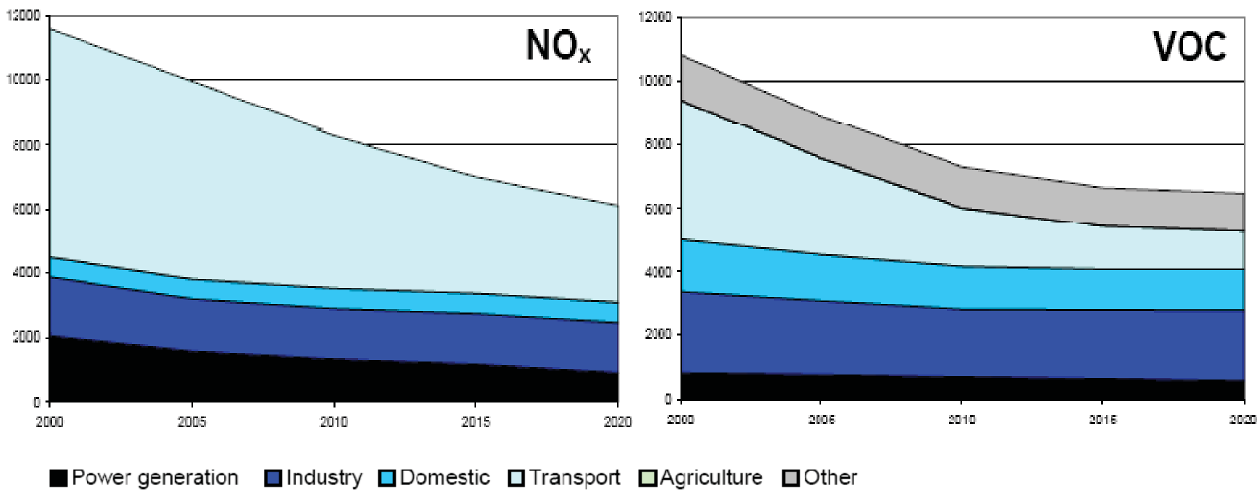

Figure 7: Expected NOx and VOC emission reduction 2020 in the EU-25 countries according to CAFE scenarios (Figure taken from Amann et al., 2005)

The CAFÉ-scenarios assume an overall reduction of emissions between 2000 and 2020. Again, the trends will be very different in different countries, depending on the emission control measures and on prior technology applications regarding emission mitigation.

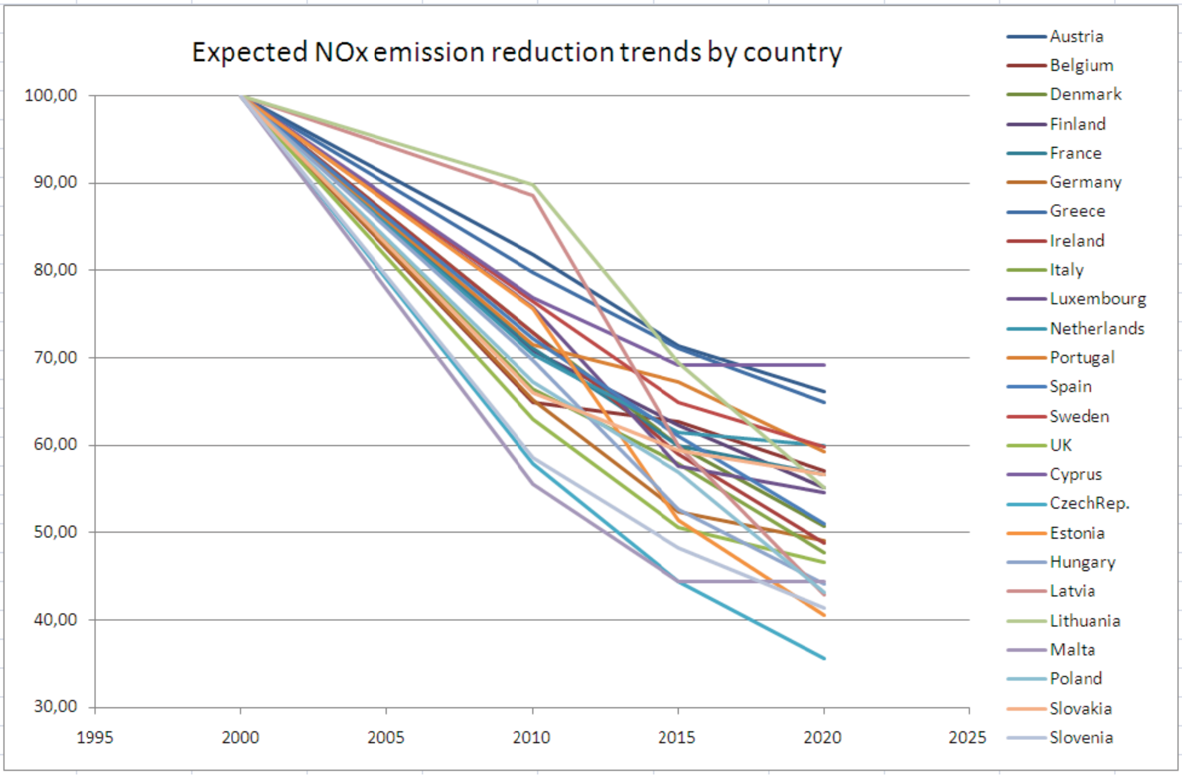

Fig. 8: NOx emission reduction trends by country according to CAFÉ scenarios in EU-25 countries ([without Romania and Bulgaria], Data from Amann et al., 2005)

The relative trends of NOx emissions between 2000 and 2020 range from about -30% (e.g. Finland, France, Austria) o -65% (in Poland). Generally, the reduction is higher in new member states than in the "old" EU-15 countries.

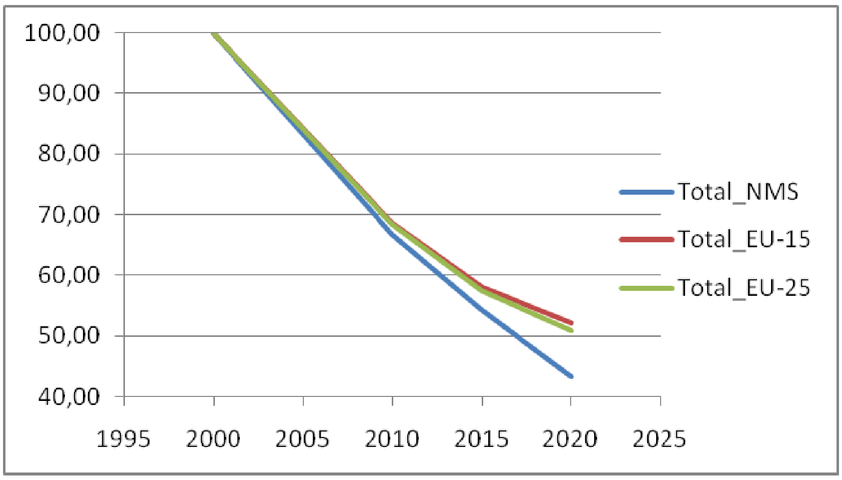

Fig. 9: NOx emission reduction trends according to CAFÉ scenarios in the EU-25, in old (EU-15) and in new (NMS) member states (Data from Amann et al., 2005)

For NMVOC emissions solvent use, by households and production, the CAFE scenarios project an overall reduction of about 20% between 2000 and 2020. The figure below refers only to these three source categories; we have excluded large industrial combustion, transport and nature.

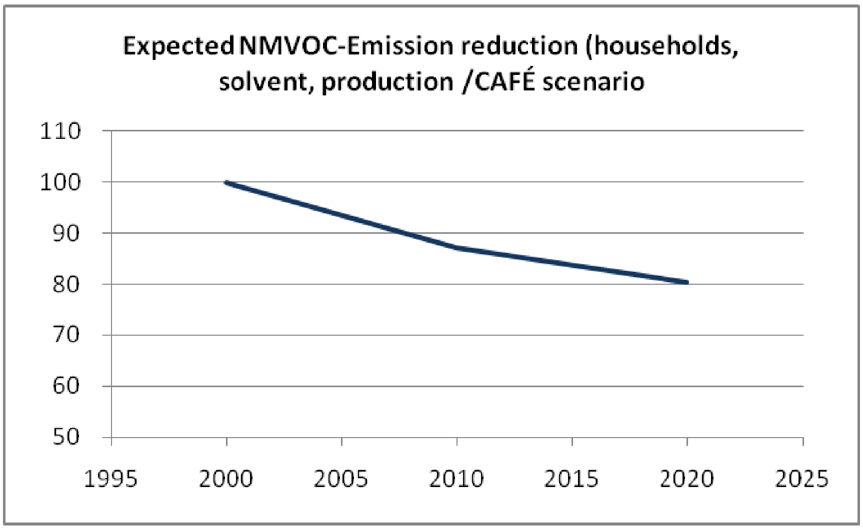

Fig. 10: Trends of NMVOC emissions from solvent use, households and production 2000 to 2020 according to CAFE scenarios (Data from Amann et al, 2005)

The presented general trends for NOx and NMVOC emissions do not allow explaining the spatial effects of the peri-urban development trends on emissions. These will be explored and estimated for the future with the help of response functions. The following chapter shows the final findings. Previous results are available in earlier versions of the paper delivered 2007 and 2009.

3 Air pollution and peri-urban development

3.1 Emission data sets related to the EMEP 50x50 km grid

The European wide CORINAIR emission inventory is based on national emission inventories and supporting data, given as annual data available for defined harmonized source categories (SNAP and NRF categories). CORINAIR emissions data are disaggregated in to the polar stereographic projection EMEP raster grid system (http://www.emep.int/index.html), which compares to an about 50x50 km grid. In the EMEP data sets, emissions from large point sources (LPS) and from areas sources are reported separately.

For the emission estimations, the original EMEP grid has been re-projected into the European standard Lambert equal area conformal conic projection to match with the other PLUREL geodata. Through this step, it was possible to overlay the EMEP grid data with CORINE land cover data, with PLUREL scenario outputs on artificial surface development, and with the NUTS region geo-datasets. Figure 11 shows the EMEP 50 x 50 km grid in original polar projection and its transformation into the Lambert projection for overlay with NUTS3 regions.

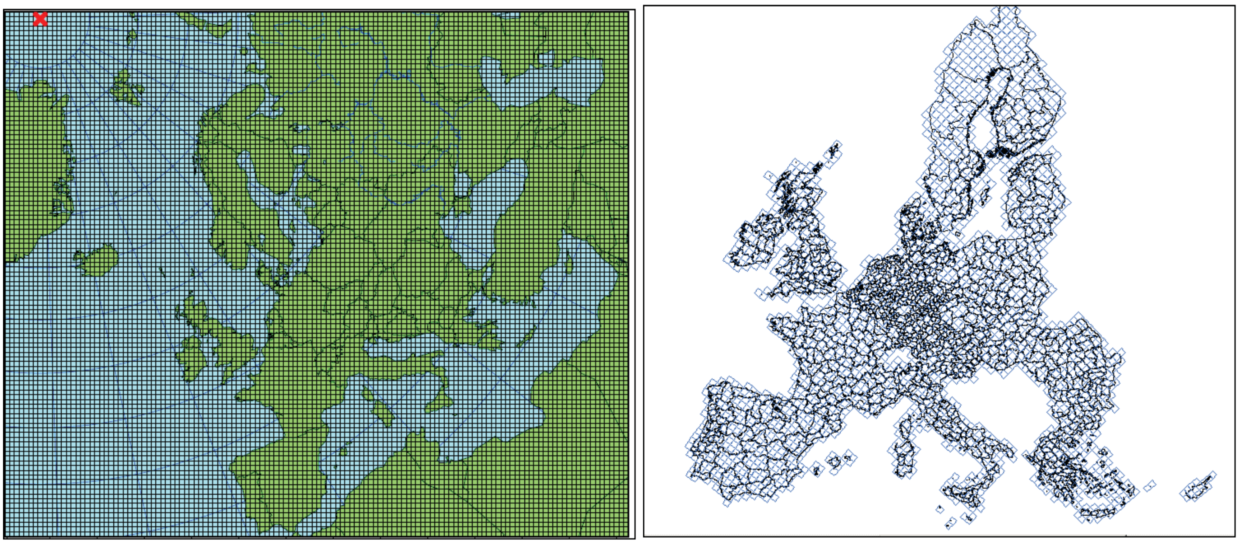

Figure 11: The 50 x 50 km EMEP grid in original polar projection (left) and transformed into Lambert equal area conformal conic projection for overlay with NUTS3 regions (right)

The EMEP gridded emission data are available from EEA as tables for each pollutant (c.f.

Table 1) and each SNAP emission source category (c.f. Table 2). For our analysis we have extracted the data for the latest available reporting year 2004. The geo-referenced EMEP emission data were then uploaded to the PLUREL data warehouse.

As an example of the EMEP emission datasets, Figure 12 shows NOx emissions from road traffic (SNAP07) for the reporting year 2004.

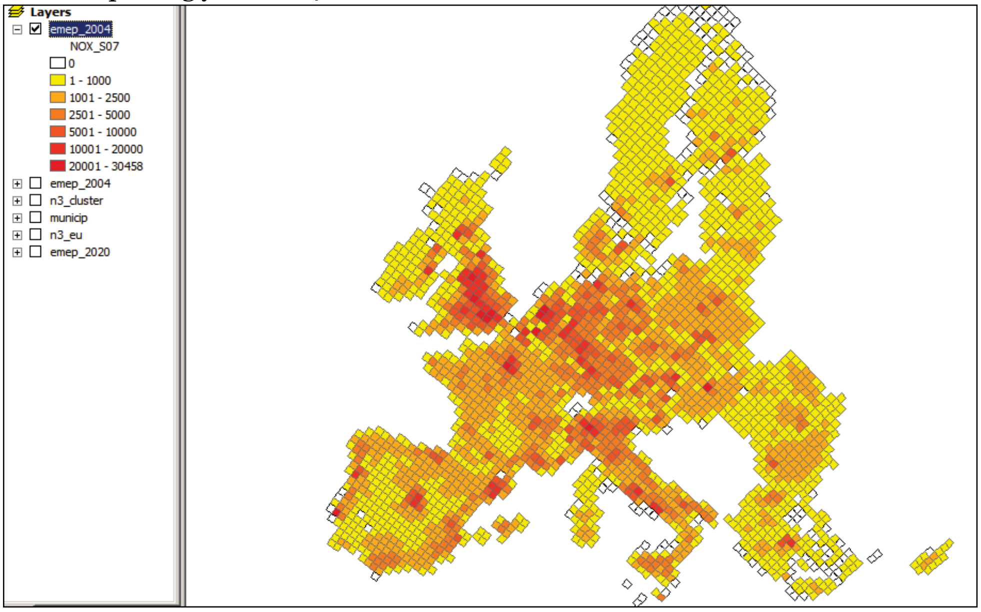

Figure 12: Spatial pattern of NOx emissions from road traffic (SNAP07) in 2004, as given in the CORINAIR/EMEP data base. (Units: tons per EMEP grid cell)

3.2 Relationship between air pollution emissions and land use

The following sections explain how EMEP emission data were spatially allocated to NUTSx regions and RUR sub-regions.

As demonstrated in Figures 13 and 14, there is a clear relationship between emission patterns and land-use patterns that reflect human emission-generating activities. Figure 13 shows NOx emissions from road traffic in EMEP grid cells. Figure 14 shows population densities by municipality which serves as a proxy for human activities and intensities.

As emission data are available only for 50x50km EMEP grid cells, statistical data serving as proxy to explain air pollutant emissions, were related to the EMEP grid cells.

Air pollution emission pattern and related proxy data reflecting land use

Emission data are available as spatially explicit data sets in Europe for EMEP raster cells. After various tests at country level and at case study level for certain areas, response functions have been derived by applying the EMEP grid cell data for entire EU-27.

The comparison between figure 13 and 14 proofs a clear relationship between the emission patterns and human activity patterns related to land use.

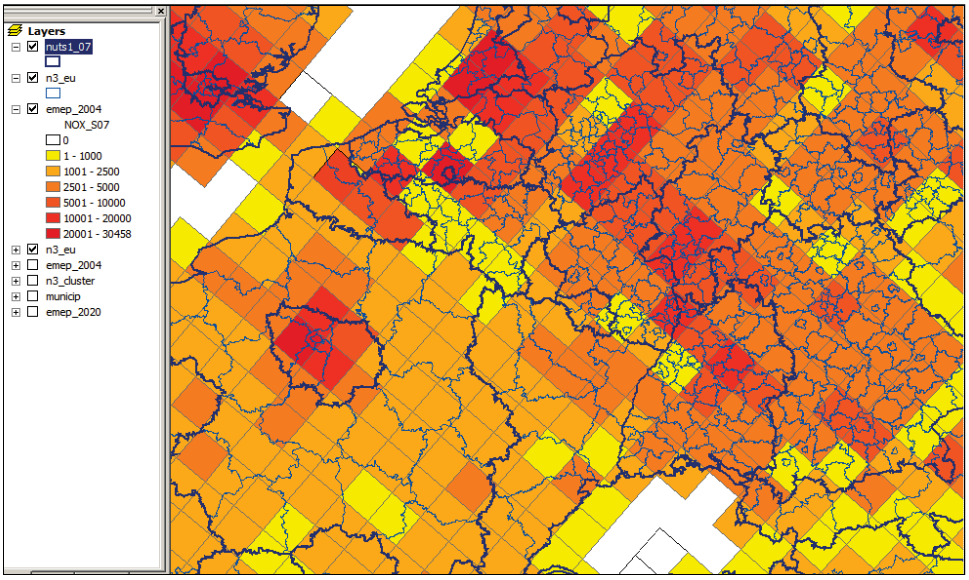

Figure 13: NOx traffic emissions (in tons) related to 50km EMEP-grid cells and underlying NUTS3 and NUTS1-polygons (Source: EEA 2007b, compilation: AIT)

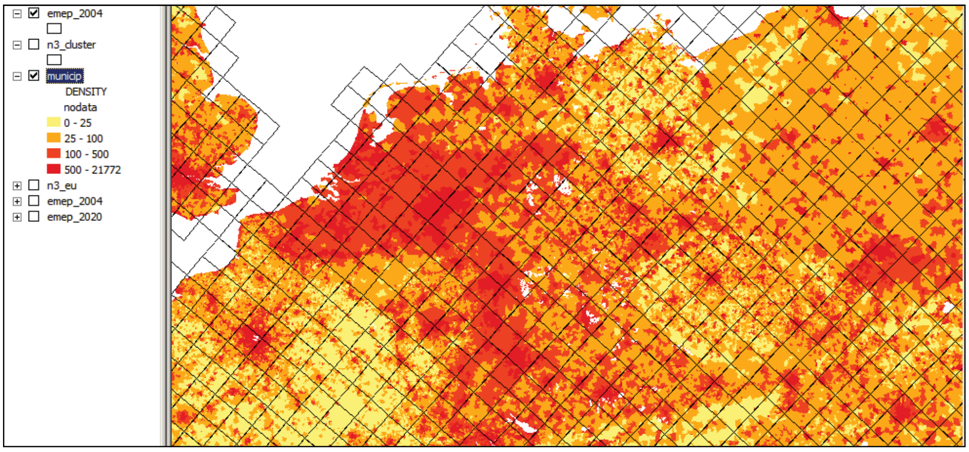

Figure 14: Population density in municipalities (Unit: pop/ha) and underlying EMEP grid cells (Data from Eurostat 2007, GISCO 2007, JRC 2007). [1]

In order to derive emission-related response functions for the regions with their urban, peri-urban and rural areas, as investigated within the PLUREL project, it is necessary to allocate emissions to areas with the respective emission-generating activities.

The following sections explain how emission data were spatially allocated to RUR regions, NUTSx regions and finally the urban, per-urban and rural sub-regions.

To explore the relation of the different shares of RUR sub-regions and the municipality population, the sub-regions have been delineated. Details regarding the RUR sub-region typology and delineation are

[1] Note: Municipality borders and population data have been provided by JRC with licence agreements of Eurostat and GISCO for exclusive use within PLUREL.

presented in deliverable D2.1.4. Figure 15 gives an example of the delineation results to demonstrate the level of detail.

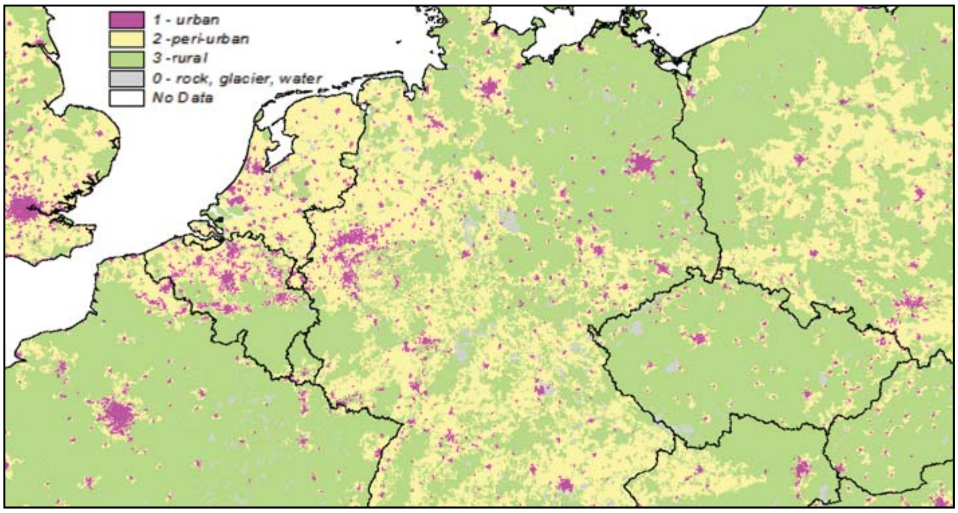

Figure 15: Example results of delineation of urban, peri-urban and rural sub-regions based on land use and population density (cf PLUREL Deliverable 2.1.4)

In order to quantify the effects of the regional structures regarding the shares of RUR sub-region in an EMEP grid cell, a first attempt was made to derive proxy data for each EMEP grid cell by intersecting the RUR sub-region delineation with the EMEP grid cell boundaries. However, the resulting quality of the response functions (see next chapter) resulting from such proxy data was not sufficient, so other approaches were used to relate EMEP emission data to NUTSx regions.

This new approach has been carried out again by intersecting the EMEP raster with the NUTSx regions and disaggregating or aggregating the emissions data by using shares of areas and population of EMEP raster cells and NUTSx regions as weighting factors to allocate emission values from different EMEP cells to the overlaying respective NUTSx regions. The population numbers for the NUTSx intersections were calculated for the RUR sub-regions based on area shares and the regions' population densities.

3.3 Response functions for air pollution as effect of land use relationships

3.3.1 Approach

Response functions describe the overall statistical relation of an explanatory cause (e.g. emission-generating activities) and their effect (e.g. air pollutant emissions). Such functions can then be used to project the future trends of the respective effect when there is a future trend of the causes and the explanatory variables describing the causes are available.

Within the PLUREL context, such response functions reflect the effects of peri-urbanisation on air pollution, expressed as emission patterns, to assess the magnitude of the driving forces and pressures (land-use characteristics) for the emission of air pollutants.

A general equation to reflect the entire response may look as follows:

Emission = f (activity, intensity, efficiency/productivity)

- Emission-generating activities can be expressed as population, road network and traffic loads etc.
- Emission intensities can be integrated through proxies such as road type (motorway, urban streets etc.) for traffic, or urban artificial surface for energy efficiency etc.
- Efficiency and productivity can be considered as a general effect of economic wealth reflected by GDP. However, GDP alone will only be able to explain a small part of efficiency or productivity factors; there is also a technology-related efficiency that is not related with GDP, such as

predominant fuel types, national standards etc. Unfortunately such factors could not be considered as these data were not available by region and no assumptions for the PLUREL scenarios could be made.

After various tests it became apparent that only few spatially explicit data are available to estimate air pollutant emissions. As the equations are based on static data they reflect static relations between drivers and pressures and do not consider dynamic effects like efficiency and technology development.

The variables to be explained are absolute emission numbers. Equations to quantify spatial emissions densities (emissions per area) do not deliver useful results, perhaps because of the highly variable sizes and populated areas of the regions, which cause a high variation of emission densities per EMEP. Similarly, estimating response functions for activity emission densities (emissions per population, per settlement area, per road length etc.) did also not provide useful results. The reason might be that these densities show very different ranges due to the very different NUTSx region characteristics.

3.3.2 Response functions

Response functions to quantify relationships between emission and driver patterns have initially been tested by means of regressions models using EU27 country data. The advantage of these initial functions was that they contain many indicators in addition to population and GDP: e.g. road network length, energy demand, predominating fuel mix. But on the other hand there were no future trend projection data for these variables, and most of these variables were not available for the required spatial level. Thus we have finally concentrate on those data, which can be provided spatially explicit based on the PLUREL scenario results, namely population numbers, artificial surface and GDP (still only for NUTS2 regions).

Various model versions was have been tested first applying country data, later case study data and finally EMEP data to estimate results for NUTSx regions based on projection results related to the PUEL scenarios. The final modelling steps are the following:

- NUTSx regions are spatially intersected with EMEP raster cells
- Emission data are used from the CORINAIR initiative for entire Europe spatially resolved on the EMEP raster (about 50x50 km). Emissions per NUTSx regions are estimated by taking the area proportion and further the population proportion of EMEP raster cells and NUTSx regions as weighting factors to merge emissions from different EMEP cells to the respective NUTSx regions.
- All explanatory data are allocated (disaggregated or aggregated) for the NUTSx regions used in the model. Input data are population numbers, artificial surface area and GDP. All explanatory data is related to the urban peri-urban and rural sub-entities of the NUTSx regions that describe the peri-urbanisation characteristics (population and settlement area distribution).
- Response functions are calculated for the NUTSx regions through regression models. These models explain the selected air pollutant emissions from a source sector through a combination of explanatory variables. The response functions allow estimating future emissions as effect of human activities reflected by land use and the expected change patterns.
- The residuals – the deviations between modelled and observed data – reflect the regional characteristics that deviate from the European-wide driver-pressure response relations. For each NUTSx region and each combination of pollutant and source correction factors are calculated to consider these regional deviations from the overall "response".
- Future emission patterns are calculated for the NUTSx regions using projected changes of explanatory variables and applying the response functions extended with the regional correction factors.

The results show the general emission trends as expected from future trends in anthropogenic settlement patterns; they do implicitly consider some technological changes as long as these are connected to GDP-growth. However, the results do not consider changes of emissions in major point sources (e.g. power generators or large industrial plants) which are – in terms of statistics – "singular events" that cannot be estimated through response functions. Similarly, the results do not consider additional potential emission reductions induced by technological standards and legislation (e.g. energy efficiency standards, motor vehicle standards, industrial release norms, product standards) are not considered within these functions. These further effects on emission intensity need to be considered when assessing the absolute amounts of pollutant release but may be neglected when examining relative differences between the land use change scenarios.

Regression analysis is a technique which examines the relationships of a dependent variable (response variable) to specified independent variables (explanatory variables). The key relationship is quantified with the regression equation. The estimated parameters measure the relationship between the dependent variable – in our case the emission volume - and each of the independent variables – in our case indicators which "explain" the emission volume.

Supposing the a response variable y can be predicted by a linear combination of some explanatory variables {x1, x2,...,xn} the general form of the applied multiple linear regression is

$$y_i = \alpha + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n + \varepsilon_{I,}$$

where α is the intercept, β are the regression coefficients weighting the explanatory variables, and ε is the error term, representing the unpredictable part of the response variable y_i.

The calculations for α und β are conducted by least square estimates given by:

$$\hat{\beta} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sum(x_i - \bar{x})^2}$$

and

$$\hat{\alpha} = \bar{y} - \hat{\beta}\bar{x}$$

Regression analysis can be used as a descriptive method without relying on any assumptions about underlying processes generating the data but the selection of the data sets has been performed considering certain assumptions as result of the investigations described in the previous chapters. And - when paired with assumptions, regression models can be used for prediction and modelling of causal relationships (cf Draper & Smith, 1998, Berk, 2004 and SAS Institute Inc, 1985).

As described in chapter 2 a limited set of response functions can be applied for certain emission sectors:

- NOx and CO emissions from residential, institutional and commercial heating (SNAP 02)
- NMVOC (non-methane volatile organic compounds) emissions from production processes and commercial and residential solvent use (SNAP 03, SNAP 04, SNAP 06)
- NOx emissions from road traffic (SNAP 07)

The explaining driver indicators are those which have been extracted for the PLUREL scenarios for all NUTSx regions:

- population (2004) in urban areas – absolute value
- population in peri-urban areas – absolute value
- population in rural areas – absolute value,
- artificial surface (2001) in urban areas – absolute value
- artificial surface (2001) in peri-urban areas – absolute value
- artificial surface (2001) in rural areas – absolute value
- GDP (total 2004) by NUTSx regions (derived from GDP per capita numbers for NUTS2 regions)
- Total area o the NUTSx region – affecting to some extent the traffic load and related emissions.

The general equation for the considered components of emission sector y_i, looks as follows:

$$y_i = (\beta_1 * \textit{urban population} + \beta_2 * \textit{peri-urban population} + \beta_3 * \textit{rural population} + \beta_4 * \textit{urban artificial surface} + \beta_5 * \textit{peri-urban artificial surface} + \beta_6 * \textit{rural artificial surface} + \beta_7 * \textit{regional GDP based on GDP per capita and population numbers} (+ \beta_8 * \textit{total region area})) * r\_fct$$

where $\beta_{i = 1 \ldots n}$ are the regression coefficients and *r_fct* is the regional correction deviation factor replacing the (usually additive) error term.

The final selection of the variable sets, explaining emission volume and distribution, is the result of various regressions analysis tests with different variable combinations, which were selected individually for the respective emission source group. Only those were selected which let expect a certain causal relationship and provide also appropriate results.

The following table gives an overview of applied explanatory variables and the related regression coefficients for the explaining variables of the equations applied as response functions and the correlation coefficients describing the share of the explained variance. The lower part contains the standardized coefficients in order to show the relative impact of the single variables to the equation.

Table 5: Response functions: land use and human activity affecting air pollution emissions

regression coefficients	CONSTANT	artif. surface urban	artif. surface peri-urban	artif. surface rural	Population urban	population peri-urban	population rural	GDP	total area	R^2
NOx from small combustion	431.173,000	1.178,000			0,707	2,697				**0,650**
NOx from road raffic	6.480.720,160	-12.537,377	-31.503,270	945,574	10,760	32,902	14,100	-226,246	37,768	**0,348**
CO from small combustion	-319.322,096	-31.639,815			13,330	10,090	16,165	-3,078		**0,712**
HC from solvent use & production	3.442.586,129	-14.526,775			1,442	-0,188	23,470	10,150		**0,177**
std. regression coefficients	CONSTANT	artif. surface urban	artif. surface peri-urban	artif. surface rural	Population urban	population peri-urban	population rural	GDP	total area	R^2
NOx from combustion		0,081			0,269	0,567				**0,650**
NOx from road raffic		-0,103	-0,283	0,007	0,492	0,831	0,174	0,022	-0,435	**0,348**
CO from combustion		-0,352			0,824	0,344	0,269	-0,008		**0,712**
HC from solvent use & production		-0,160			0,088	-0,006	0,387	0,026		**0,177**

(Calculations: AIT)

In general the population allocated to the urban, peri- urban and rural sub-regions within the NUTSx regions have been selected. The artificial surface numbers (allocated to the sub-region compartments per NUTSx region and the GDP numbers contribute to the equations to some extent and are applied partly for the emission source groups. To estimate road traffic emissions the total area has been also included as explanatory variable, to consider transit traffic load, even if the local population (causing only local traffic) is small.

Some functions show a high explanation quality (NOx from small combustion: R^2=0,650; CO from small combustion R^2=0,712); others a much lesser one (NOx from road traffic: R^2=0,348; NMVOC from processes & solvents: R^2=0,177). The R^2 shows the share of the explained variance on the total variance of the explained values). The R^2 of 0,348 and 0,177 indicates that only 35% respectively 18 % of the variance of the regional emission volume is explained by the response function, which means, the changes in peri-urban activity patterns have only little influence on total change of emissions. Thus the equations express only one influence on air pollution emissions which is the spatial pattern and the relationships of human activities as reflected by land use, triggered by peri-urbanisation, others are hidden in the residual term.

The response functions are a product from statistical analysis, whose quality is defined by the quality of the input data. As most of these data are estimates for sub-regions from regional totals based on proportions of proxy data the results cannot explain more as what is reflected by the input data. Considering the residuals (the deviations between the modelled and observed results) is essential to include the influence of the respective regions. These deviations have been included by the regional correction factors describing the proportion between modelled and observed results for the analysis year where regional emission data were available (year 2004).

Even with inclusion of a correction factor the equations could deliver odd results when some of the explaining variables show untypical changes, leading to implausible emission volumes. [2] As the results show general change trends (as necessary when compared with the EU-wide emission projections) and the local changes of the explaining variables (artificial surface, population) for the sub-entities within the regions are expected to be much higher than the overall emission change trends, the final local change range was limited to a maximum of +/-25% between 2005 and 2015 and to a maximum of -/+ 50% between 2005 and 2025 (for different emission sources different maximum ranges were applied).

4. Effects of future urbanisation-trends on air pollution emissions

In general the air pollutant emission intensities from human activities will decline with increasing energy efficiency, new production and pollution reduction technologies, triggered by economic welfare allowing to financing the necessary investments. This will be counter-acted partly by the increase of emission-generating activities and goods consumption which again triggers increase of energy consumption that will again trigger further increase of emissions.

4.1 Overall trends

The overall air pollutant emission trends in Europe are expected to decline, despite increasing emissions-generating activities and goods consumption patterns. However, the trends show different directions and intensities.

Trends by emission sectors

- NOx emissions from small combustion sources are expected to increase with increasing population and increasing GDP. This is an effect of more activities (more heating) and a trend towards use of higher energy efficiency through use of high-efficiency heating systems from which more NOx is released. In some advanced areas, increased NOx emissions are compensated through use of advances low-NOx-technologies.
- CO emissions from small combustion sources are expected to decline. This is an effect of change from old low-efficiency heating technologies (e.g. open furnaces) and fuel types (e.g. brown coal) towards efficient systems and fuels, somehow boosted by peri-urbanisation due to applying new technologies when building new houses.
- NOx emissions from road transportation are expected to decline despite an increase in traffic. With increasing GDP and implementation of EU standards, a relative rapidly changing composition of the vehicle fleet will quickly introduce new emissions concepts and engine technologies.
- NMVOC emissions from industrial combustion, production and solvent use are expected to decline but they are only loosely related to changes in settlement patterns. With increasing GDP, households and small production sites will increase their solvent-related activities, such as coating, painting, cleaning. On the other hand, organic emissions will be reduced with better technologies and new low-NMVOC solvent products.

Trends for emission sources

[2]) A further reason for possible unrealistic results is the definition of the NUTS regions: The NUTSx regions are administrative entities, which to not match the rural-urban influence sphere. Small NUTSx regions around capitals cover either urban or peri-urban areas which may lead only to changes in urban or the peri-urban subsets of artificial surface and population leading to implausible emissions changes in the certain NUTSx region.

- Households will respond on GDP growth with better quality of housing, and transition from use of solid fuels towards natural gas and advanced renewables, resulting in more NOx (and partly more NMVOC) but significantly less CO emissions. Increased NOx emissions are compensated with used of low-NOx heating equipment.
- Industry will - with growing GDP - likely reduce NOx and CO emissions due to generally evolving better energy efficiency and better production and pollution reduction technologies.
- Road traffic will grow, but release of pollutants is expected to decline significantly, forced by improved exhaust control technologies and legislation. E-mobility would radically erase emissions, but their market share is expected to be still small in 2025 (Mantzos & Capros, 2006).
- Power generation will increase emissions of large sites but would on the other hand substitute emission from small sources with less efficient energy efficiency and less efficient mitigation technologies.

Regarding the estimated trends it has to be stated that most emission source sectors show parallel increasing and declining emission trends, with individual causal trends hidden in all others. Thus it is not easy to predict whether a given region will experience a dominance of emission reductions because of new technologies, or emission increases because of population growth, lifestyle changes and (peri-)urbanisation trends.

As the response functions refer to the relationships between land use, population, GDP and emissions for a certain observation time, they follow certain *ceteris paribus* conditions: it is assumed that effects of human activities (as far as reflected by land use) on emissions remain stable. The response functions reflect static relations between the drivers and pressures and do not consider the possible dynamics in technical development, particularly with respect to production and energy efficiency.

The final driver data refer to the narrative scenarios A1, A2, B1 and B2 (Ravetz et al, 2008).

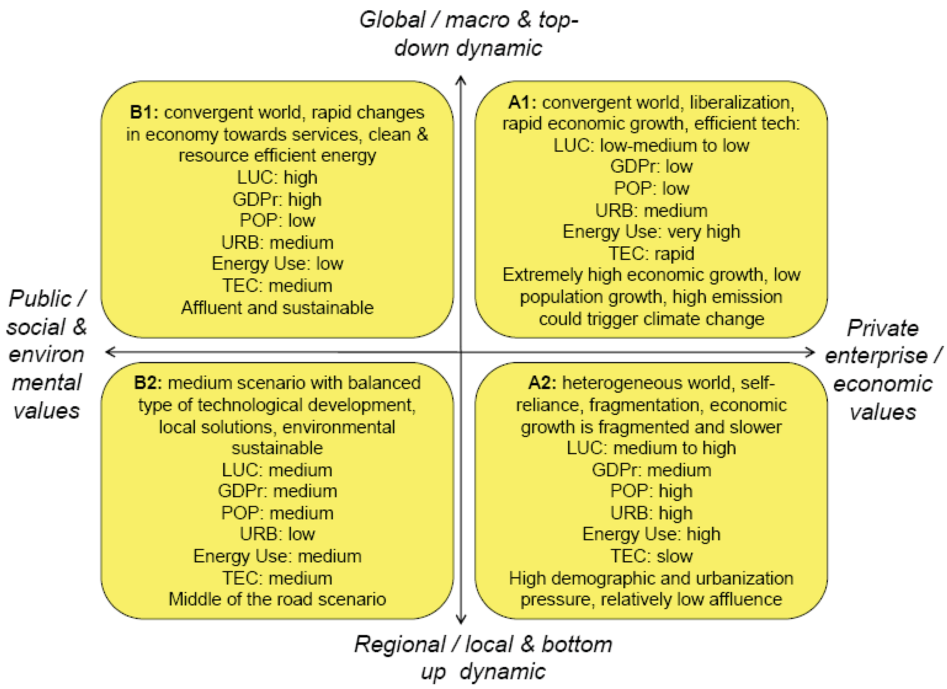

Figure 16: Driver pressure trends of the 4 PLUREL scenarios (J. Ravetz et al., 2008)

- Scenario A1 “Hypertech” assumes fast growth, technological development and distinct economic growth, forcing urban migration as well as counter-urbanisation, which may provoke urban sprawl with negative effects on emissions.
- Scenario A2 “Water world” is fast growing but diverging. It considers certain impacts due to climate change with some areas suffering increased flooding, others suffering from drought. As a result of in-migration cities will density, releasing less emission per person.

- Scenario B1 “Peak oil” expects high energy prices and the high demand for renewable energy, affecting the economy and travel behaviour. High commuting costs will bring people living near their work, leading densification of cities. Urban sprawl will decrease, releasing fewer emissions.
- Scenario B2 “Social fragmentation” assumes processes of decentralisation, increased regional competition, and competition for resources among the generations. The lack of a central driving economy will slow down urban growth, relatively lower emissions in the urban areas and relatively more emissions in the rural sub-regions.

For the scenarios quantitative results have been conducted for NUTS 2 regions for population (from the IIASA population model . Skirbekk et al, 2007)) and for regional GDP (from the NEMESIS economic model; Boitier et al, 2008). Artificial surface numbers (based on the population and GDP results) have been carried out by the RUG model spatially explicit for 1 km2 grid cells for entire Europe (Rickebusch, 2009).

Again it should be emphasized that results of the response function model must be interpreted with respect to the underlying assumptions: the response functions refer to the static relationships between explanatory variables and emission data and they do not include a given trend over time (such as technological development). Thus our response functions describe the spatial relationships between air pollution patterns and patterns of human emission-generating activities, as far as these are reflected by land use change. To a certain extent, technological improvements are indirectly considered through changes in GDP (as a proxy for the technological development of a country or region), but the major emission-relevant technical trajectories such as those in the CAFÉ scenarios presented earlier are not explicitly considered. Nevertheless our response functions are compatible with Europe-wide emission projection trends whose assumptions are based on technology and energy price development, but which do not consider spatial effects and indications.

The results and the respective emission source classes for the 4 PLUREL scenarios (without considering explicit energy efficiency efforts and explicit technology development dynamics!) reflecting the effects of the scenarios different peri-urbanisation developments look as follows:

Table 6: Changes of air pollutant emissions caused by peri-urban development for the four PUREL scenarios 2004 - 2025 (Base year 2004 = index 100)

PLUREL scenarios	NOx emissions from small combustion	NOx emissions from road traffic	CO emissions from small combustion	NMVOC emissions from solvent & production
A1_2025	105,4	86,0	96,6	96,3
A2_2025	105,0	88,7	97,6	94,9
B1_2025	104,2	93,0	97,3	95,3
B1_2025	104,8	93,3	100,1	95,6

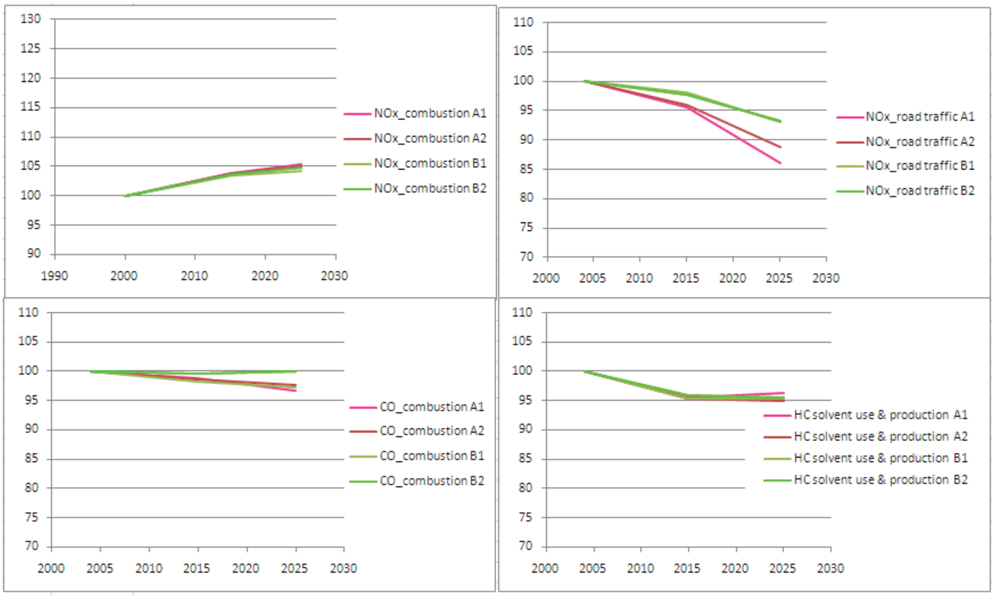

Fig.17: Emission projections taking into account the human activities related to land use (AIT)

For NOx and CO emissions from small combustion and for NMVOC (HC) emissions from production and solvents the 4 different peri-urbanisation scenarios have a relative small impact on the development of emissions on an aggregated level for the EU-27. For these pollutants and source categories, all 4 PLUREL scenarios follow the general European trends. In may be concluded that settlement trends (alone) and associated land use change has a much smaller effect on emissions than other factors such as lifestyle, technology, industrial development. The “A”- scenarios show more distinct changes (either increase or reduction) than the “B”-scenarios, which indicates that a minor GDP growth will influence emission changes more than differences in spatial distribution of human settlement patterns.

For NOx emissions from road traffic there are significant differences of emission trends among the 4 scenarios on an EU-27 level. This indicates that emissions are expected to be triggered to a larger extent by differences in the spatial development.

- The “A”-scenarios indicate higher reductions of NOx emissions than the “B”-scenarios: the highest emission reduction is expected for A1 scenario “Hypertech”, caused (a) by increased economic growth and a concurrent higher emission mitigation impacts and (b) by greater urbanisation, concentrating more population in the cities, which may reduce traffic growth. The A2 scenario “Water world” projected a somewhat lower decrease of NOx emissions as effect of reduced peri-urbanisation and less economic growth than in scenario A1.
- The “B”-scenarios show lower emission reductions that the “A”-scenarios; caused by a lower economic development, which leads to lower technological development.

4.2 Spatial trends of the spatial framework conditions

The following figures depict (a) the baseline situation regarding population distribution, peri-urban population share, peri-urban settlement share and (b) the changes as expected for the PLUREL scenarios. The PLUREL scenarios provide indicators for changes in the population and settlement structures and thus emission-generating human activities. The change patterns for each of the scenarios show certain hot spots, with certain differences from the average development.

a.1. Current Population densities (Fig. 18)

- A transect ranging from UK, BeNeLux, Germany to Italy shows the highest population densities in the respective NUTSx regions. Further hot spots can be observed in southern Poland, in the Czech Republic and generally in capital regions (Helsinki, Dublin, Paris, Lyon, Lisboa, Madrid, Barcelona, Vienna, Budapest, Bucuresti, Athens, etc.)

a.2 Population changes in PLUREL scenarios (Fig. 19)

- The highest (relative) growth rates are expected in Western Europe: Ireland, UK, France and Spain. Some further regions show also significant growth: southern Scandinavia, the Netherlands, southern Germany, parts of Austria and Northern Italy.
- A distinct decline is expected for Eastern countries in Europe: regions in the Baltic countries, East Germany, Hungary, and Romania.

The differences between the scenarios are expected from a European view to be rather small:

- The scenarios A2 and B2 show a growth concentration in the Southern regions in France and along the Spanish Mediterranean coast, experiencing distinct acceleration of peri-urbanisation.
- Scenario B1 shows additional growth in scattered NUTSx regions with higher peri-urbanisation ratios in Western and Central France.

b.1 Current Population in peri-urban sub-regions (Fig. 20)

- The transect with the highest share of peri-urban population ranges from UK to Italy, passing Benelux, Germany and Austria. Further hot spot areas are a large part of Poland, Northern Portugal, parts of Greece and NUTSx regions around capitals like Dublin, Paris, Madrid, Budapest, and Bucuresti.
- Low shares of peri-urban population are observed in the scarcely populated Nordic and Baltic countries, in Romania, Spain and the more rural parts of central France, Ireland and Scotland.

b.2 Changes of population in peri-urban sub-regions in the PLUREL scenarios (Fig. 21)

The changes in the shares show the peri-urban deviations from the overall population dynamics in the NUTSx regions. If the changes remain little the peri-urban population change follows the general population dynamics. If the changes are high, the peri-urban dynamics are expected to be more pronounced than the urban or the general population dynamics in the region.

The growth and decline patterns in Europe follow in general the patterns for the total population.

- Highest (relative) growth rates are expected in Western Europe: Ireland, UK, France and Southern Spain. Some further regions with growing peri-urban population are: Southern Scandinavia, the Netherlands, Southern Germany, Austria and Northern Italy.
- A distinct decline is expected for Eastern European countries: the Baltic countries, East Germany, Hungary and Romania.

The differences between the scenarios are – from a European view - again expected to be small:

- The scenarios A1, A2 and B2 exhibit a growth concentration along the Mediterranean coast in France and Spain and some moderate growth Southern parts of the Scandinavian countries.
- Scenario B1 shows a slightly diverse trend with less growth in some Scandinavian regions, additional growth in scattered regions in Western France with less pronounced peri-urban growth concentration in Southern coastal France.

- Distinct additional decline can be observed for Southern Italy in scenario A2, B1, in Atlantic Spain in Scenario B1.

Generally speaking it can be observed that the regions with population decline will experience a shrinking share of peri-urban population – there the population will remain more concentrated in the centres; in dynamic regions there will be an increase of the shares of peri-urban population; in such regions, urban population will move out into the peri-urban areas.

c.1 Current Share of peri-urban artificial surface (Fig. 22)

The share of peri-urban artificial surface relative to the total artificial surface indicates the importance of suburbanization within the regoins. The overall patterns follow to some extent the population distribution pattern. As the relative shares of peri-urban artificial surface are generally higher than shares of the peri-urban population it can be assumed that the artificial surface always grows faster than the population.

- A transect with highest shares of peri-urban artificial surface ranges from UK to Northern Italy, passing BeNeLux and Germany. Further hot spots are throughout a large part of Poland and North Portugal. The capital areas addressed before show a different pattern which let assume that those are more affect by sprawl in dispersed settlement, which are not identified as artificial surface.
- Low shares of peri-urban artificial surface are estimated in the Nordic and Baltic regions, in East Germany, in the Czech Republic, Southern Slovakia, Hungary, Romania, in central Spain and in some more scattered regions in central France, further in central Ireland and Northern Scotland.

c.2 Changes of peri-urban artificial surface in PLUREL scenarios (Fig. 23)

The changes in the shares show the peri-urban deviations from the overall land use dynamics in the NUTSx regions. If the changes remain little the peri-urban artificial surface change follows the general trend in the region. If the peri-urban artificial surface share is expected to increase, the peri-urban compartment let expect more dynamics than in the overall region

The expected changes of peri-urban artificial surface in the four PLUREL scenarios show somehow different patterns as even in areas in which the population is likely to shrink there is seemingly no decline of the share of peri-urban artificial surface.

- Highest (relative) growth rates are likely in the well known transect: ranging from England, Netherlands and (western) Germany to Northern Italy.

The differences in the dynamics between the four scenarios are rather explicit:

- The “A”-scenarios show similar patterns and indicate the highest increase of peri-urban artificial surface shares (above 10%-points), concentrated in some regions of the transect addressed above. Some regions around larger urban centres (Krakow, Warszawa, Budapest, Marseilles) show also higher increase (5-10%-points)
- The “B- scenarios with show a less pronounced growth of the proportion of the artificial surface in the peri-urban compartments.

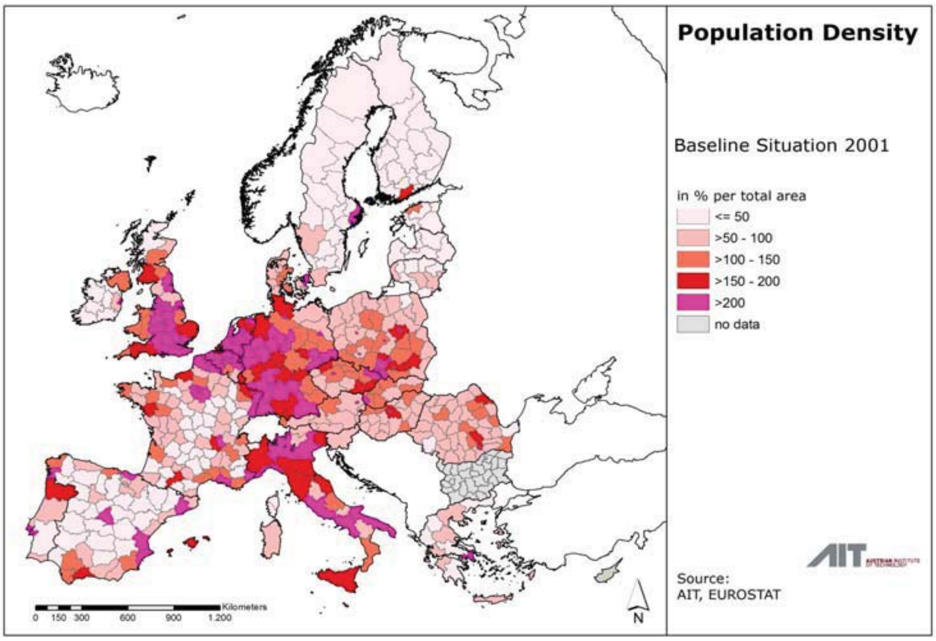

Fig. 18: Population densities per NUTSx region 2001 (Data from EUROSTAT)

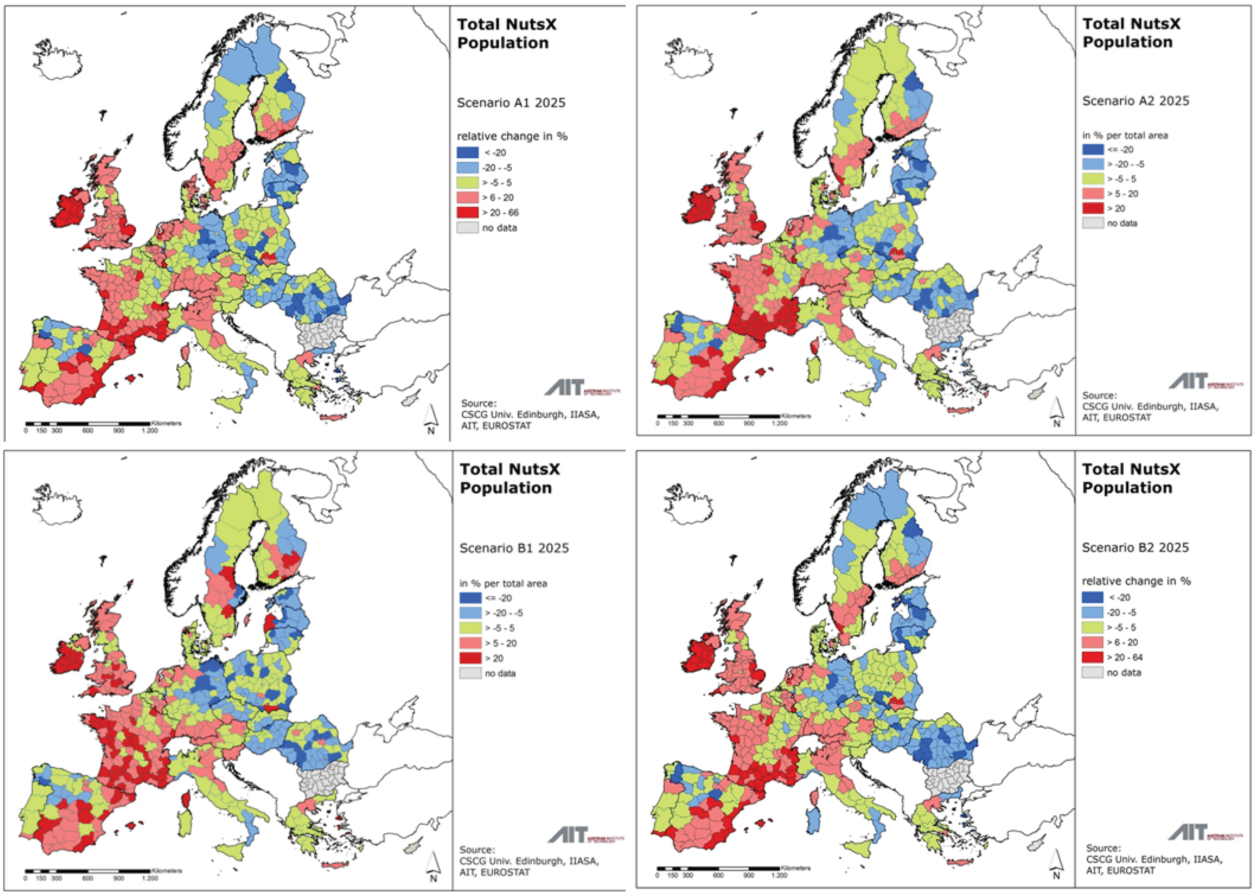

Fig. 19: Relative Change of population 2001- 2025 for PLUREL scenarios (Data from AIT & IIASA)

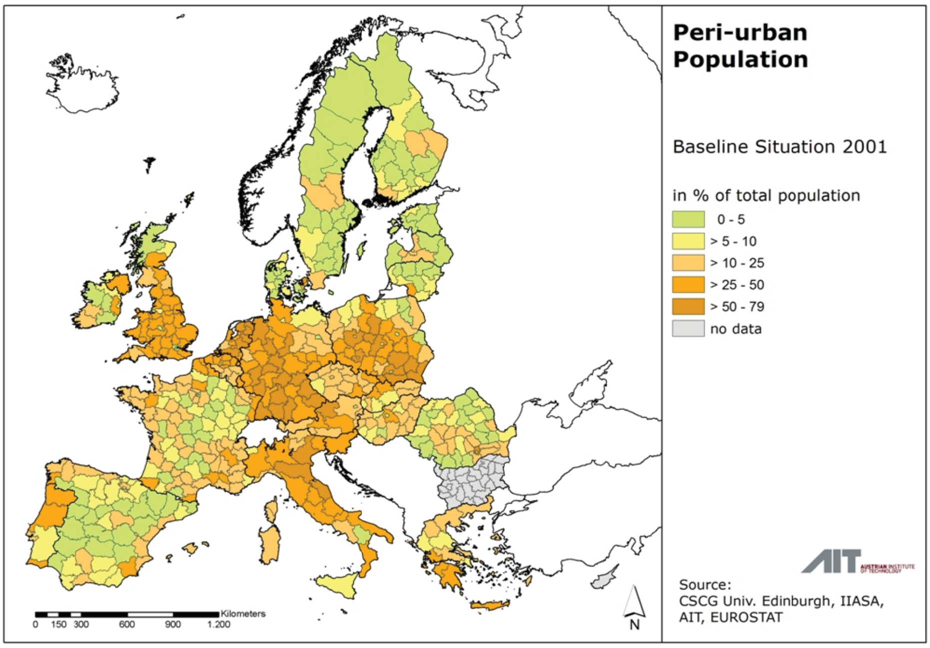

Fig. 20: Relative share of peri-urban population on total population 2001 (Data from EUROSTAT & JRC)

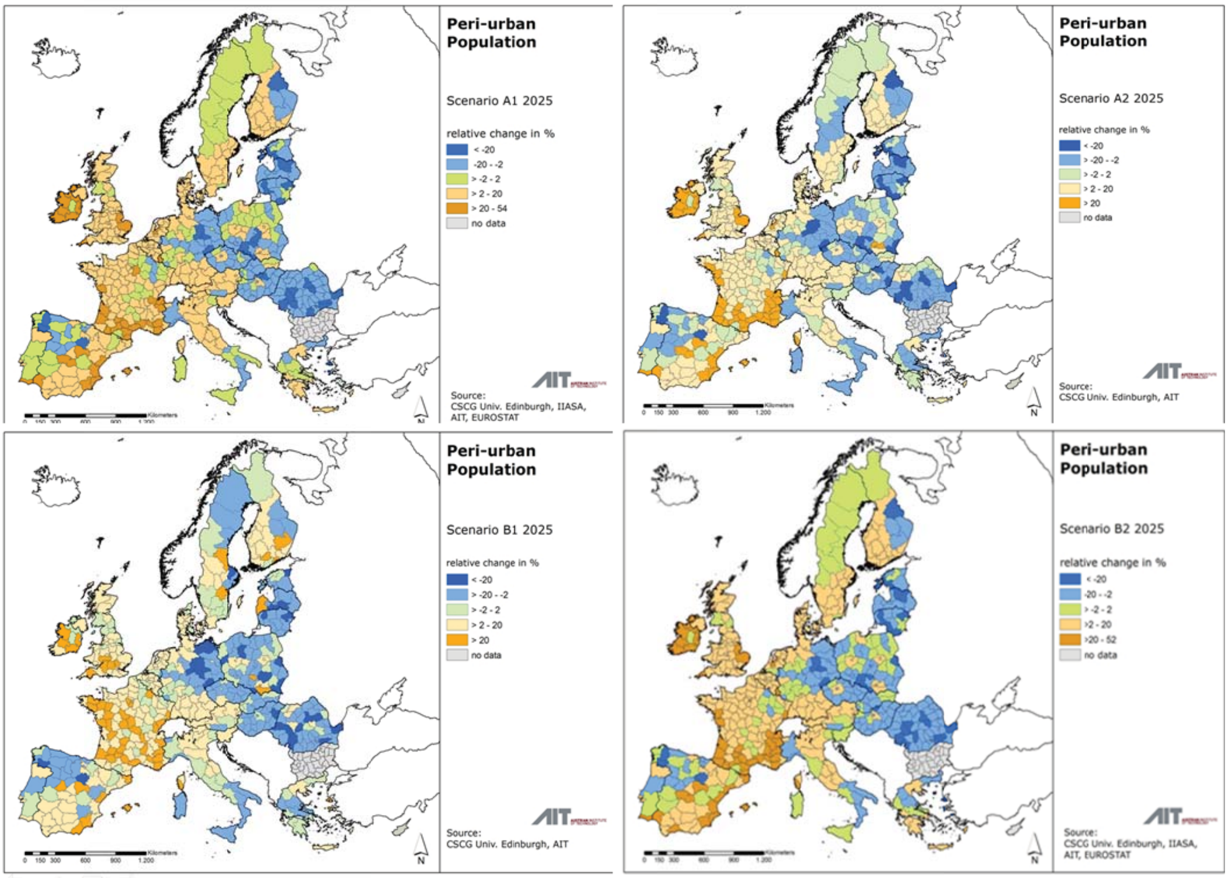

Fig. 21: Change 2001 - 2025 of the relative share of peri-urban population on total population for the PLUREL scenarios in %-points (Data from Univ. Edinburgh, allocation to peri-urban: AIT)

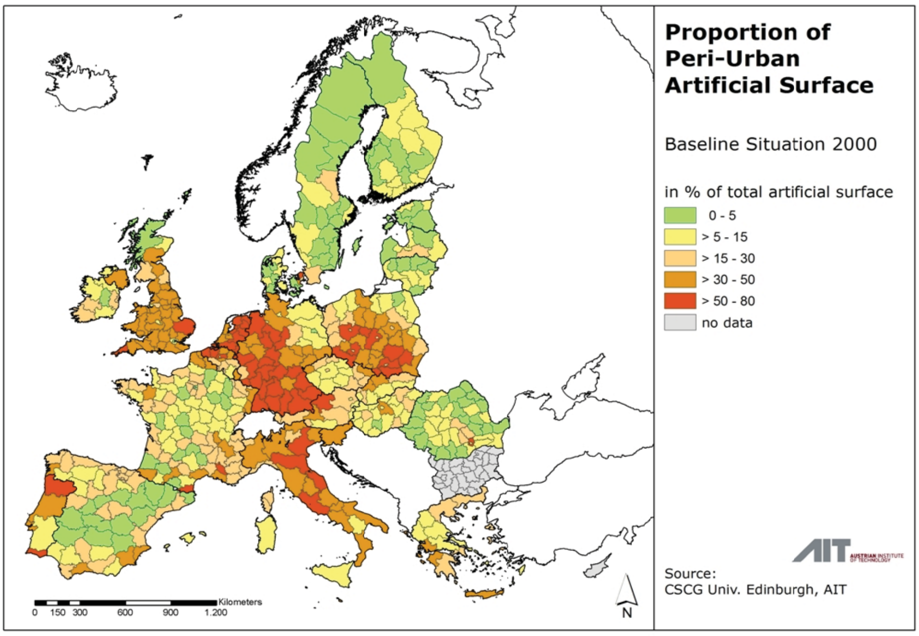

Fig. 22: Relative Share of peri-urban artificial surface on total artificial surface area 2000 (Data from Univ. Edinburgh, allocation to peri-urban: AIT)

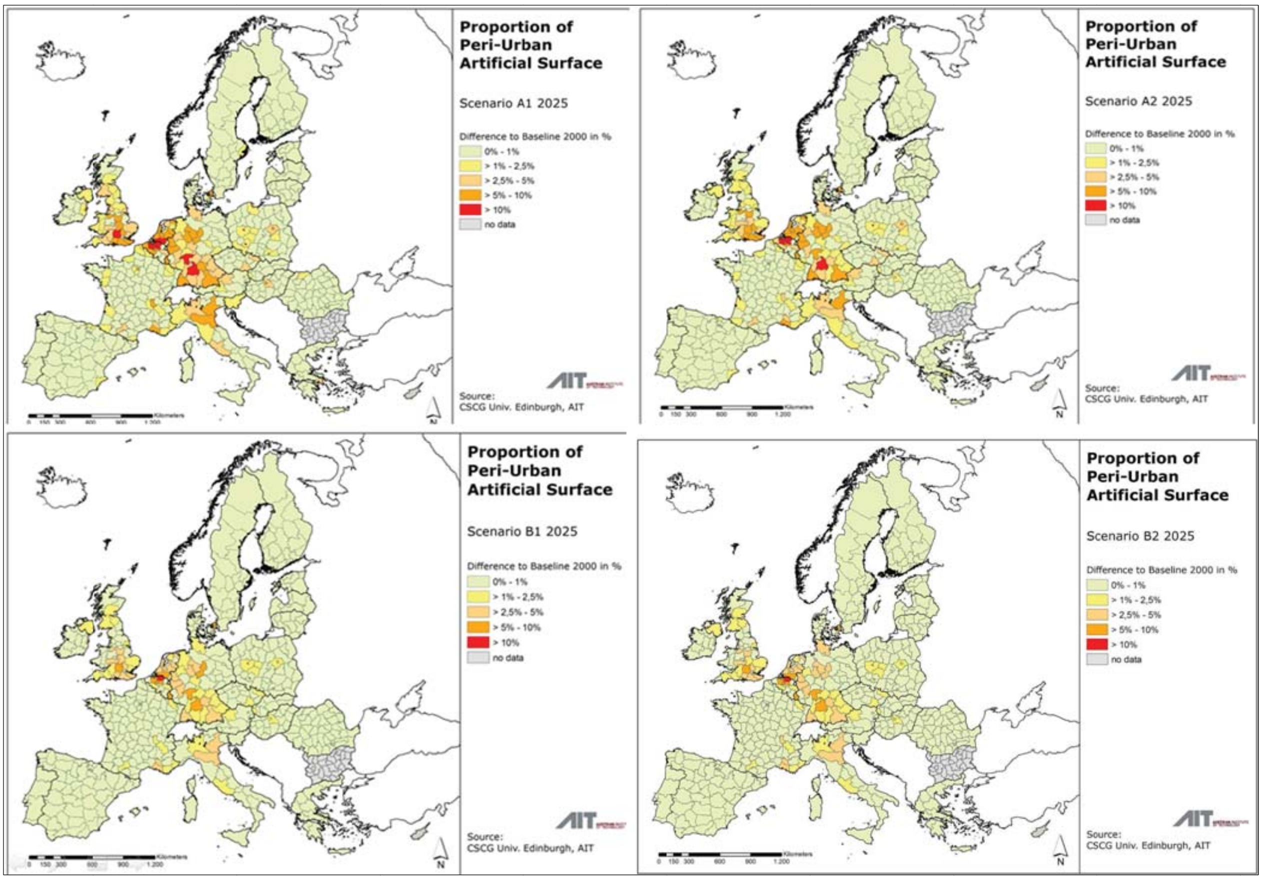

Fig. 23: Change 2001-2025 of the relative share of peri-urban artificial surface on total artificial surface area (Data from Univ. Edinburgh, allocation to peri-urban: AIT)

4.3 Air pollutant emission trends

The maps below visualize the overall results of the (statistical) response functions that describe the effects of changing population, GDP and settlements patterns on air pollutant emissions. As in any spatial model none of the local situations is "true" because the exact local particular situation is never known, but it is expected that all overall regional trends are properly reflected through the spatial relationships between land use and air pollution.

The emissions from pollutants and emission sources categories chosen for our model are expected to be generally sufficiently related to urbanisation as well as peri-urbanisation. For instance CO and NOx emissions from small combustion come to a large share residential and institutional heating, NMVOC emissions from production and solvent use are also significantly related to settlements and human activities. NOx emissions from road traffic emissions reflect the effect of human interactions between and within the settlements.

4.3.1 NOx emissions from road traffic

Figure 24 depicts the baseline situation, namely the NOx emissions from road traffic on the level of 50x50 km EMEP cell raster.

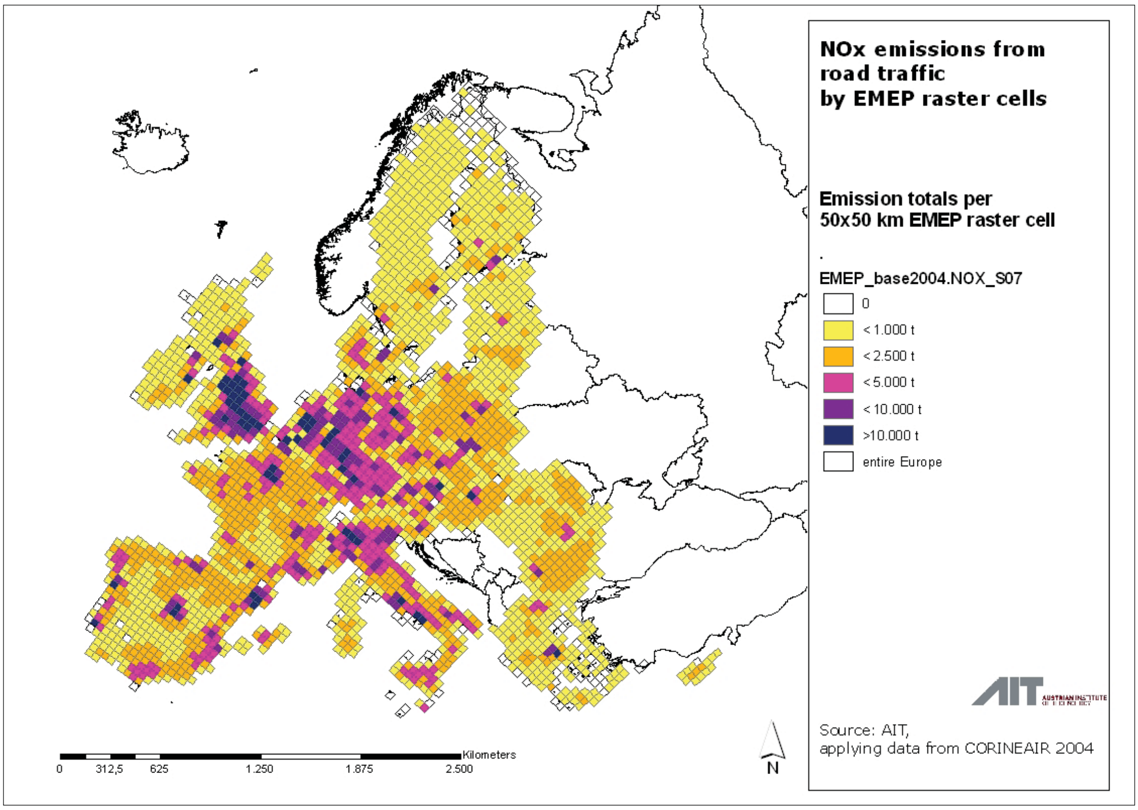

Fig. 24: NOX emissions (2004) from road traffic, (EMEP, AIT)

The modelled local pattern does not completely match the reality, because of local differences of influence, causing local deviations. But it is expected that the overall pattern as reflected through the spatial relationships between land use and air pollution, show the right trends.

Fig. 25 shows the deviations between the NOx emissions from road traffic as estimated by the response functions and the EMEP/CORINAIR emission data. While in many parts of Europe the deviations are small (indicated by pale yellow color), in some parts there are high deviations: the model underestimates the situation in some regions, particularly in Spain, but also in a central transect between England, BENELUX, Germany, Austria and Italy. This is possible caused by a different spatial structure and or different traffic structure. The model overestimates the situation in large regions in the northern and southern remote areas of Europe (Scotland, Scandinavia, Portugal, Greece).

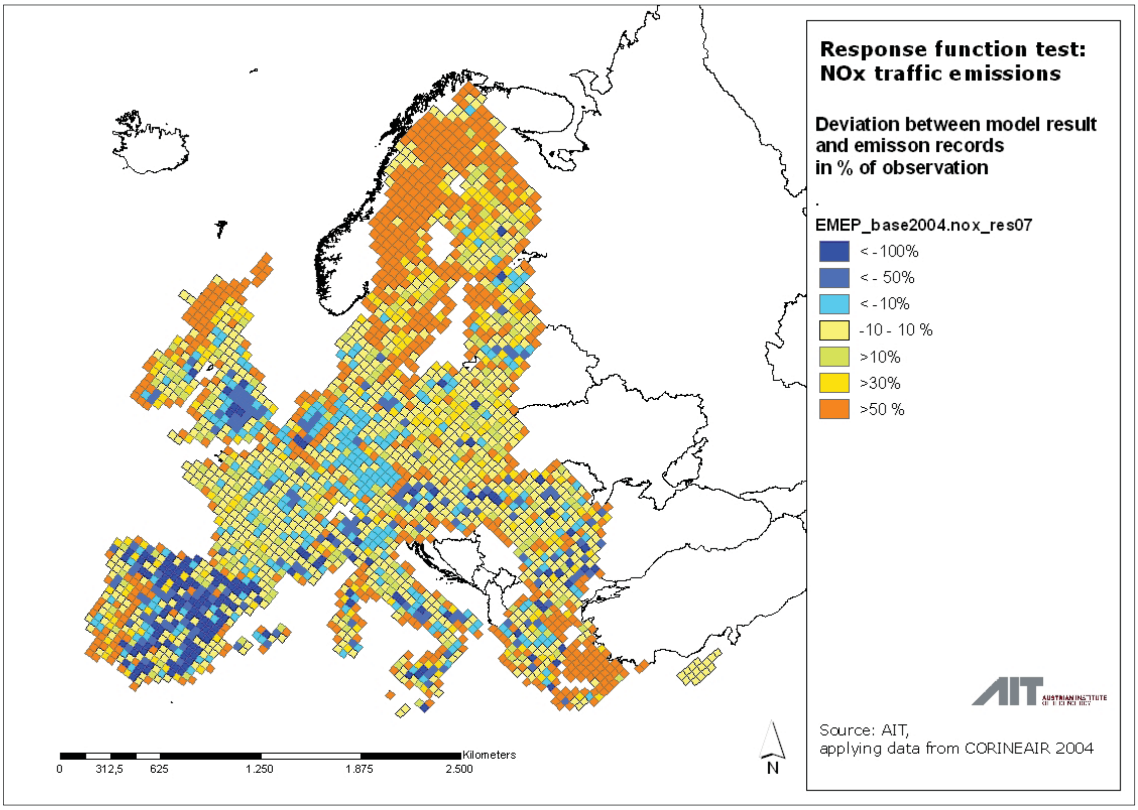

Fig. 25: NOX emissions (2004) from road traffic, deviation between recorded data and model results (AIT)

Figures 26-29 summarize the spatial dimension of expected NOx emissions from road traffic in the four PLUREL scenarios.
The summary results show that for NOx emissions from road traffic, there are relatively high differences among the four PLUREL scenarios (cf Figure 17). The reason for this is that (absolute) share of the urban versus the on peri-urban population as well as the parts of the settlement area related to the sub-region compartments have a much higher impact on the NOx emissions from road traffic than on the emission pollutants/source combinations.

Both “A”-scenarios show higher reductions, caused by a faster economic development (expressed as higher GDP):

Scenario A1 “Hypertech” consists of economically dynamic areas with a predominant development of the urban sub-regions with a lower growing peri-urban sub-region, leading to lower traffic requirements and fewer emissions. The areas with highest reductions can be observed in a central European transect which also has the highest increase of peri-urban artificial surface, supported by slow population growth , ranging from England, BeNeLux, Germany to northern Italy. Various other European areas show less reduction, only in a few regions an increase will be expected – either because of less economic development hindering to renew the car fleet or because of growth of population – which is the case along Spanish and French coastal areas.

A2 scenario “Water world” shows a similar reduction pattern as the A1 scenarios, but with a lower reduction of NOx emissions from road traffic. This is an effect of a lower economic growth and less peri-urban growth - than in scenario A1.The Scandinavian and South-eastern regions and other less urbanised, more rural regions show generally less emission reduction due to still little baseline traffic and transportation emissions. Some regions show an increase of NOx emissions; these might be modelling artefacts, caused by the NUTSx delineation problems that result in “incomplete” rural urban regions with unrealistic proportions of RUR sub-regions and untypical change indicators.

Both “B”-scenarios show a lower reduction of NOx emissions from road traffic. This is due to a lower economic development and different population dynamics. Distinct differences in emission reduction between the A and the B scenarios can be experienced in Western Europe (UK, Ireland, France, and Spain). This seems to be caused by increasing population that causes over-proportional increase of traffic.

Scenario B2 “Social fragmentation” shows a higher emission reduction than scenario B1 in central France and in remote regions in Greece and Italy; on the other hand, there is a distinct increase of emissions in southern and western France, in southern Spain, and in parts of Ireland and England.

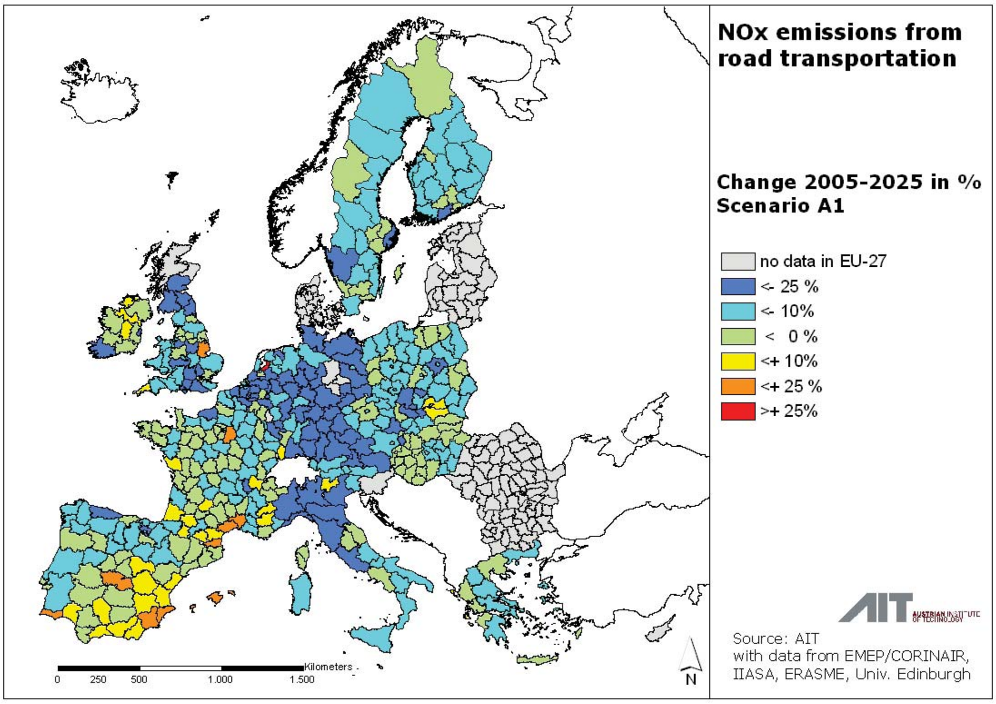

Fig. 26: Relative change 2005-2025 of NOx emissions from road traffic in PLUREL scenario A1 (AIT)

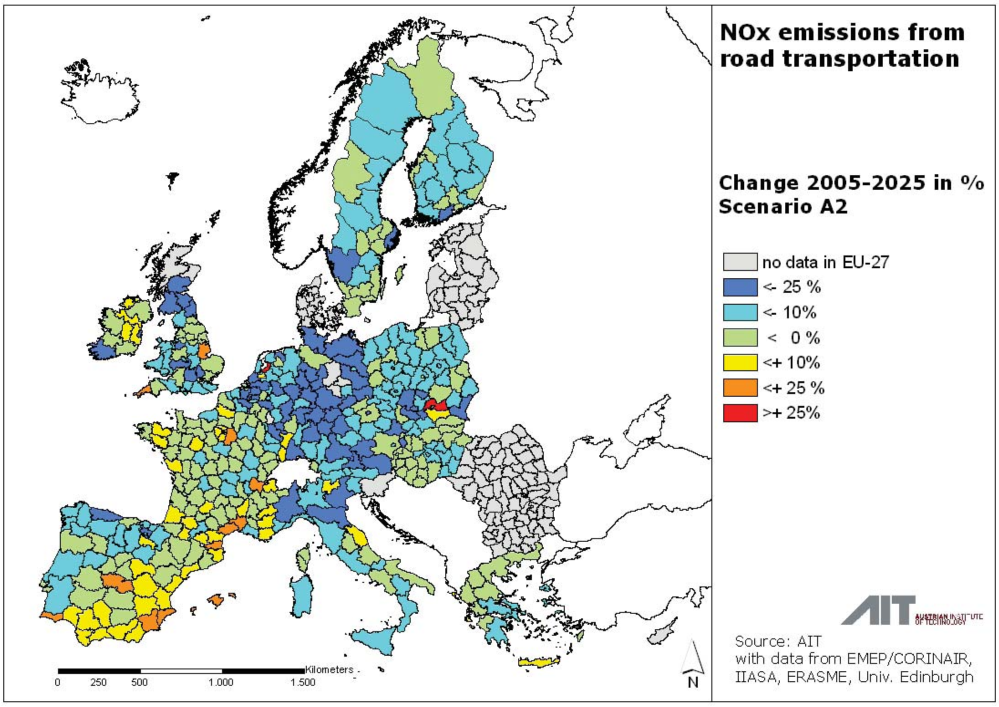

Fig. 27: Relative changes 2005-2025 of NOx emissions from road traffic in PLUREL scenario A2 (AIT)

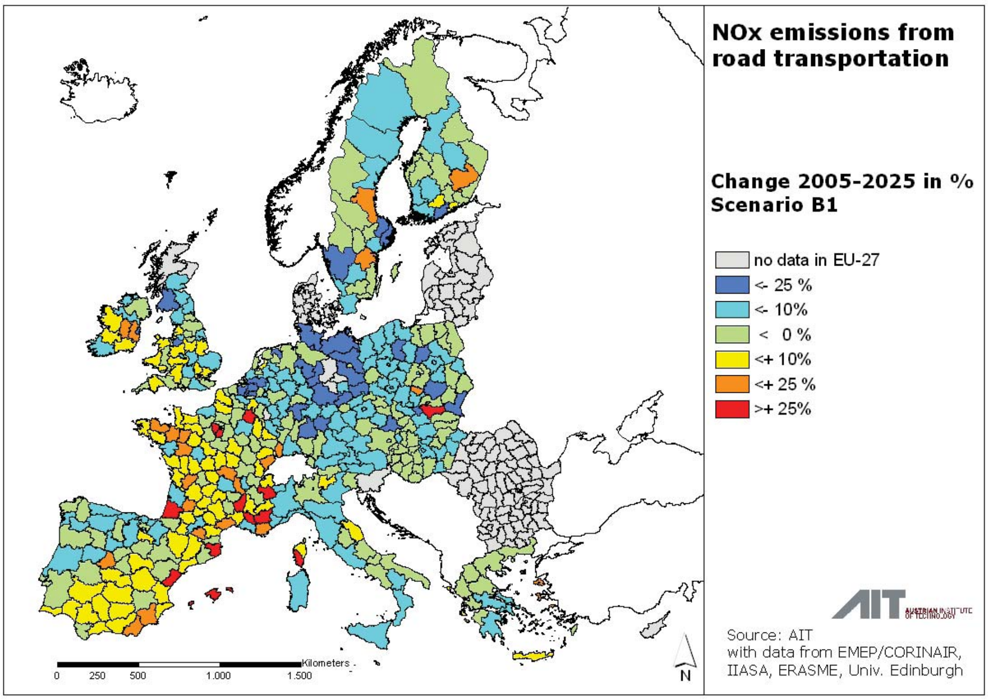

Fig. 28: Relative changes 2005-2025 of NOx emissions from road traffic in PLUREL scenario B1 (AIT)

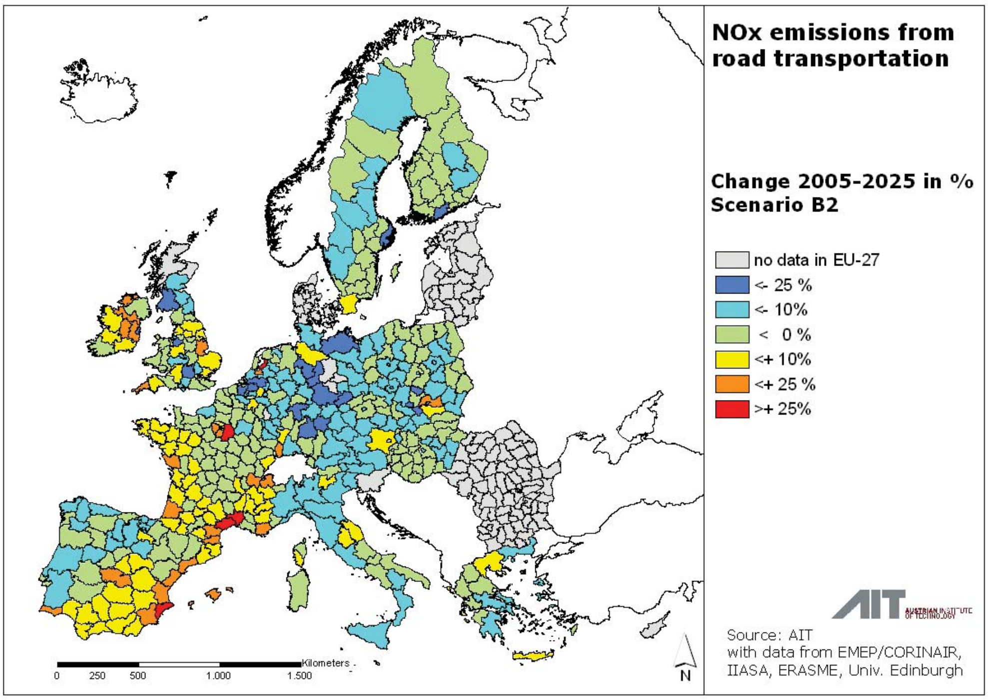

Fig. 29: Relative changes 2005-2025 of NOx emissions from road traffic in PLUREL scenario B2 (AIT)

In general the changes of NOx emissions from road traffic depend to some extent on the respective peri-urban development, but to a much higher extent on the economic development (expressed as GDP/cap) which facilitates faster use of emission control technologies.

4.3.2 NOx emissions from small combustion

Figure 30 shows the NOx emissions from small combustion sources in 2004 as extracted from the EMEP data sets.

Higher NOx emission densities are concentrated in densely populated areas in regions with significant heating requirements, particularly in wealthy economies where there are efficient fuels and heating systems. On the other hand, areas with low population densities (northern Europe), regions in southern Europe with lower heating requirements (Spain, Greece), and less developed economies (the Baltic and Romania) have relatively lower NOx emissions.

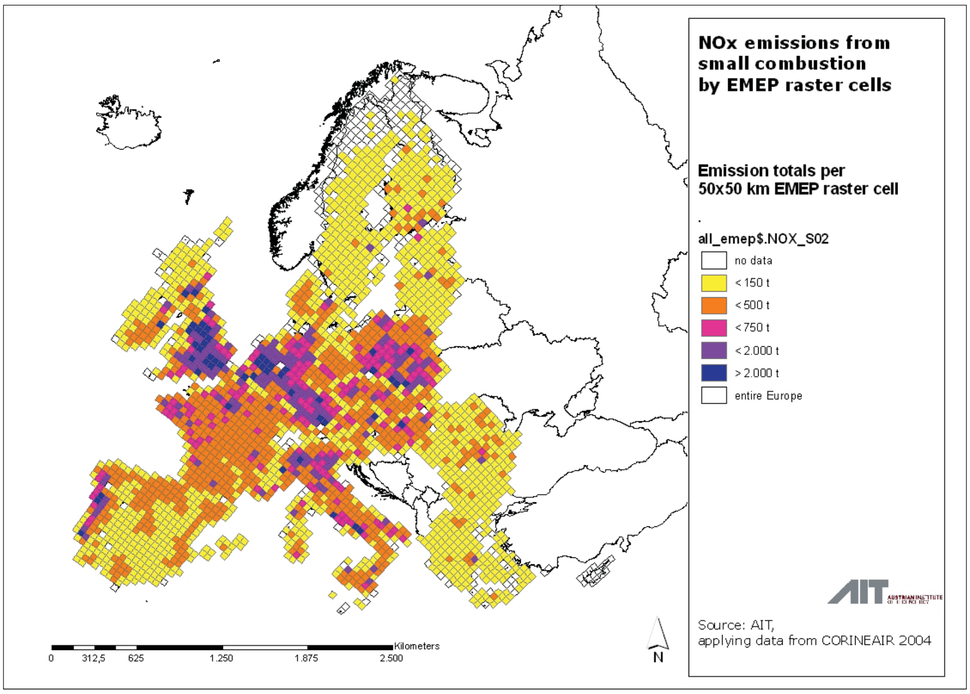

Fig. 30: NOx emissions from small combustion 2004 (AIT, Data from EMEP)

The differences of the spatial distribution of NOx emission from small combustion in the 4 PLUREL scenarios are small (Fig. 31-34). The effects of different heating types between the urban and peri-urban sub-regions turn out to be almost negligible. Thus there is seemingly no impact of different urbanization scenarios on air pollutant emissions.

In some regions (in eastern and southern Europe) there will be emissions reductions because of a lower population growth, particularly expressed in the "B"-scenarios). All other regions are likely to experience a low or moderate increase of emissions, due to using more energy-efficiency technologies, through which more NOx will be released. The biggest changes can be observed in the UK and in coastal regions. Only the B1-scenario shows less NOx increase in some (UK) regions, which may be effect of lower GDP growth and less peri-urbanisation effects.

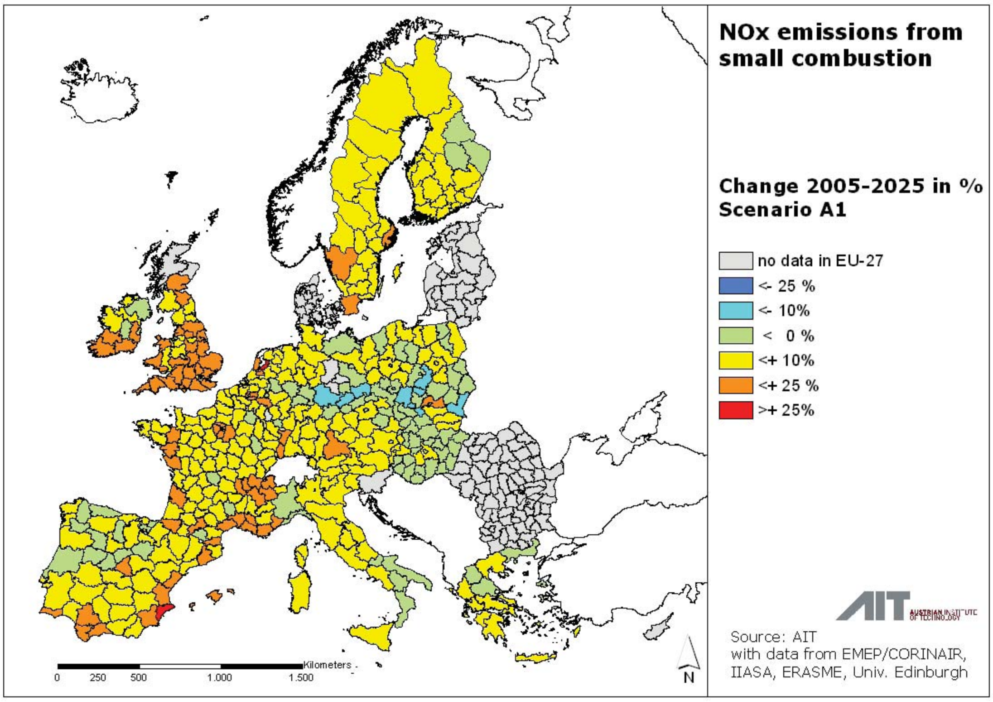

Fig. 31: Relative changes 2005-2025 of NOx emissions from small combustion in PLUREL scenario A1 (AIT)

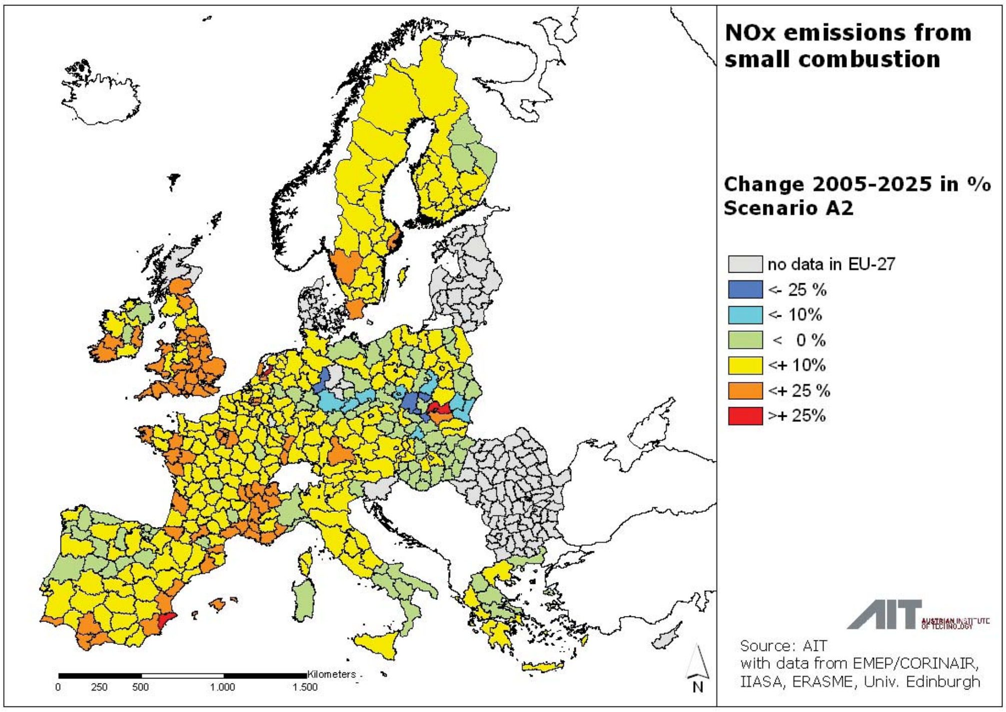

Fig. 32: Relative changes 2005-2025 of NOx emissions from small combustion in PLUREL scenario A2 (AIT)

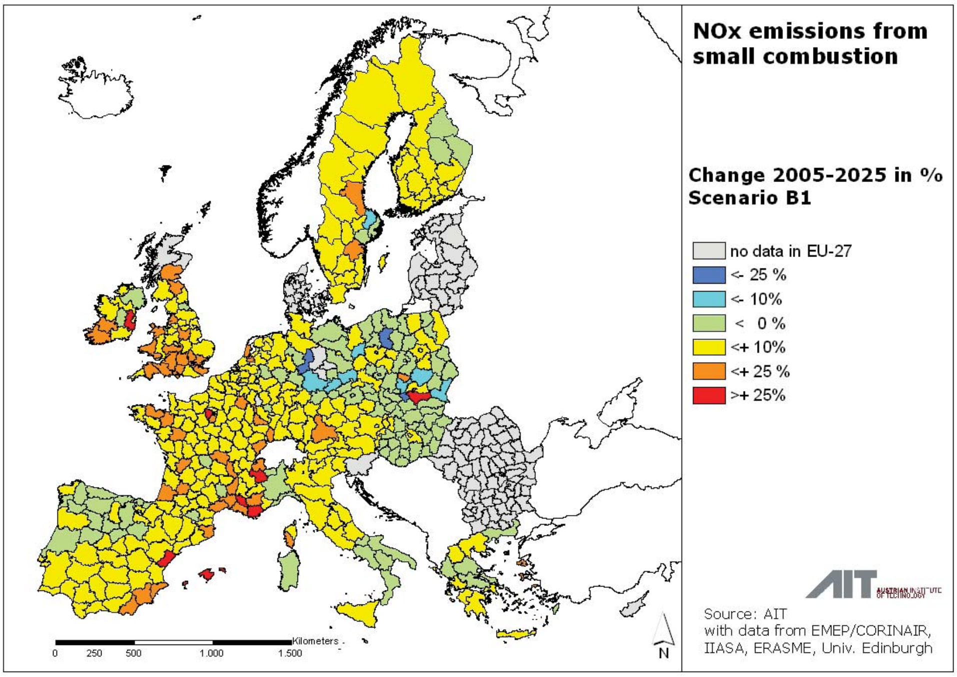

Fig. 33: Relative changes 2005-2025 of NOx emissions from small combustion in PLUREL scenario B1 (AIT)

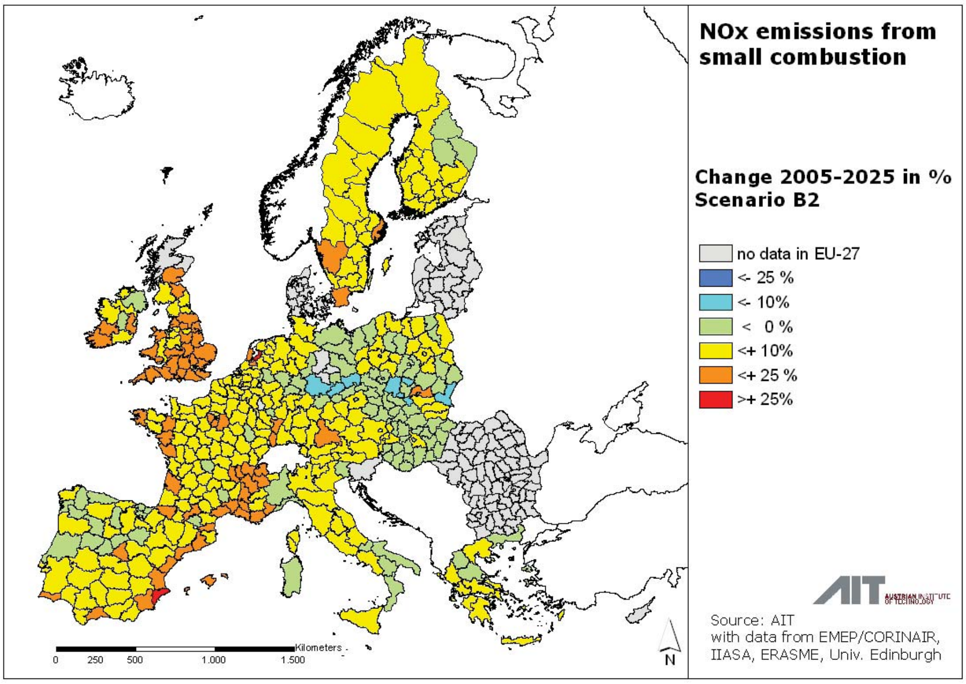

Fig. 34: Relative changes 2005-2025 of NOx emissions from small combustion in PLUREL scenario B2 (AIT)

4.3.3 CO emissions from small combustion

Compared to the patterns of NOx emissions, the CO emissions have a quite different distribution over Europe (Fig. 35). This is because of regional differences in predominating fuels and heating technologies.

Higher CO emission densities occur in densely populated areas with considerable heating requirements, particularly in rural regions (such as France, Poland, Romania, Bulgaria) and/or in less developed regions (such as Romania, Bulgaria) with a larger share of inefficient heating systems and or fuels (such as coal, wood or peat).

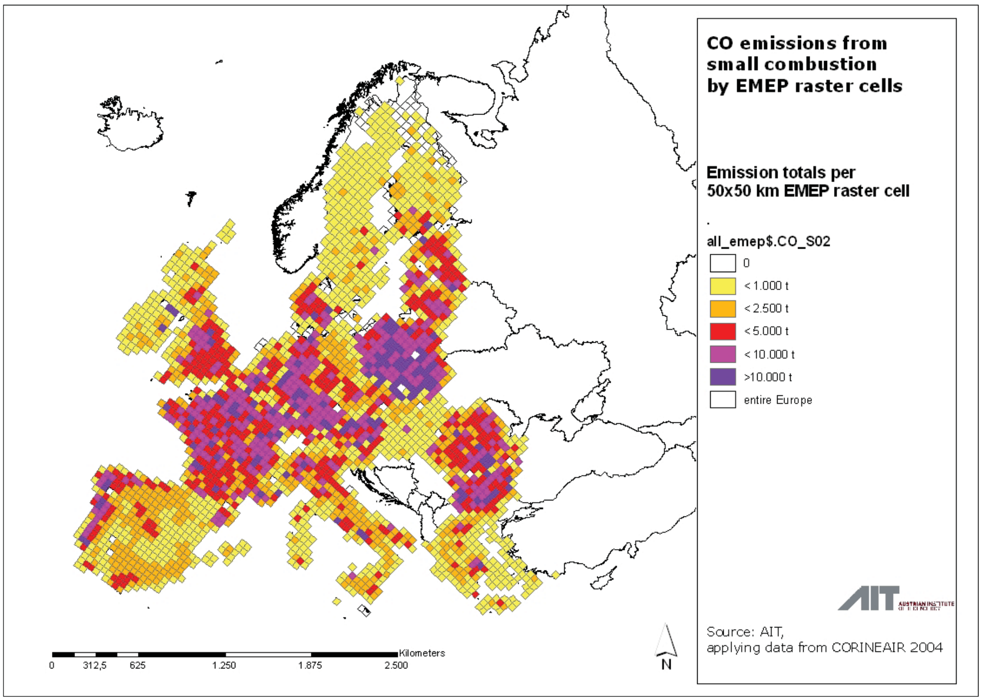

Fig. 35: CO emissions from small combustion 2004 (AIT, Data from EMEP)

The differences of the spatial distribution of CO emission from small combustion in the 4 PLUREL scenarios are small (Fig. 36-39). The effects of different heating types between the urban and peri-urban sub-regions turn out to be almost negligible. Thus there is seemingly no impact of different urbanization scenarios on air pollutant emissions.

Increase of urban artificial surface will cause a general reduction of CO emissions, as newly urbanized areas are expected to use less solid fuels and more efficient heating systems. On the other hand population change will drive the emission-generating activities; so that more emissions are expected in areas with population growth and lower emissions in areas with population reduction.

In all 4 scenarios the regional variability of emission changes is generally very high. In northern Europe, there are neighbouring regions in which the CO emissions from small combustion are expected to grow and fall by more than 25%. While the overall trend show a general decline, in some regions emission increase is projected. The pattern is rather patchy; a certain trend cannot be identified. One reason might be certain miss-proportions of artificial surface between the urban and peri-urban sub-regions because of the NUTSx borders, which might divide rural-urban regions into either urban or rural parts. A further reason might be accelerated population growth demanding more heating, which is supplied in rural areas more often by solid fuels, releasing (without certain mitigation technologies) more CO emission. This is the case in southern Spain, southern and western France, in Ireland, England, southern Scandinavia and some Alpine regions, where a significant increase of CO emission from small combustion is estimated.

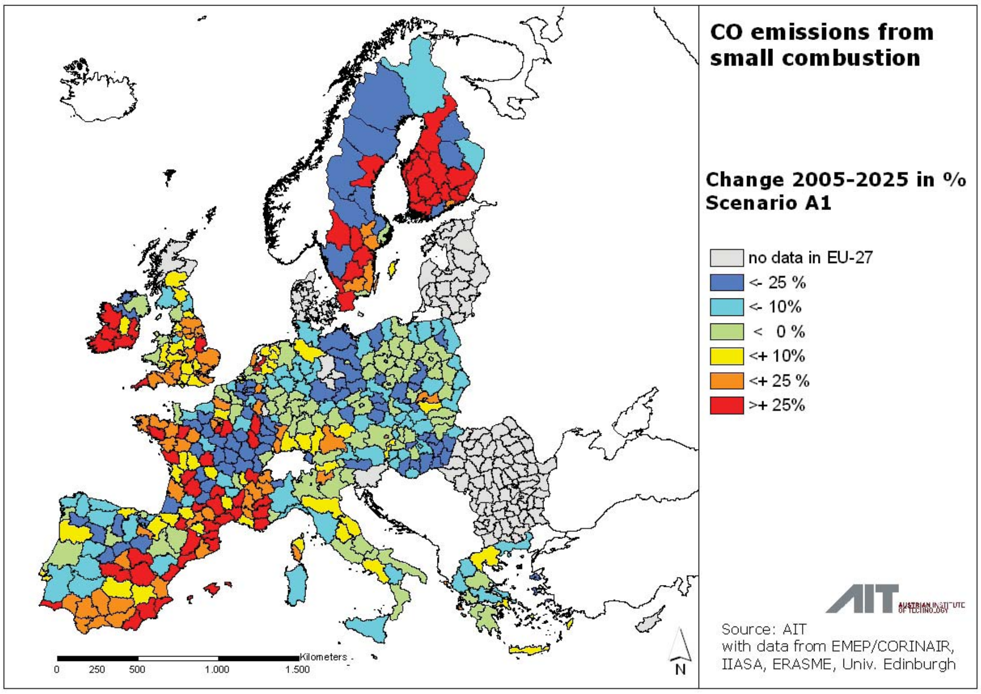

Fig. 36: Relative changes 2005-2025 of CO emissions from small combustion in PLUREL scenario A1 (AIT)

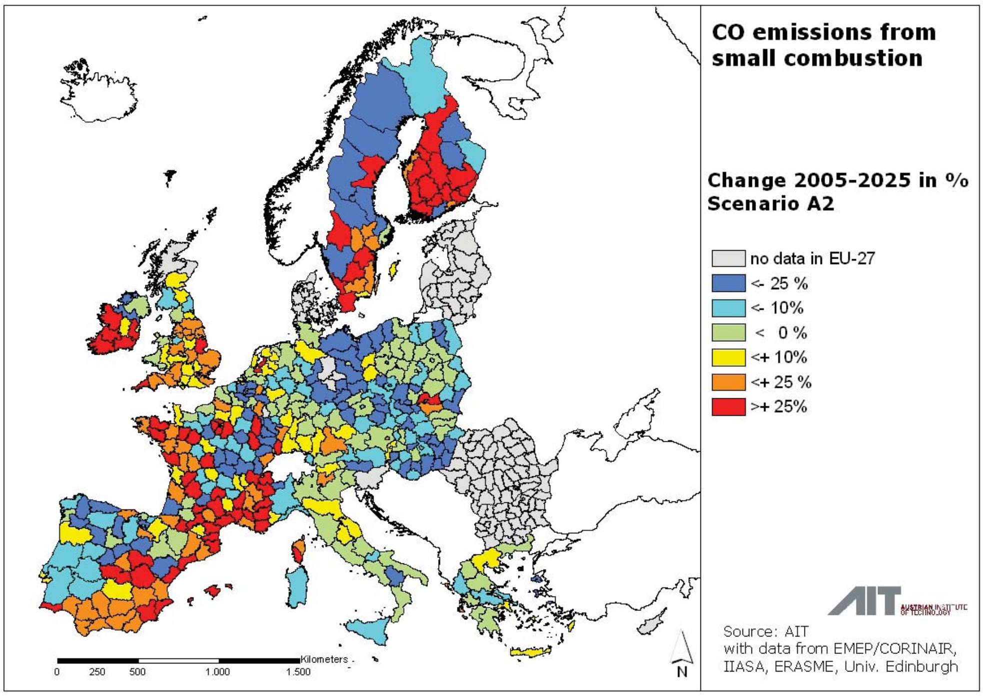

Fig. 37: Relative changes 2005-2025 of CO emissions from small combustion in PLUREL scenario A2 (AIT)

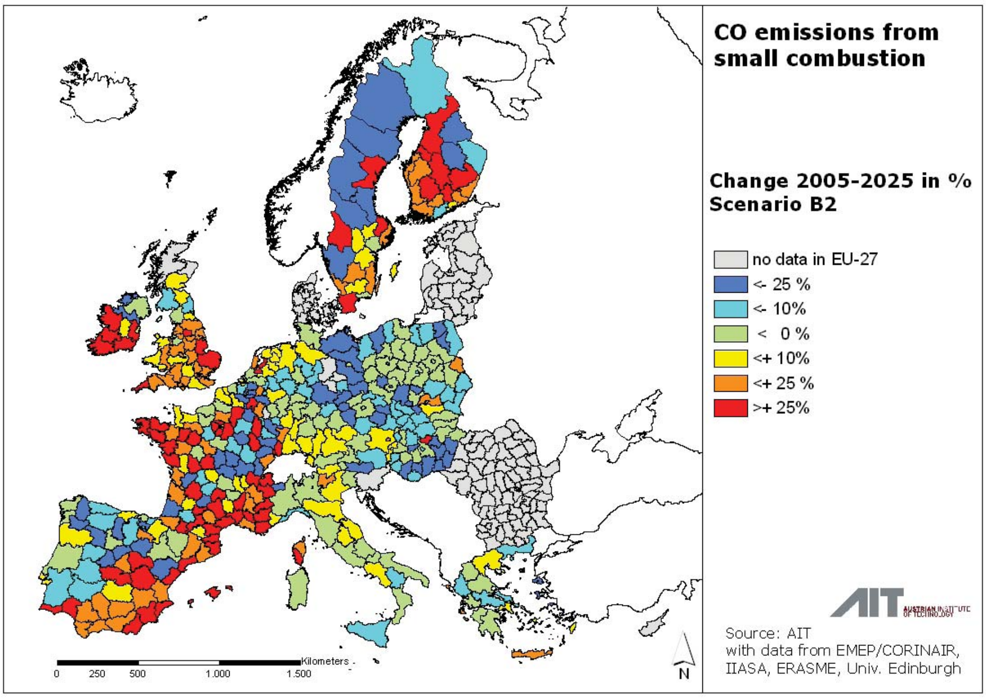

Fig. 38: Relative changes 2005-2025 of CO emissions from small combustion in PLUREL scenario B1 (AIT)

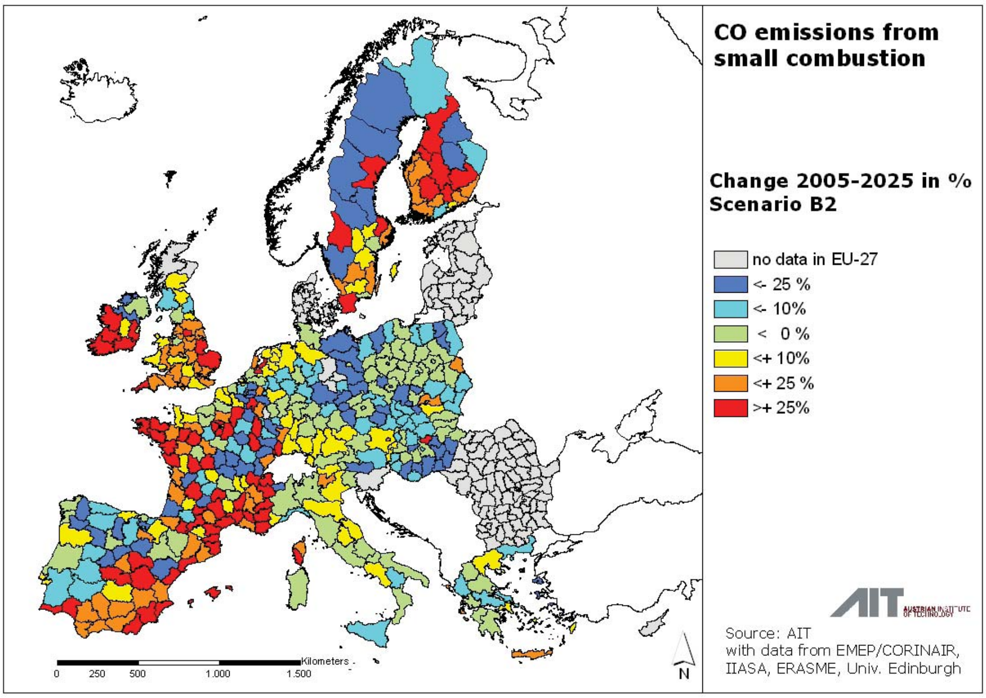

Fig. 39: Relative changes 2005-2025 of CO emissions from small combustion in PLUREL scenario B2 (AIT)

4.3.4 NMVOC emissions from solvent use and production

Areas of high NMVOC emissions are in the highly populated areas between southern England and northern Italy (Fig. 40). There are also relatively high emissions in Spain. On the other hand, the NMVOC emissions in northern, eastern and south-eastern Europe are rather low. While in northern Europe this can be explained by the low population densities, the low emission data in eastern and south-eastern European could also be a result of inventory methodologies. In general, the NMVOC emission seem to be released from different sources which do not follow population or settlement distribution patterns; thus the core data do not favour a proper emission projection as an effect of population and settlement trends.

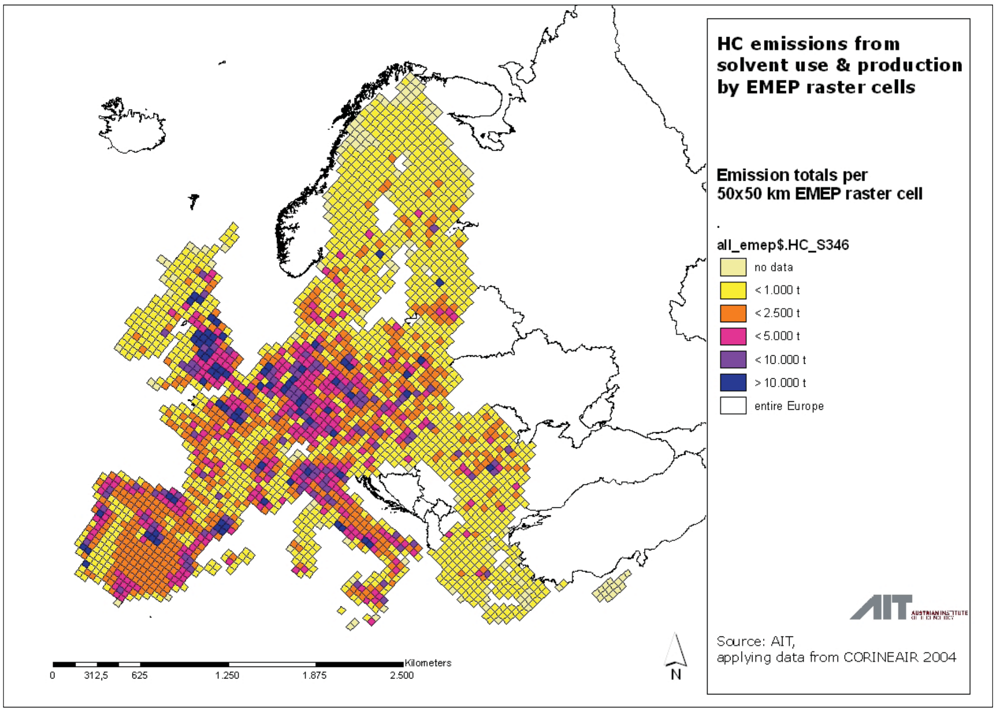

Fig. 40: NMVOC ("HC") emissions from solvent use and production 2004 (AIT, Data from EMEP)

As with NOx and CO emissions from small combustion sources, the differences of the spatial distribution of NMVOC emissions from solvent use and production in the 4 PLUREL scenarios are small (Fig. 41). In most regions, emissions trends tend to be around zero, releasing a rather stable pattern of regions marked in light green and yellow.

In terms of settlement distribution effects, the differences of the emission trends between the scenarios cannot be identified with certainty. The NMVOC emissions are released from a mixture of sources which show different shares in different regions and seemingly do not follow population or settlement distribution patterns. Accordingly, the response function has little explanation value and delivers almost stochastic results, which do not allow proper conclusions regarding settlement development effects. Thus the results for modelling NMVOC emissions from solvent use and production will not be further considered.

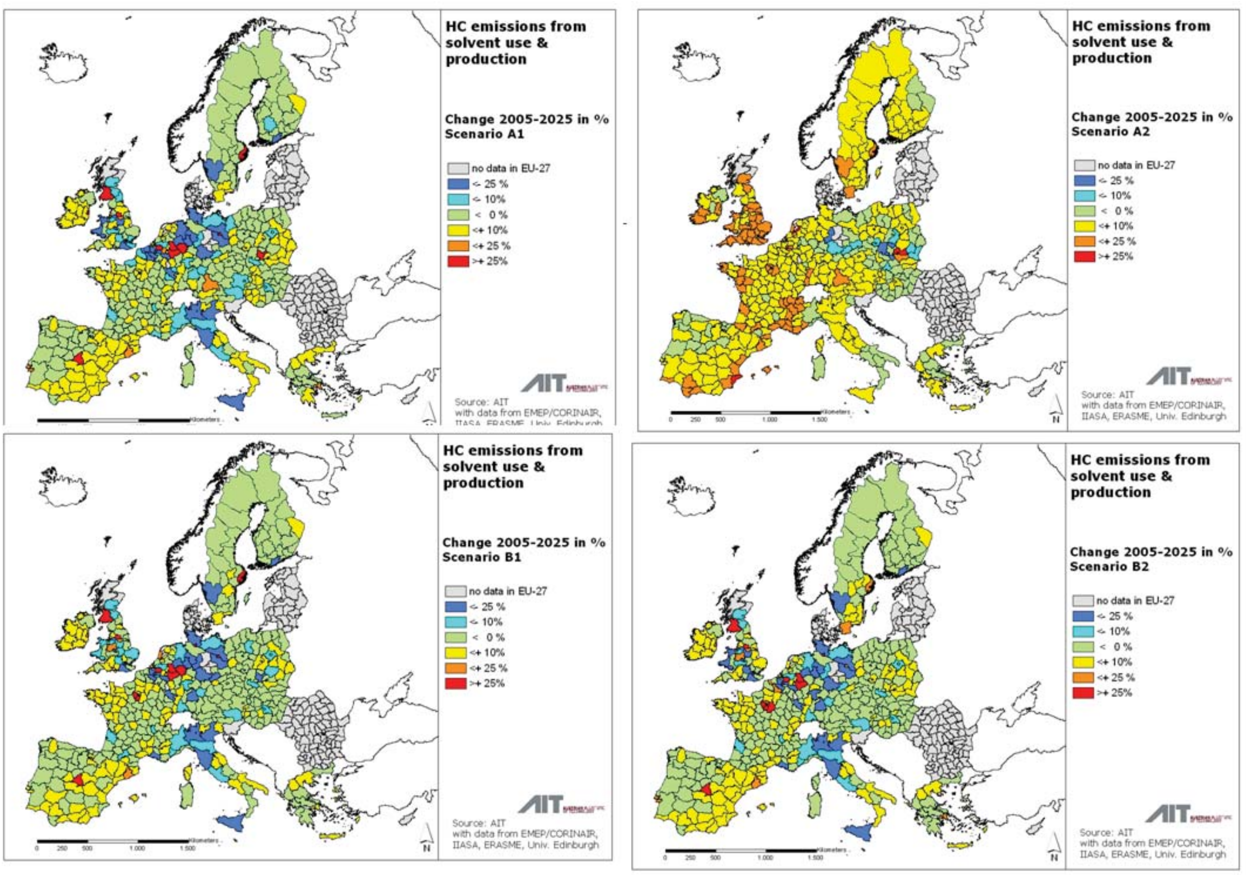

Fig. 41: Relative changes 2005-2025 of NMVOC emissions from solvent use and production in all PLUREL scenarios ((AIT, estimations not further considered because of low R^2 of the model results)

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