Deliverable Number

DA05/5.2

Deliverable Name:

Integrated Model System, operational web implementation

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Dissemination Level:

- **PU**: Public
- **PP**: Restricted to other program participants (including the Commission Services)
- **CO**: Confidential, only for members of the Consortium (including Commission Services)
**Introduction**

This Deliverable describes the operational integration of the DUST erosion model (Deliverable DA04.2) and in particular relates to

- **Action/task A05/5.1**, Aerosol modelling, long range transport (CAMx, 3D dynamic nested grid Eulerian fate and transport model)
- **Action/task A05/5.2** Nested grid modelling (CAMx) with inputs from
  - task 1.3, Wind statistics, episodes from MM5/WRF and CAMx runs, validation data (see also: Deliverable DA01.3)
  - task 4.3, Dust entrainment model, input to CAMx (fate and transport) see also: Deliverable DA04.2)
  - task 2.2, Dust sampling, monitoring data for CAMx validation;
  - task 3.4 Operational AOT assessment, CAMx validation, see also: Deliverable DA03.3)

for validation, and provides the main input to the multi-criteria optimization related tasks 7.2, 7.3, and 7.4.

- **Action/task A05/5.3** Synoptic model validation (CAMx) using inputs from
  - task 3.3. (Regional AOT, CAMx (vertically integrated) intercalibration, see also: Deliverable DA03.3)
  - task 3.4 (Operational AOT assessment, CAMx validation).

The operational implementation of the integrated model system provides the analytical framework and computational resources for

- **OPERATIONAL FORECASTING** with the potential for public information, early warning, continuous compliance monitoring, and regular periodic reporting of compliance:
  - the continuous, daily forecasts of air quality (cascade of meteorological (numerical weather) forecasts with MM5;
  - emission modelling with DUST, based on the wind field and soil moisture estimates provided by MM5;
  - the fate and transport modelling of the dust emissions with CAMx.

- **SCENARIO ANALYSIS** for a range of tasks including model sensitivity analysis, calibration/validation and EIA applications;

- **EMISSION CONTROL OPTIMIZATION** as a major input to the Dust Management Plan.

For these three closely related purposes, the central DUST emission model has been integrated with the operational air quality modelling system AirWare, developed in the EUREKA project E13266 WEBAIR that includes a test case for Cyprus. This original web-based model system has been extended in terms of:

- spatial coverage (up to a master domain of 4,800 km that includes and exceeds the EMEP emission data spatial coverage, see also: Deliverable DA4.1) and the associated input data;
- the long-range transport modelling associated with that spatial extension;
- the DUST emission model, that adds wind driven erosion of dust from natural surfaces in addition to the pyrogenic emission of the original model system emission inventory;
the integration of the DUST emission matrices into the CAMx fate and transport model system;

- the extension of the models display and analysis functions to cover the DUST model contributions and associated analysis to relate hourly model simulation results to the daily PM10/2.5 air quality standard;

- the extension of the optimization model to include DUST emissions (see deliverable DA07.1, DA07.2).

**Technical aspects of the deliverable**

All results and associated interactive model and analysis tools are accessible from the PM3 model home page: [http://www.ess.co.at/LIFE](http://www.ess.co.at/LIFE).

The model system provides:

- Integrated simulation models:
  - MM5, DUST, CAMx

- Data bases for:
  - monitoring data (see also: Deliverable DA01.2, DA01.3) including the model generated reference meteorology for the reference year;
  - emission inventory for pyrogenic emissions, for Cyprus (national emission inventory) and the extended model domains, EMEP emission data;
  - GIS data layers as input to the meteorological modeling, the DUST emission model,
  - the model scenarios (real-time forecasts, scenario analysis, optimization).

**Model system implementation**

The basic model framework was adapted on the basis of AirWare, developed mainly in the EUREKA WEBAIR project E!3266, into which the DUST emission model was integrated to provide hourly particulate emission matrices as input to the CAMx fate and transport model implementation.

**Application domain: Cyprus**

(section courtesy of P. Charalambos, ATLANTIS)

While the model system covers an area of 4,800 km centered around Cyprus and the long-range transport from the surrounding regions, it is only the territory of Cyprus, and thus the central model domain, where any dust management measure can be implemented.
Cyprus is located in north-eastern edge of the Eastern basin of Mediterranean Sea at 35° North and 33° east. It has an area of 9.251 square kilometers and expands 240 kilometers long and 100 km wide. The population of Cyprus is about 1.14 million (July 2012 estimate; Greek Cypriots, Turkish Cypriots and other minorities) and the official languages according to the Constitution of 1960, are Greek and Turkish.

Cyprus has a gross domestic product (GDP) around $23.77 billions (CIA, World Factbook, 2011 estimate). The per capita income amounts to about $20.85 (CIA 2012 estimate) which places Cyprus at the 47th position worldwide in terms of per capita income. From the period between 1961-2003 the island managed a rate of growth of around 5.1 %, which has slowed to 0% for 2011.

The standard of living is considered comparable with that of member states of the European Union 15 and the economy is compared favorably with that of most members of European Union.

Physiographically, Cyprus may be separated in four regions:

- **The Troodos range**, which is located at the central-western section of the island. Olympos peak is the highest point of the island reaching 1951 meters.
- **The Pentadaktylos range** which is located along the northern shores of the island. It is a long and narrow mountain range extending from west to east, with its foothills ending at the northern shores. It is characterized by several peaks which reach an elevation of about 1000 meters.
- **Mesaoria valley**, which is located between the Troodos and Pentadaktylos mountains. It is characterized mostly by flat plains interrupted by minor hills. Its elevation in the Nicosia area is about 180 meters.
- **The coastal plains and valleys**.

Cyprus has a Mediterranean climate and is characterized by hot and dry Summers and mild winters. The dry summer season persists between May and September while the winter, coinciding with the rainy period, stretches from November to March. The two transient seasons, autumn and spring are of relatively duration.

During the summer period Cyprus weather is dominated by the seasonal low pressure system that centers in south-west Asia. This system produces persisting dry weather and high temperatures.

During the winter, the weather is influenced by the frequent passage of small low pressure systems and fronts moving in the Mediterranean from west to east. These disturbances may last from one to three days and are responsible for most of the rainfall. The Troodos mountain and, to a lesser degree, the pentadaktylos mountain, play a significant role in the production of local weather phenomena. Offshore currents are also an influencing factor, generally limited in the coastal areas.

The average rainfall for the island is 480 mm (statistical average for the period 1951 – 1980), but ranges widely between the various regions. At the wind prone higher Troodos areas to the northwest, rainfall reaches 1100 mm while at the shadowed eastern plains it reduces to between 300-350mm.

Snowfall occurs typically every winter at the higher areas of Troodos, with an elevation above 1000m, but is rare in the lower valleys. Hail also typically occurs each winter with a frequency
of 2-3 times in the plains and about 10 times in the higher mountain areas. On average 4 storms occur each month during the winter period but are rare over the rest of the year.

Temperature is influenced by elevation (on average decreasing 5°C for every 1000m and by the sea, making the climate milder near the seashore. Mid Summer (July-August) mean temperatures range from 29 °C in the central valley to 22 °C at the higher Troodos areas. In January mean temperatures range from 10 °C inland to 3 °C in the coastal areas. Mean low temperatures in January are respectively 5°C and 0°C.

Sea surface temperature during the summer averages at around 22 °C and can reach 27°C in August. During the coldest winter months it drops to 16-17 °C.

Soil temperature in the plains at a depth of 10 cm is about 10 °C in January and 33 °C in July. At a depth of 1m temperature is 14 °C in January and 28 °C in July. Respective temperatures for elevations above 1000m are on average 5 °C lower. Peak surface temperatures during the summer can reach 60 °C.

Distance from the sea and elevation play an important role in the distribution of relative humidity. During the winter daytimes and during the night in all seasons, RH ranges between 65% and 95%. In the summer period during the day RH typically ranges around 30% but can drop to 15%.

Insolation periods are relatively high with hours of sunshine reaching 75% of daytime hours. During the summer there is an average of 11.5 hours of sunshine per day, a number that is reduced to 5.5 hours in December and January.

Winds in the eastern Mediterranean are generally low to moderate and usually are westerly or southwesterly in the winter and northerly to northwesterly in the summer. These synoptic level winds are strongly influenced by local land-sea currents near the coast, though they may extend to 35km inland, and anabatic / katabatic winds in the higher elevations. Peak winds of 24 knots may occur during severe storms. Extreme winds of 34 knots occur rarely.

During the last years temperature has been showing an upward trend while rainfall has been showing a downward trend. The drop in rainfall is quite significant having dropped by 17% from the average value of the first 30 years to the average value of the latest 30 years of the last century. The temperature rose from an average of 18.9 °C in first 30 years to an average of 19.7°C in the latest 30 years of the last century.

Existing situation regarding the Air Quality Monitoring, Assessment and Management in Cyprus

The Ministry of Labour and Social Insurance (M.L.S.I.), via the Department of Labour Inspection (DLI), is the responsible Authority for the monitoring, assessment and management of air quality in Cyprus. The Department, within the framework of its responsibilities, has fully harmonized the Cypriot Legislation with the corresponding European Directives.

Within the scope of implementing its monitoring and reporting requirements, the department has established a network of Air Quality Monitoring Stations. The monitoring system is complemented by an on-line information system, which makes monitoring data available to the public at an hourly temporal resolution. Information is also provided by indoor and outdoor panels placed at frequented public locations.
The relevant EU Directives, regarding the air quality, which Cyprus has incorporated in its National Legislation, are the following:

- 2001/81/EC: Directive on National Emission Ceilings (NEC) for certain atmospheric pollutants

Within the scope of fulfilling the requirements of the abovementioned legislation, the DLI has recently upgraded its network of air quality monitoring stations, and now operates nine stations. These stations are fully equipped with automatic analysers for the monitoring of Nitrogen Oxides (NO, NO2, NOX), Sulphur Dioxide (SO2), Ozone (O3), Carbon Monoxide (CO), Particulate Matter (PM10 & PM2.5), Benzene as well as meteorological parameters including Wind Speed (W/S), Wind Direction (W/D), Relative humidity (R/H), Ambient Temperature (T), Barometric Pressure (B/P) and Solar Radiation (S/R). In addition four mini stations for Ozone (O3) and nitrogen oxides (NO, NO2, NOX) are being installed in various agricultural and forest areas, for the monitoring of Ozone and Nitrogen Oxides concentrations, all over Cyprus.

The stations are connected to a centralized system for the collection, evaluation and dissemination of data. The system is connected via internet with all the monitoring stations and the collected data are transferred to an air quality dedicated web page (www.airquality.gov.cy).

Additional six similar air quality monitoring stations are operated by the Cyprus Electricity Authority around the electricity power stations of Vasilikos, Dekeleia and Moni. It is planned that these will also be connected to the DLI's air quality monitoring network.

In addition to establishing the monitoring network, the DLI has also proceeded with the installation of Air Quality Management Software capable of forecasting, now casting, impact assessment and scenario analysis (Moussiopoulos et al., 2010). This system, once completed, will provide a dynamic emission inventory system for atmospheric pollutants in Cyprus and to complete the development of the air quality management software. With the successful completion of the development phase of the project (2008/2009), the DLI has completed the infrastructure, information and know-how necessary for the implementation of all its regulatory requirements.

**The AirWare Model System**

With a similar structure as the AQMS, and early version of the AirWare model system developed in EUREKA WEBAIR was installed at DLI during 2003-2006.
The Model System

AirWare is a web-based, fully integrated modular air quality assessment and management system (Fedra, Rashidi and Kim, 2009; 2004; Fedra, 2002). The software is being developed within the framework of the EUREKA project E!3266 WEBAIR with currently projects partners from four continents and 19 countries (http://www.ess.co.at/WEBAIR). The implementation combines a set of cascading and nested grid models, linked to a set of data bases and optional real-time monitoring sensors. Technically, it is based on a distributed client-server architecture that integrates high performance cluster computing with web and data base servers.

The distributed client server architecture and web access for any remote client requires only a networked PC with any industry standard browser (Fedra, 2008). This facilitates the implementation as SaaS (Software as a Service) to better support the sharing of data and hardware, and institutional cooperation. SaaS solutions minimize the investment requirements for individual user institutions through shared use of common hardware and the necessary technical support for complex models and high-performance cluster computing needed for the meteorological forecasts, high-resolution 3D photochemical models, stochastic forecasting, and multi-criteria emission control optimization.

2.1. Prognostic meteorology

The starting level of the cascading model system is the prognostic meteorology. This is based on either daily forecast from the NOAA GFS servers (one degree and 6 hourly resolution) or NCEP re-analysis for historical data. The system uses either WRF or MM5 3 D nested grid non-hydrostatic meteorological forecasting models in three levels of nesting for the dynamic downscaling of the GFS data to a 1 km hourly resolution (Figure 2a,b). This is used to either drive the 3D Eulerian model CAMx with 3D meteorological data fields, or the regulatory USEPA AERMOD system, based on station data extracted from the meteorological data fields. The Gaussian
model AERMOD, using “advanced” turbulence parameterization based on Monin-Obukhov roughness length rather than Pasquill-Turner stability classes, is run with the meteorological data from one or more stations, pre-processed with AERMET.

Figure 2a: MM5 prognostic meteorology scenario interface, 4,800 km master domain
2.2. Dynamic boundary conditions

The main application domain for AirWare is urban conglomerates of a minimal size; for example, the EU air quality framework Directive 2008/50/EC defines a size of 250,000 inhabitants. This urban scale is usually covered by a model domain of 40 to 60 km (width of a square domain). This is embedded in a master domain of between 300 to 600 km. This in turn is embedded into a continental domain (a square of 3,000 to 6,000 km width) providing dynamic boundary conditions based on low resolution (usually at 0.5 degrees, and with emissions summarized into several economic sectors) data sets such as EMEP or NASA-ACES, ACE-ASIA. To support the real-time dynamic modeling with an hourly resolution, these annual average data are used as the basis for dynamic emission modeling using monthly, daily and hourly corrections factors. Another possibility is to compute emissions (e.g., domestic heating in Northern Europe) as a non-linear (sigmoid) threshold function of temperature, as predicted by the meteorological models.
2.3. Emission modeling: integrating the DUST model

The dispersion modeling is based on the meteorological driving conditions, and the emissions. These emissions are either from

- point, area, or line sources described in the emission inventory
- the embedded dynamic DUST model.

Emissions for pyrogenic of fugitive sources for a given model domain are automatically taken from the emission inventory. For Cyprus, the latest version of the emission inventory is taken. For the areas outside, the EMEP emission data are used, as well as first order emission derived from RS data.

Emission data are based on

- annual average data per source and scaling factors to generate hourly estimates with a combination of monthly, daily and hourly weights;
- real-time emission data from monitoring for larger point sources;

These data are compiled into a set of point sources (PIG, point in grid simulation) and hourly emission matrices aggregated to the model resolution for the respective domains, see Figure 4 below.
Figure 5: emission scenario including PM10 (from emission inventories) and dust (generated by the DUST model).

The DUST hourly emission matrices are generated from

- the static spatial data bases (land cover, vegetation, soil, slope, aspect)
- the dynamic MM5 results (wind speed, direction, soil moisture)

these matrices are combined with the PM10 emission from all other sources (Figure 5) and fed as input to the CAMx transport model. Alternatively, the DUST emission matrices can be exported for processing with any alternative fate and transport model.
2.4. Nested grid air quality: CAMx

The central model used is CAMx (latest release R 5.10, ENVIRON 2009) which uses the CBM 05 chemistry mechanism. The model describes both conservative pollutants, particulates with diameter specific IPM 10/2.5) net settling velocity, and the contribution to photochemical processes and ozone formation. CAMx is used with the 3D dynamic inputs from the meteorological models, and is set up in a three level nesting with two-way coupling. CAMx uses 8 or more vertical layers, and the model resolution ranges from several km to a minimum of 500 meters.

2.5. City-wide high resolution traffic impacts

For higher resolutions at local scales, AirWare uses either a full 3D CFD model, or a Gaussian approach (Fedra, 2004). The latter is based on assumptions of steady-state, and will generate an upper bound of concentration estimates, but does not consider initial and boundary conditions. With these limitations and appropriate interpretation, the Gaussian model is used with very high resolution (e.g., 10 m) to generate near-field solutions that use a mixing zone approach for the road sources,
and a convolution model with a computational kernel to generate city wide solution very fast and efficiency through scaling a unit emission solution along the line sources. The resulting concentration estimates are overlayed with population density from census data to provide a first order estimate of population exposure. A more refined approach would have to consider indoor-outdoor relations, but also the temporal pattern of population density between working and sleeping environments.

For the LIFE application, AirWare exports the regional concentrations (hourly) to provide dynamic boundary conditions for an alternative high-resolution urban street canyon model (see also: Deliverables DA06.1, DA06.2)

### 2.6. Operational forecasts and hourly now-casts

To address the public information requirements, but also as the basis for any possible operational control options in case of emergency (smog) situations such as change of fuel in major power plants or industries, closing the city to individual traffic etc. one of the operational modes of AirWare is continuous real-time modeling. This combines daily forecasts over several days (3 to 5) and hourly now-casts that can use real-time data assimilation where on-line monitoring data are available.

Forecasts start with the daily download of GFS global weather forecasts which are dynamically downscaled to the respective model domains, ultimately to 1 km and hourly resolution. Emissions are estimated from the base value (average) and monthly, daily, and hourly scaling factors. In parallel, for every hour, these weather forecasts (including ensemble forecasts, see 2.6 below) and hourly emission estimates drive the nested grid air quality model forecasts. These dynamic model results (for 72 to 120 hours) are available hourly (Figure 7) and as animations with a
Java player and can be exported as mpeg files. Results are also exported as time series data to all monitoring stations for comparison with the observed data.

Figure 7a: forecast results for a user selected domain, hour, and pollutant

Figure 6b: hourly thumbnails for a 24 hour scenario
The now-casts are run every hour. They can use emission data in real-time (e.g., from major point sources or adjusted line source emission estimates corrected by traffic observations, and can use monitoring data for simple data assimilation: nudging of initial conditions to minimize an error term (such as the root mean square error RMSE) when comparing the previous hour now-cast results (as initial conditions for the next hours now-cast) with the current observations. The nudging would first correct for any bias, then adjust the spatially distributed model results with a distance weighted correction to the bias corrected observations.

### 2.7. Stochastic forecasts

Stochastic forecast are based on the meteorological forecast ensembles, and user specified distributions around individual or class level emission corrections which are sampled with a stratified sampling or randomly in a straight forward Monte Carlo approach. Since the individual runs are independent, this lends itself to a task parallel implementation for cluster computing.
2.8. Model validation

Before the model results are used for public information and as the basis for emission control, the quality of results against observational data is analyzed.

Model validation measures the agreement between model generated and observed concentration values (e.g., AIAA 1998; Macal, 2005; Sargent, 2003). The new consolidated air quality framework Directive 2008/50/EC (replacing 1999/30/EC) defines acceptable model performance as within 50% plus or minus hourly observation data.

However, the comparison of model results and monitoring data is difficult due to the every different nature if not incommensurability of these data: continuous point measurements of a highly dynamic process involving turbulent mixing and high spatial variability, and the hourly average over a large volume of air. The direct comparison of model results and monitoring data therefore requires careful consideration of sampling statistics. Alternative monitoring data for model validation can be derived from large scale synoptic observations, such as aerosol optical density from satellite imagery. While covering large areas in space, they are comparably infrequent, and describe the entire vertical atmosphere, while the monitoring data only sample the bottom layer.

Model validation examples (MM5, CAMx)

O\textsubscript{3}/NO\textsubscript{2} model validation examples, CAMx/CB4, Cyprus, May 2005;
NO\textsubscript{2}, CAMx/CB4, Korea/Seoul, August 2001;
Humidity and temperature, MM5, Korea June 2007.
2.9. Public information: web and 3G mobile communication

The web implementation facilitates easy access and thus both institutional collaboration and public information. As an additional communication channel, the system supports communication through 3G mobile phones by SMS/MMS.

This includes the distribution of personalized messages on a subscription basis for sensitive target groups such as patients suffering from respiratory diseases such as asthma or COPD (chronic obstructive pulmonary disease) which affects up to 20% of urban populations older than 40 years; the effects of air pollution, and specifically particulates, are summarized below with examples from the recent literature.
Public-health impact of outdoor and traffic-related air pollution: a European assessment. Künzli et. al (2000). One of the first and most influential papers on the health effects of air pollution: “Air pollution contributes to mortality and morbidity. We estimated the impact of outdoor (total) and traffic-related air pollution on public health in Austria, France, and Switzerland. Air pollution caused 6% of total mortality or more than 40,000 attributable cases per year. About half of all mortality caused by air pollution was attributed to motorized traffic, accounting also for: more than 25,000 new cases of chronic bronchitis (adults); more than 290,000 episodes of bronchitis (children); more than 0.5 million asthma attacks; and more than 16 million person-days of restricted activities.”

Cardiopulmonary mortality and air pollution Peters and Pope (2002). Provides a re-analysis of classical smog episodes: “Studies of extreme air-pollution episodes in the Meuse Valley, Belgium; Donora, Pennsylvania; and London, UK, provide early compelling documentation of serious adverse effects on health from air pollution.”

A breath of fresh indoor air. A recent discussion of the WHO guidelines for indoor air quality: “Poor quality indoor air is a major cause of morbidity and mortality worldwide; this effect on health is substantial and the burden of disease is much greater than that caused by outdoor-air pollutants.”

Air pollution attributable post-neonatal infant mortality in U.S. metropolitan areas: a risk assessment study. Kaiser et. al. (2004). A risk assessment approach: “In a country where infant mortality rates and air pollution levels are relatively low, ambient air pollution as measured by particulate matter contributes to a substantial fraction of infant death, especially for those due to sudden infant death syndrome and respiratory disease.”

Study on the association between ambient air pollution and daily cardiovascular and respiratory mortality in an urban district of Beijing. Zhang et al. (2011). A recent example for a somewhat dramatic pollution situation: “The association between daily cardiovascular/respiratory mortality and air pollution in an urban district of Beijing was investigated over a 6-year period (January 2003 to December 2008. Concentrations of PM10, SO2, and NO2, were measured daily during the study period. The results show that the daily cardiovascular/respiratory death rates were significantly associated with the concentration of air pollutants, especially deaths related to cardiovascular disease.

COPD prevalence in Salzburg, Austria: results from the Burden of Obstructive Lung Disease (BOLD) Study. Schirnhofer et al. (2007). COPD is projected to be the third leading cause of death worldwide by 2020. The Burden of Obstructive Lung Disease initiative was started to measure the prevalence of COPD in a standardized way and to provide estimates of the social and economic burden of disease. One quarter of residents of Salzburg County (Austria) who were >or= 40 years of age had at least mild irreversible airflow obstruction. The high prevalence of COPD highlights the impending health-care crisis that will affect many countries as a result of this greatly underappreciated condition.
The prevalence of COPD in Austria--the expected change over the next decade.

Firlei et. al (2007). In the context of the international Burden of Obstructive Lung Disease (BOLD) study, a random sample of the population of Salzburg was surveyed to determine the prevalence of COPD. A prior physician's diagnosis of COPD, emphysema or chronic bronchitis was evaluated by questionnaire. The age- and sex-specific prevalence of COPD was extrapolated using demographic data of the Austrian population for the years 2005, 2010, 2015 and 2020. For 2005 1.047.150 Austrians aged 40 years and older were estimated in GOLD stage I-IV. Measures to prevent COPD are absolutely necessary to forestall the projected burden of this disease in Austria.

3.0 Improving air quality

The ultimate objective of air quality assessment and management must be the improvement of air quality. While regulatory targets and standards and thus compliance are, of course, a first set of objectives, for some pollutants such as PM2.5, no safe lower limits that exclude negative health effects can be defined.

Improving air quality is basic emission control i.e., emission reductions. While this is fairly straightforward for conservative substances including particulates, it is more complex for photochemical processes and ozone formation. Here, the reduction of any one of the precursor emission may not necessarily lead to immediate reductions in observed ozone levels, resulting in counterintuitive strategies (e.g., Bankes 2002).

This non-linearity of the underlying air quality processes together with the non-linear cost functions for emission control poses special requirements for an optimization approach that has to represent this non-linearity as well as the dynamic and distributed nature of the fate and transport system. There are no gradients that classical optimization methods are based on, so that an inverse methodology is used: successful (pareto-optimal) solutions are mapped back into the decision space to identify structural properties (ranges, cross-correlation) that can be used to make the search process more efficient.

The optimization approach is therefore based on the full resolution non-linear dynamic model CAMx, and adaptive heuristics and genetic algorithms for the generation of feasible alternatives in an iterative implementation. The strategy is evolutionary, combining adaptive heuristics, genetic algorithms, and neighborhood search strategies: generation of large numbers of alternatives, and their ex post evaluation to find feasible, non-dominated, and eventually an efficient (best) solution given a multi-criteria preference structure (criteria, objectives, constraints). The challenge is to improve the efficiency of the iterative search strategy to generate likely candidate solutions in the absence of simple gradients.

For each emission source or class of sources, one or more possible mechanisms, strategies or technologies are selected for possible applications with rules for their combination or mutual exclusion. These measures are described in terms of their costs (annualized investment and operations) and their efficiency in reducing individual pollutants from the source’s emissions.
3.1. Scenario analysis and comparison

Scenario analysis addresses WHAT-IF questions to evaluate the consequences, costs and benefits, of possible projects and design, eventually, a “best” solution that contributes to the objectives and meets all the constraints. The easiest strategy is try, based on expert knowledge, to design and simulate alternative scenarios, each representing a possible policy, strategy, or set of measures (which may represent any stakeholder’s or decision makers favorite plan) for direct comparison and the possibility for ranking. This puts the two solutions (baseline and alternative) side by side for visual inspection and the comparison of selected criteria (performance measure) and computes the deltas, tabular and as a topical map of relative or absolute change (Figure 9).

While this one step at a time approach is easy to understand and control, it is highly inefficient, given the very high dimensionality of the decision space (number of possible choices) and the complexity and non-linearity of the models. The main advantage is that decisions (selections of alternatives) can be based on direct and thus easy to understand pair-wise comparison that lends itself to direct stakeholder involvement.

![Figure 9: Scenario comparison, Seoul traffic scenarios](image)

3.2. Multi-criteria optimization

The optimization methodology starts with a series of Monte Carlo runs, based on a priori probabilities for the application of specific emission control measures.

From an initial set of alternatives a set of parameters are derived that are used to reconfigure the generation of alternatives based on the structure of decision and model performance space.

The multi-stage alternative generation utilizes both adaptive heuristics and basic GA concepts to increase the efficiency of the search;
An optimization run starts with:

- Definition of a preference structure (A07/7.1, DA07.1) this includes the selection and definition of the criteria (such as compliance or exposure), related objectives (minimization of exposure), and constraints (enforce compliance if feasible);
- Selection of a CAMx baseline scenario in terms of
  - Domain (defines the emission sources)
  - Date (defines the meteorology)
- Definition of the emission control scenario:

For a given domain, the system automatically generates a list of emission sources, individually (large boilers and stacks) or grouped by class:
- Small stacks/point sources
- Residential area sources
- Commercial sources, and in particular open cast mining;
- Traffic (line sources, and in particular unpaved roads);
- DUST emission sources: all measures affecting:
  - the extent of areas with an erodibility > 0 (increased sealing of surfaces, vegetation cover)
  - the reduction of erodibility for any such areas (increased density, different types of vegetation, maintenance of soil moisture).

For each source or class of sources one control technology can be selected from an embedded emission control technology data base. Multiple technologies: this mechanism can be repeated for any source so that several alternative or potentially combined measures can be applied to each source or source class.

For each source/technology combination, the user can specify:
- a relative a priori weight (probability of selection of the technology)
- minimum and maximum application rate (once the technology was selected)
- investment costs (annualized) and annual operating cost
- emission reduction factors for the key pollutants treated by CAMx.

Strategy for the generation of alternatives:
- Phase I: naïve Monte Carlo based on the user selection of emission sources and applicable (multiple, alternative or combined) technologies, initial weights, and application ranges (where applicable; some technology/source combinations are binary (on/off, which can be represented by setting the application rate min and max % to 100 each.
- Phase II: analysis; this is done by the DMC (discrete multi-criteria DSS tool, see Activity A07); this filters the initial set into feasible and infeasible solution (user defined selection of criteria and constraints on the criteria ranges); dominated and non-dominated solutions (given the current set of criteria and the implied UTOPIA or reference point; and as a scalar property, the (normalized) distance from UTOPIA. The analysis (a) classifies the solutions; (b) ranks the solutions by individual criteria or overall “performance (= distance from UTOPIA);
analyses the relationship between decision variables (selection, application rate) and classification as well as scalar performance measures. This is the basis for

- **Phase III: refinement of search space and search strategy:**
  this includes
  - Redefinition of the a priori probabilities (weights) of individual technology/source combinations (based on a co-incidence matrix);
  - Adjustment of the application ranges (based on the comparative histogram analysis for pareto-optimal versus the rest of the alternatives);
  - Selection of a (best = closest to UTOPIA) subset (population) for the exploration of any local improvements (neighborhood search).

This multiphase structure lends itself very well to the low-granularity task-parallel implementation described above.

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http://jtac.uchicago.edu/conferences/05/resources/V&V_macal_pres.pdf


Proof of deliverable

The operational air quality simulation framework that uses the dynamic DUST emission model is implemented at: http://80.120.147.34/CYPRUS as a web based client-server system with open, public access (limited to read-only user privileges for user group: guest).

AirWare/Cyprus, start page of the operational model system, hourly updates
Real-time forecast scenario, PM10, inner domain (Cyprus, 270 km)
PM10 forecast scenario, 4,800 km domain
PM10 forecast scenario, 4,800 km domain centred around Cyprus, 24 hourly thumbnails
PM 10 forecast scenario, 4,800 km domains, daily aggregate (24 hour average)
PM 10 forecast scenario, 4,800 km domains, daily aggregate (maxima over 24 hours)