

National and regional emissions projections in Europe: methodology, tool and case studies

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ABSTRACT

The paper reports on emissions projections from an emission inventory for a specific year (*base year*) in different scenario.

First a Reference Scenario (do-nothing scenario), including all *planned and approved* actions taken at local, regional and national levels, is defined. In addition, this scenario will contain all socio-economical and technological trends, like gross domestic products, population trend, fuel use, etc. This Reference Scenario is used to compare all alternative scenarios, in order to define additional measures to achieve the air quality goals and related economic costs.

Projections are evaluated for different kind of sources (area, line and point) using drivers. Emissions for future years in a single area (e.g. municipalities), line (e.g. highway) or point (e.g. plant), related to a specific activity, are estimated starting from the base year emissions and using specific projections factors (drivers) of activity level and emission factors. Drivers can be related to the whole region or limited to selected areas, lines or plants. Finally, new additional emissions are evaluated for new planned plants, units of plants, roads or area emissions.

Drivers for activity levels and for emission factors can be related to multiple activities, plants and lines. As for example, regarding activities, the model can use trends of population, energy demand, industrial productions, road vehicle fleet, average mileage and fuel consumptions. In the paper the complete methodology, the software tool and the result of application, at regional scale, in Italy and, at national scale, in some Balkan countries are reported.

INTRODUCTION

Work on emissions projections at regional and national level in Europe dates more than ten years^{1,2}. This process in assessing future pollutants emissions is of key importance to assess the evolution of air pollution and to assess the respect of the legislative targets.

In the last years in European Union (EU) air quality directives³ have been introduced requiring Member States to divide their territory into zones related to air quality standards and to adopt plan and programs inside zones when air quality standards are not respected. The legislation introduces limit values: levels fixed with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole. EU has also introduced National Emission Ceilings for certain pollutants⁴ (NEC Directive) that sets upper limits for each Member State for the total emissions in 2010 of the four pollutants responsible for acidification, eutrophication and ground-level ozone pollution (sulphur dioxide, nitrogen oxides, volatile organic compounds and ammonia). A proposal to amend the NEC Directive is still under preparation and should set emission ceilings to be respected by 2020 for the four already regulated substances and for the primary emissions of PM_{2.5} as well.

The many variables involved in considering this development at different levels, from national scale to single pollutant source, are efficiently managed by the model **E²Gov Projections** developed by Techne Consulting and applied to many geographical areas in Italy and Europe, helping local and national authorities in planning future regulations.

In **Figure 1** the schema for emissions inventory and projections is resumed. In the following of the paper emission inventory fundamentals are recalled, emission projections methodology is introduced, software is presented and case studies are reported.

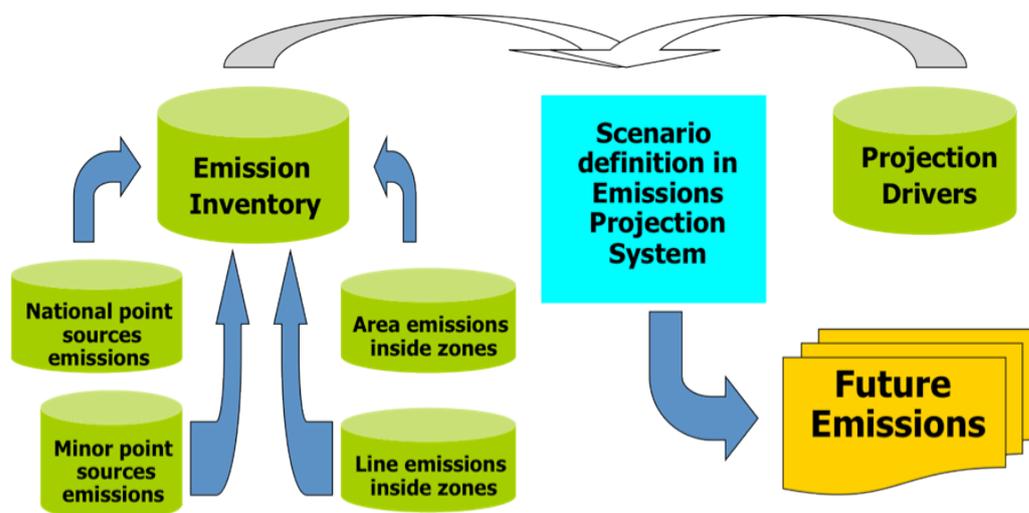


Figure 1 – Emissions inventory and projections schema

EMISSION INVENTORY

Nomenclatures

Activities taken into account are those related to the following 11 groups, according to Convention on Long-range Transboundary Air Pollution (LRTAP) SNAP classification (Table 1).

Table 1 – SNAP Classification macro-sectors

01 Combustion in energy and transformation industries	07 Road transport
02 Non-industrial combustion plants	08 Other mobile sources and machinery
03 Combustion in manufacturing industry	09 Waste treatment and disposal
04 Production processes	10 Agriculture
05 Extraction and distribution of fossil fuels	11 Other sources and sinks
06 Solvent and other product use	

Pollutants

Pollutants included in the inventories are:

- main air pollutants, namely nitrogen oxides (NO, NO₂), sulphur oxides (SO₂, SO₃), non-methane organic compounds (NMVOC), carbon monoxide (CO) and suspended particles with diameter less than 10 µm (PM₁₀) and than 2.5 µm (PM_{2.5}) and ammonia (NH₃);
- heavy metals (arsenic, cadmium, nickel, lead, chrome, mercury, copper, selenium, zinc);
- benzene, polycyclic aromatic hydrocarbons (benzo[b]fluorantene, benzo[k]fluorantene, benzo[a]pyrene, indeno[123cd]pyrene), other aromatics (hexachlorobenzene and polychlorinated biphenyls), polychlorinated dibenzodioxin and polychlorinated dibenzofuran;
- greenhouse gases: carbon dioxide (CO₂), methane (CH₄) and nitrogen protoxide (N₂O).

Sources classification

Point sources are stationary sources whose emissions exceed some fixed thresholds, differently set depending on the aim of the inventory. In order to compile a national inventory according to LRTAP, stationary emission sources with total annual emissions of at least one pollutant exceeding the thresholds listed in Table 2 are considered as Large Point Sources (LPS)⁶. In the same table thresholds used in local inventory in Italy, Montenegro⁷ and Albania are also reported.

Line/nodal sources are the main communication ways (roads, rivers, railways, and seaways) and nodes (ports, airports). The related emissions are considered as national totals for the national inventory, and localized over the territory in the local inventory.

Table 2 – Large Point Sources according to LRTAP Guidelines and in Local Emissions Inventories

Pollutant	National LRTAP Thresholds	Local Inventory Thresholds	units
SO _x	150	5	Mg
NO _x	100	5	Mg
CO	500	50	Mg
NMVOCs	100	5	Mg
NH ₃	10		Mg
PM _{2.5}	50	5	Mg
PM ₁₀	50	5	Mg
Pb	200	50	Kg
Cd	10	10	Kg
Hg	10	10	Kg
Other Heavy Metals		50	Kg
PAHs	50	50	Kg
PCDD/F	0.1		G
HCB	10		Kg
Benzene		50	Kg
CO ₂		5000	Mg

Area sources are all other sources which are below the emission thresholds established for point sources and/or whose emissions are spread over the territory. The related emissions are evaluated as national totals for LRTAP inventory. In the compilation of the local inventory they are allocated over the territory at District level.

Emissions estimation

The emissions are estimated using all available data obtained by direct surveys, statistical information and knowledge of the sources and through the software ad hoc developed (**ESGov Emissions**⁵), according to the methodology recognized at European level and thanks to the job of a team of experts.

In particular, the EMEP/EEA Air Pollutant Emission Inventory Guidebook 2009⁸ and the 2006 IPCC Guidelines for National Greenhouse Gas Inventories⁹ were applied.

Stacks emissions from point sources are calculated through the following formula:

$$E_i = 10^{-6} \cdot P \cdot g \cdot h \cdot C_i$$

where: P, hourly gas flow; i, pollutant; g, working days for year; h, working hours for day; C_i, average concentration of pollutant i.

Input data are validated for completeness and accuracy and declared emissions are compared with those estimated through the application of standard emission factors. This procedure is used to validate information and to complete data entering on existing pollutant emissions, even if no declaration by the industries is available. The same procedure is used for diffuse emissions from point sources (for example emissions from material handling).

The basic formula to calculate emissions from area and line sources is:

$$E = A \cdot F$$

where: A represents the activity indicator and F the emission factor, generally expressed in grams per unit of activity. The same methodology is used to evaluate point sources emissions where stack emissions are not available or not applicable.

In absence of direct activity indicators, it is possible to use indirect parameters that, because of their high correlation with the activity, allow almost reliable results to be obtained.

Specific models are used to estimate emissions from some sectors, in particular forests and forest fires, air, sea and road traffic, landfills, storage areas, etc.

EMISSION PROJECTION

Pollutant emissions projection is a key issue in an efficient environmental management; emissions coming from an inventory related to a specific year (the *base year*) can be forecasted for future years following a methodology summarized in the scheme of **Figure 2**.

The first step for a correct emissions projection is the creation of a Reference or Business as Usual (BAU) Scenario; this scenario will consider all *already planned and approved* measures, in order to respect air quality standards, taken at local, regional and national level. In addition, this scenario will contain all socio-economical and technology trends not related to measures strictly devoted to air quality, like gross domestic products, population, import-export of goods and so on.

This Reference BAU Scenario is used as a basis to which all alternative scenarios will be compared, in order to define additional measures for minimizing economic costs after air quality goals have been set.

An important example of an alternative scenario is the Plan or Mitigation Scenario; this kind of scenario will include all *proposed* measures directly related to air quality improvement, like introduction of renewable energy sources or emission abatement measures on selected industry plants and so on. The main difference with the Reference BAU Scenario is that the Mitigation Scenario must contain measures that will affect emissions in order to fully comply air quality standard, often counterbalancing Reference BAU Scenario trends that will produce an emission raise (like for example a raise in gross domestic product and consequently on emissions by higher production of goods)

Often a Reference or Mitigation scenario could provide different projection factors (here referred as *drivers*) for the same activity or pollutant source, in this case a single scenario will be created for every kind of projection factors. For example, if the gross domestic product (and other planned measures) will show three different forecasted trends, often referred as High, Low and Mid trends, three different Reference BAU scenarios will be created and consequently three different emissions trends in future years will be produced.

The forecasted emissions can then be used also as an input to computer-based dispersion models in order to find out direct impact of the aforementioned measures on air quality at national, regional and local level.

Methodology

Emissions projection is evaluated for different kind of sources: area, line and point. In the following paragraphs detailed methodology for every kind of them is reported.

Area emissions for future year (k) in a single zone (e. g. municipality) (n) related to a specific activity (i) are estimated starting from the base year (0) emissions and using specific projections factors (drivers) of activity level (a_{ik}), specific drivers for emission factors (f_{ijk}) for a selected pollutant (j), specific drivers for activities related to a selected zone (a^z_{ikn}), specific drivers for emission factors related to a selected pollutant (j) related to a selected zone (f^1_{ijkn}) and, if any, additional emissions foreseen for a selected activity in a selected zone k (E^z_{ijkn}):

$$E_{ijkn} = E_{ij0n} \cdot a_{ik} \cdot f_{ijk} \cdot a^z_{ikn} \cdot f^z_{ijkn} + E^z_{ijkn}$$

Line emissions for future year (k) for a selected line (n) related to activity (i) are estimated starting from the base year (0) emissions and using specific drivers of activity level (a_{ik}), specific drivers for emission factors (f_{ijk}) for a selected pollutant (j), specific drivers for activities related to a selected line (a^l_{ijkn}), specific drivers for emission factors related to a selected pollutant (j) related to a selected line (f^1_{ijkn}) and, if any, additional emissions foreseen for a selected line k (E^1_{ijkn}):

$$E_{ijkn} = E_{ij0n} \cdot a_{ik} \cdot f_{ijk} \cdot a^l_{ikn} \cdot f^1_{ijkn} + E^1_{ijkn}$$

Point source emissions for future year (k) related to a selected production unit (m) for a selected plant (n) related to specific activity (i) are estimated starting from the base year (0) emissions and using specific drivers of activity level (a_{ik}), specific drivers for emission factors (f_{ijk}) for a selected pollutant (j), drivers for activity related to the selected production unit (a^p_{kmn}), driver for emission factor of a selected pollutant (j) related to production unit (f^p_{ijkmn}) and, in case of new production unit or new plants, additional emissions for future year k (E^p_{ijkmn}):

$$E_{ijkmn} = E_{ij0mn} \cdot a_{ik} \cdot f_{ijk} \cdot a_{kmn}^p \cdot f_{ijkmn}^p + E_{ijkmn}^p$$

New additional emissions for point, line and area sources are used to simulate planned plants, planned units of a plant, planned roads and so on.

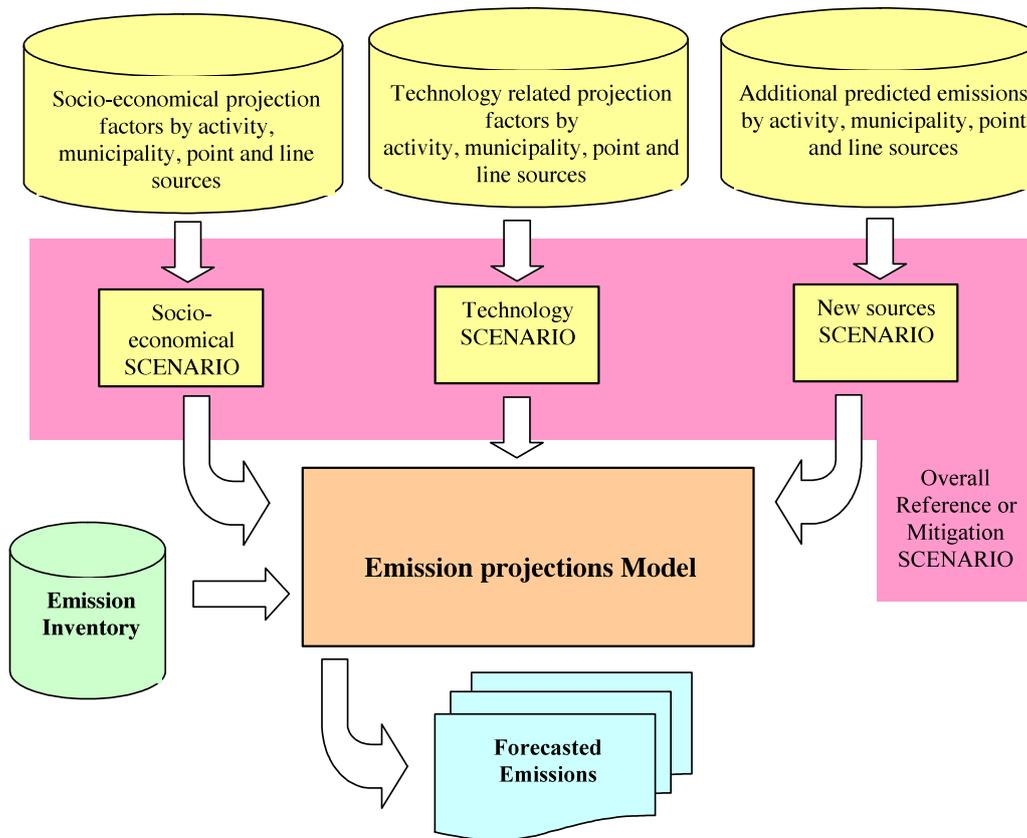


Figure 2 – Scheme for evaluating forecasted emissions

Drivers

It is possible to manage the following groups of drivers:

- Drivers for activity levels related to single activities, zones, lines, production units of industrial plants.
- Drivers for emission factors related to single activities, zones, lines, production units of industrial plants.
- Additional emissions related to single zones, lines, production units of industrial plants.

As for example, regarding activities, the model can evaluate:

- Trend of energy demand.
- Trend of industrial productions related to activities considered relevant for pollutant emissions in atmosphere.
- Trend of vehicle fleet, average mileage and fuel consumptions for road traffic.
- Trend of socio-economical variables related to pollutant emissions from household sector.

Drivers for activity levels and for emission factors can be related to multiple activities, plants and lines; for example the “population” driver can be used to forecast emissions coming from glue or paint applications in household as well as drivers related to fuel consumptions in residential sector, and sulphur content of distillate oil can be used for the projections of emission factors for sulphur dioxides in the industry and service sectors.

Besides, an abatement system for sulphur oxides can be applied to a single activity (e.g. power plants with output higher than 300 MWth) and to one or more production units related to another activity (e.g. power plants with output between 50 MWth and 300 MWth). The drivers are equal 1 in the base year.

Activity drivers a_{ik} are generally defined from economic variables values, V_{i0} at base year (0) and V_{ik} at future year (k), as;

$$a_{ik} = V_{ik} / V_{i0}$$

Typical examples of economic variables are:

- population,
- gross domestic product,
- agricultural production,
- wastes production,
- number of vehicles (cars, motorcycles, off road vehicles),
- number of takeoff/landing in the airports,
- tons of freight transported by road and sea,
- etc.

Technology drivers f_{ijk} are defined from parameters which affect emissions, C_{ij0} at base year (0) and C_{ijk} at future year (k), as:

$$f_{ijk} = C_{ijk} / C_{ij0}$$

Typical examples of parameters which affect emissions are:

- sulphur content of fuels,
- new regulation limits on emissions from point sources (for power plants stacks, industrial stacks, etc.) and mobile sources (for cars, trucks, motorcycles, off-road vehicles, etc.),
- solvent content of products (paints, inks, glues, etc.),
- modification of technologies (application of Best Available Technologies - BATs),
- modification of practices (application of Best Available Practices - BAPs),
- etc.

Scenarios definition

When a lot of technology, activity and point source drivers are defined, scenarios are introduced:

- activity scenarios are defined associating to selected activities, specific activity drivers:
- technology scenarios are defined associating to selected activities and pollutants, specific technology drivers;

Technology and activity drivers can be shared by several activities. For example the activity driver "population" can be used to project "domestic paint consumptions" and "residential fuel consumptions"; the technology driver "distillate oil sulphur content" can be used to project sulphur oxides emission factor for "domestic distillate oil consumption" and "ports - distillate oil ships".

The combination of activity, technology and point sources scenarios produce emissions scenarios for air pollution planning.

Within the realization of the air quality management plan, the projections of emissions of air pollutants for 5-15 years in absence of interventions ("do nothing" or "business as usual" or "reference" scenario) are carried out using projection of population, energy demand, relevant industrial production, vehicle park, mileage and consumption, social and economical variables connected to activity of domestic type and evaluating the different technologies of emission reduction. The different aspects of regional planning (transport, energy, etc.), are analyzed in order to obtain information about the projections of activity indicators.

Starting from the "do nothing" scenario it is possible to construct alternative scenarios introducing the different plan measures. Alternative scenarios of economic and energy type (activity) and technology type (emission factors) are supplied. The joining of the two scenarios supplies the emission scenarios for the plan. The "do nothing" scenario is used for comparison with the alternative scenario in order to determine, subsequently to the definition of the objectives of air quality management, possible interventions of emissions control.

In the following a review of the most important measures proposed in the different plans is reported.

Each plan scenarios contain measures selected from the following list:

- regarding fixed area sources:
 - energy saving in industry and tertiary combustion;
 - solar energy use in tertiary combustion;

- heat recover for district heating in selected power plant areas;
- incentives for combustion of wood and wood wastes in district-heating;
- prohibition on the use of fuel oil in tertiary combustion;
- progressive control of open burning of agricultural wastes;
- reduction of methane emissions from livestock;
- reduction of VOC emissions from paint application;
- incentive to use low solvent domestic products;
- forest fires prevention;
- reduction of VOC emissions from maritime terminals;
- regarding transport:
 - reducing private road transport by increasing local and regional rail transport;
 - reducing private road transport by “car pooling”, “car pricing”, “car sharing”;
 - increasing electric or hybrid (electric and methane) public urban transport;
 - extending cycle-path;
 - extending “traffic closed” areas;
 - optimize car – public transport interchange;
 - reducing road-good transport by increasing train transport;
 - optimize ship-truck and rail-truck interchanges;
 - improving car maintenance;
 - reducing road abrasion by using better road pavement or introducing road soaking;
- regarding main and minor point sources:
 - conversion to gas by plants burning fuel oil, localized in areas connected to methane pipelines;
 - switch to very low content of sulphur oil (0,3%) for plants localized in vulnerable zones and not connected to methane pipeline;
 - denitrification and desulfuration of emissions of main point sources.

EMISSION PROJECTION TOOL

Projections of **E²Gov** is devoted to projections of data contained in data manager, energy and air pollutants emissions over a period of 5, 10, 15 years and is fully integrated with **E²Gov** regarding the starting year data and all other information. The module integrates and extends the system for the projection of determinants, energy variables and emissions previously released by Techne Consulting.

E²Gov (Energy & Environmental Governance) is the basic tool for the Governance of Environment and Energy, which contains within it the models for the compilation of emissions inventory and energy balance.

The system originally was born (1997) as a system for managing air pollutants emissions inventory (APEX) and subsequently developed expanding the inventory to other environmental sectors (water and waste). Then, starting from the observation that the base information for the realization of emission inventories is also functional to the evaluation of pressure on other environmental media, the system evolves into a system for managing the pressures and more recently as a system for energy and environmental governance (APEX.com).

Projections allows to model global area actions and local interventions on individual points, lines, areas and statistical zones. The model also allows the inclusion of new lines, areas and points.

CASE STUDIES

The methodology and the computer model were used in several regional air quality management plans in Italy and at national level in Italy, Albania and Montenegro.

The following examples of emissions scenarios are reported for two different studies. In the first one (see Figure 4) **E²Gov Projections** model was applied to assess pollutants emission variation in Reference Scenario for every Municipality of Montenegro¹⁰; the picture clearly shows some municipalities with raising emissions and one with decreasing emissions of PM₁₀, due to

different specific driver values related to the corresponding SNAP activities. Figure 5 shows the emission trend of PM₁₀ for the whole Umbria region in Italy, in this case emissions from a proposed high-traffic road were considered in a separate scenario, thus witnessing the high flexibility of the system.

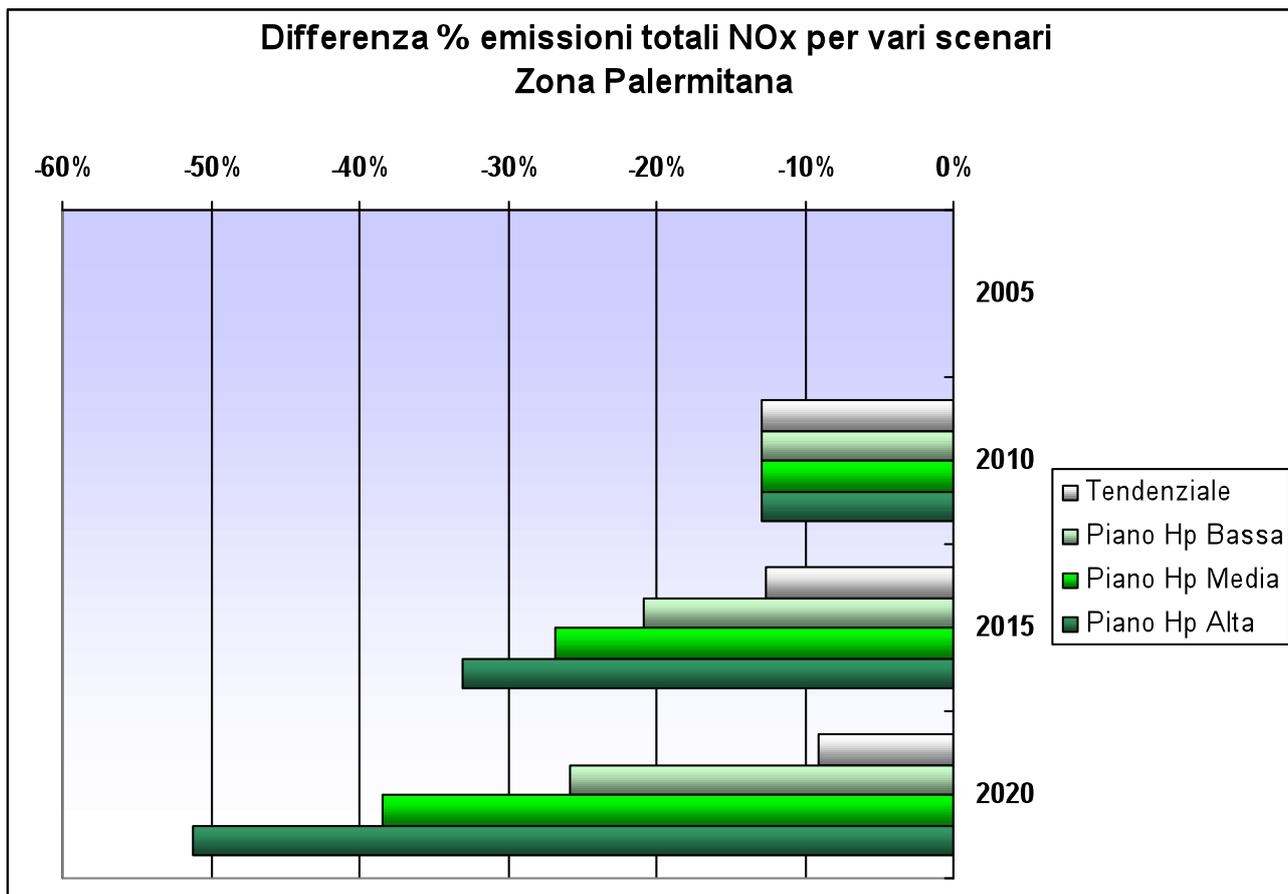


Figure 3 – Example of NO_x variation for different scenarios in Palermo area between 2025 and 2020

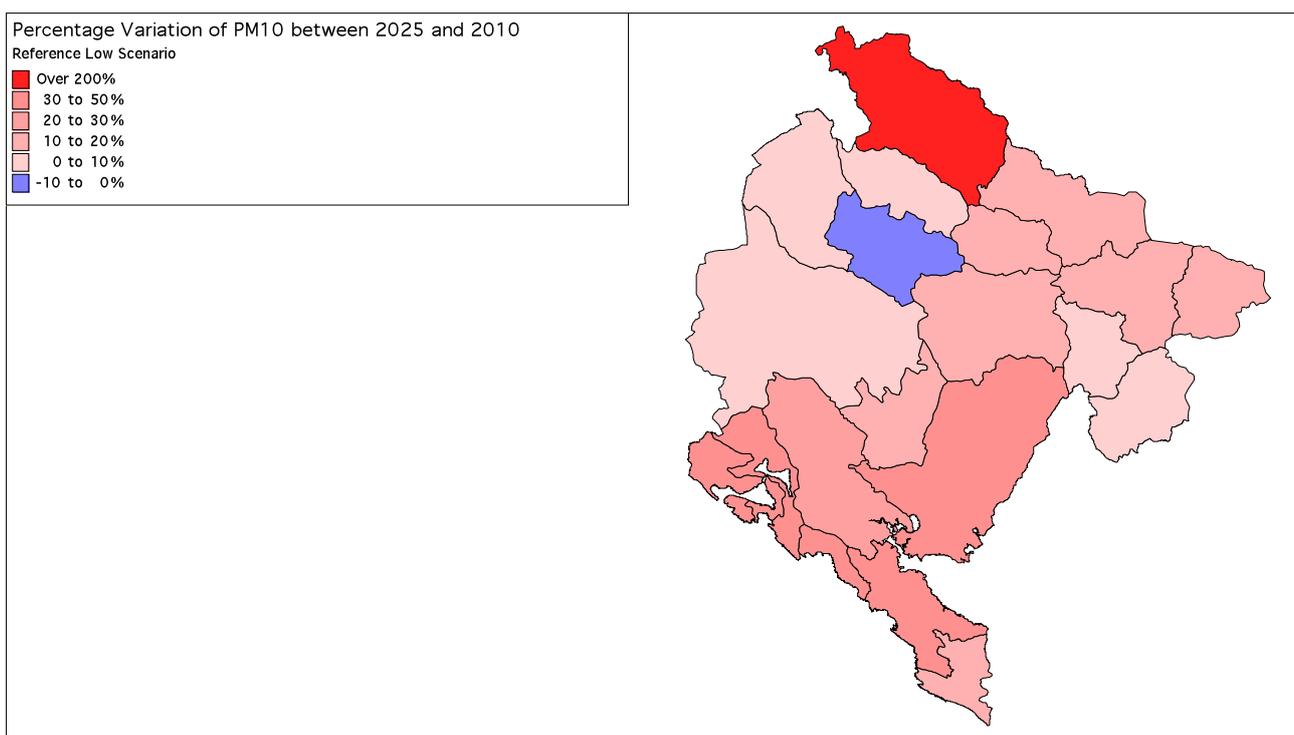


Figure 4 – Example of regional PM₁₀ variation for a single scenario in Montenegro between 2025 and 2010

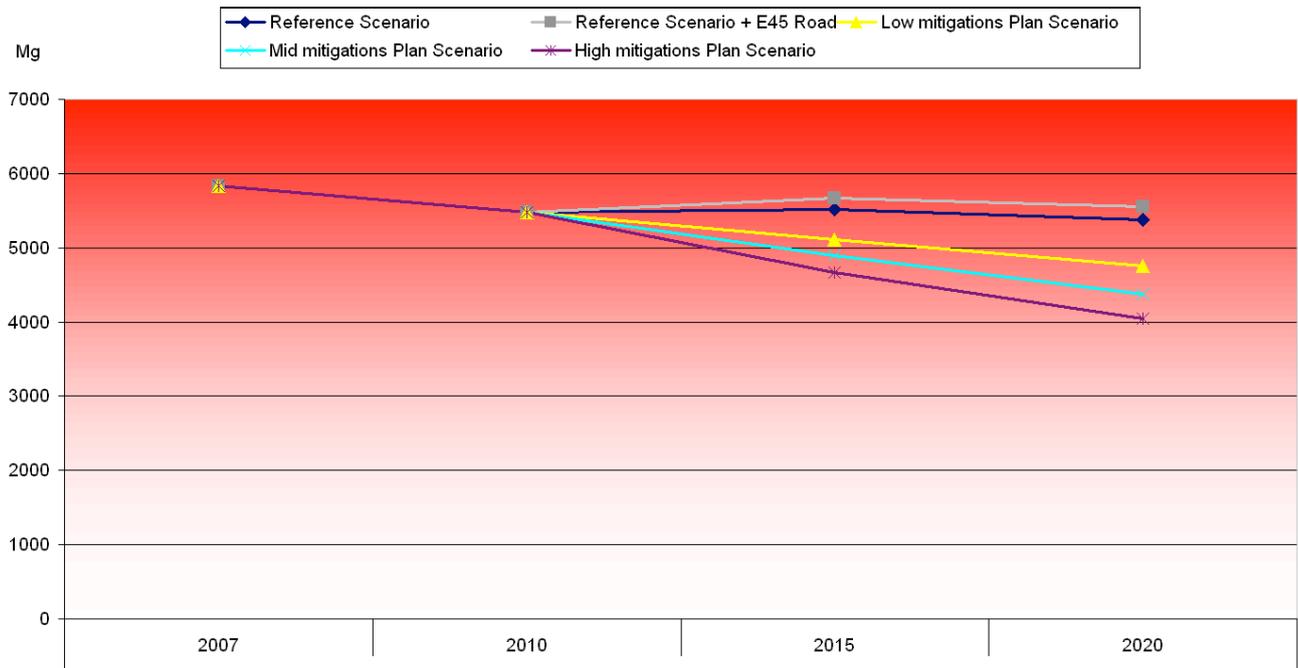


Figure 5 – PM₁₀ Emission Trend in different scenarios for Umbria Region

Emissions computed with the Projections system were used as well as input to different air quality models in projection, in various scenarios, to evaluate the effect of measures (Figure 6).

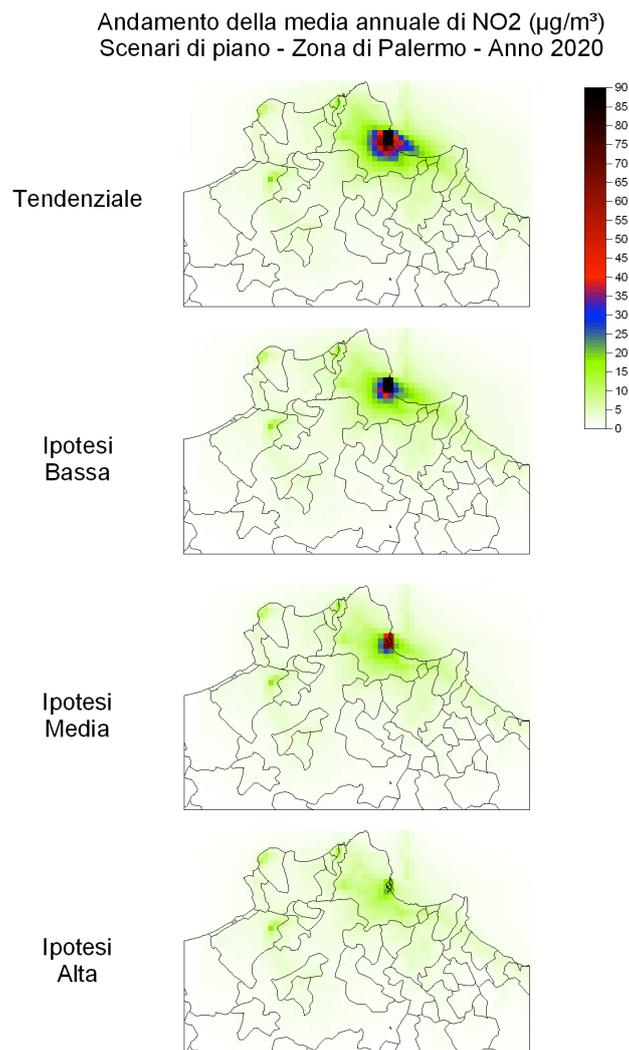


Figure 6 – NO₂ 1km x 1km grid concentrations elaborated with Calpuff model for Palermo area in different scenarios

CONCLUSIONS

The need of additional tools to expand traditional emissions inventories is raising worldwide, national and local authorities acknowledge the importance not only to know how much the activities inside their jurisdiction contribute to pollution level but also how to comply to regulations in future years.

E²Gov Projection model is a complete tool for this kind of issue, it can be used with emission inventory data coming not only from the **E²Gov** system but also from every other emission inventory software, making this model highly portable. Application of this model in the last years made possible the introduction of national and local regulations that effectively improved the overall air quality in their respective geographical areas.

ACKNOWLEDGEMENT

The methodology and tool was applied in the last twenty years in Italy, Montenegro, Albania and in several local regional administrations in Italy (work has been realized for Liguria, Friuli Venezia Giulia, Toscana, Umbria, Abruzzo, Campania, Basilicata, Sicilia, Trento, Bolzano, Roma, Firenze regional administration in the framework of regional air quality management plan). The authors wish to thank all people involved in the realization and improvement of this model among the years.

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