Opera

Operational Procedure for
Emission Reduction Assessment

R+ RIAT+ User Guide

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0   INTRODUCTION

RIAT+ system has been developed in OPERA project (www.operatool.eu - co-funded by the EU-LIFE+ program LIFE09 ENV/IT/000092) under the coordination of Agenzia Prevenzione Ambientale Emilia-Romagna (ARPA ER) and the partnership of University of Brescia - Dipartimento di Ingegneria dell'Informazione, TerrAria srl, Centre National de la Recherche Scientifique (CNRS), Université de Strasbourg (UNISTRA). JRC, Emilia-Romagna Region and ASPA (Association pour la Surveillance et l'Etude de la Pollution Atmosphérique en Alsace) are the stakeholders.
RIAT+ is the evolution and the integration of different regional experiences, of which in particular, RIAT (Regional Integrated Assessment Tool) was developed by University of Brescia and TerrAria during a project funded and coordinated by JRC-IES (Joint Research Center – Institute of Environmental Sustainability) and Lombardy Region.

RIAT+ is a DSS tool implemented thinking to regional decision makers who, when designing air pollution reduction policies, face a limited budget that should be used to set-up efficient measures impacting on several pollutants in different ways to obtain the respect of EU air quality standards.
RIAT+ is a regional integrated assessment software tool that helps tackling this challenge, supporting the policy makers in the selection of optimal emission reduction technologies, to improve the air quality at minimum costs.
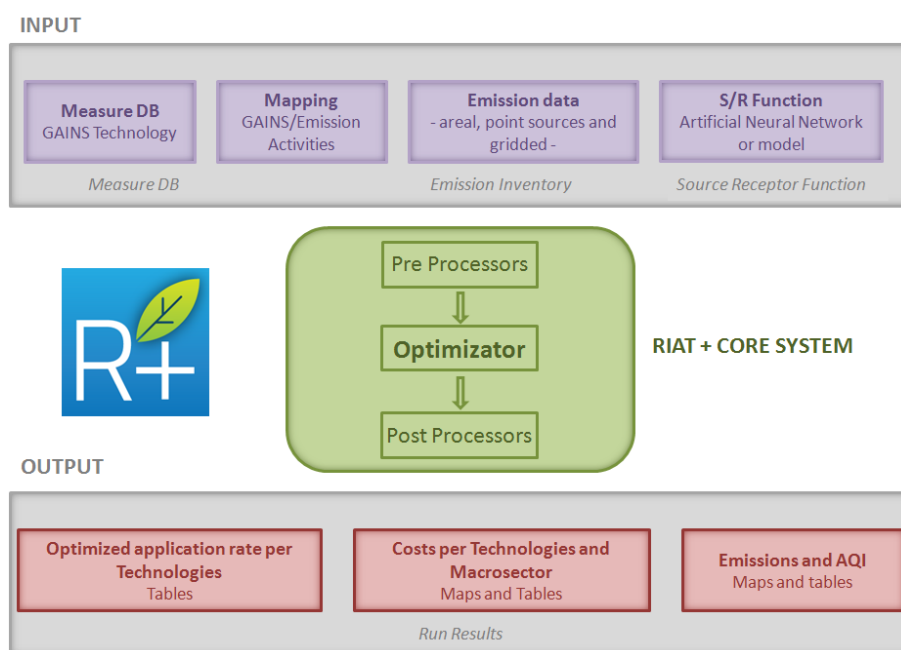
Figure 0-1: RIAT+ block diagram with I/O and core system

RIAT+ is an integrated modeling environment using tabular and geographic data, simulation and optimization models, graphical and geographical user interface, focusing on the regional scales (see Fig. 0-1 for a scheme of RIAT+). The method and

the tool are general and easily applicable to different regions, incorporating explicitly the specific features of the area with regional input datasets:

- precursor emissions of local and surrounding sources
- measures (technical and non technical) described per activity sector and technology with application rates, emission factor and cost
- meteorology and prevailing chemical regimes through some source receptor functions (or models)

Peculiar components of RIAT+ core system are:

1. a multi-objective optimization problem solver, i.e. one or more air quality indicators (e.g. yearly PM10 average) are reduced in the policy application domain, minimizing the costs of emission reduction measures costs to obtain this concentration reduction. The solver is able to select and present to RIAT+ user the entire set of efficient abatement measures, in terms of application rates (i.e. penetration levels to be reached).

2. since a CTM (Chemical Transport Model) cannot be run in real time within RIAT+ optimization procedure for its CPU time requirements, a simpler relationship between emission sources and air quality indicators at given receptor sites (S/R models) is used in RIAT+ optimization algorithm (Artificial Neural Networks – ANN in the following regional applications).
   This approach compared to the traditional linear regression model (used in other systems), captures the non-linearities in the relationships between emissions and concentrations, maintaining a low CPU time.

3. In RIAT+: different air quality indexes are included (yearly average of PM10, PM2.5, and NO_2, PM10 daily exceedances, AOT40, O_3 8hrs maximum); the budget can be constrained to a specific value (cost-effectiveness approach) or can be split in different macrosectors; policy application subdomain (e.g. critical air quality zones) can be defined; state-of-art technologies may be fixed for some years while older technology could be substituted; optimization can be limited to a subset of macrosector technologies; scenarios can be simulated fixing aggregated emissions or specific technologies.

Figure 0-2: RIAT+ GUI (Graphical User Interface) opening screen-shot.

Innovative elements of the instrument RIAT+ are:

- application to regions and sensitive areas concerned by exceedance of air pollution standards;
- the introduction of non-technical (efficiency) measures;
- the flexibility of the optimization in terms of air quality objectives, areas of intervention, sector budgets;
- the capability to manage different kinds of input data (e.g. gridded or polygonal, annual or seasonal, SNAP detailed or aggregated emissions);
- various integrated assessment approaches (Multi Objective and Cost Effectiveness approach, Scenario Detailed and Aggregated approach);
- user friendly interfaces both to input data with check and validation controls and to elaborate and navigate output with tables, charts, maps.

RIAT+'s Licensors (JRC – IES and all OPERA partners) distributes RIAT+ granting a personal, non-exclusive and royalty-free license, whose copyright and other intellectual property right remain sole property of the Licensor. RIAT+ has been applied in Emilia-Romagna Region (IT) and in Alsace (FR) during OPERA project, while RIAT in Lombardy Region. Other EU Regions will apply RIAT+ in the context of APPRAISAL project (www.appraisal-fp7.eu).

This User Guide is divided in three parts:

- the first "USER INSTRUCTIONS" is mainly devoted to provide the user with the instructions to set up and run RIAT+; the tool description is organized following the standard sequence of Input&Output data management panels (in the following, briefly GUI)
- the second "RIAT+ METHODOLOGY" describes the main methodology used in RIAT+ to provide the integrated assessment of the air quality plan and/or the optimal solution in terms of most efficient policies.
- the Annexes "RIAT+MODEL ALGHORITMS" describes the main procedures integrated in the system.

PART I: RIAT+ USER INSTRUCTIONS

1   RIAT+ SYSTEM

1.1   RIAT+ software specifications and hardware requirements

RIAT+ system (graphical user interfaces – GUIs, and operation processes) is developed on J2SE platform (java 2 standard edition). RIAT+ data pre- and post-processing is managed by FORTRAN executables. The optimization module (including S/R and their application) uses MATLAB functions. RIAT+ database is developed in Apache Derby, an open source relational database implemented entirely in Java. RIAT+ GIS interface is implemented using NASA World Wind and can interact with GOOGLE EARTH. So with the exception of the computation modules, RIAT system is developed with open-source technologies.

RIAT+ is developed for Windows operating systems.
The minimum hardware requirements are:
- CPU, no request, the current standard (3 - 3.50GHz) will guarantee an acceptable computation time
- RAM: minimum 2GB
- Disk storage: minimum 4GB (each simulation will require additional disk space)

RIAT+ has a user friendly interface that sequentially guides the user by the folder approach through eight main modules which could be directly accessed with some sequencing rules (detailed in the following chapters) through the general project set-up configuration screen (see Figure 3-1).
Besides the GUI, the main RIAT+ modules are the following :
- *Project Setup*
- *Domain*
- *Emission Inventory*
- *Measures (database and management)*
- *S/R Functions*
- *Run Preprocessing*
- *Run Settings*
- *Run Results*

This User Guide provides a chapter for each module describing step by step how to obtain an evaluation run. For technical details reference should be done to the second part of this guide. A great part of this User Guide is available directly through the *Help* html page present in each RIAT+ screen.

1.2 RIAT+ installation

The installation kit includes:

- RIAT+ (RIAT+ setup - Riat+Setup.exe)
- Java virtual machine (Java Runtime Environment installer - jre-7u25-windows-i586.exe)
- Google Earth (last version - GoogleEarthSetup.exe)[1]
- MatLab Compiler Runtime installer (MCRInstaller.exe)
- This user manual (RIAT+UserGuide.pdf)
- Instruction to install (readme.txt)
- End User Licence Agreement (EULA)

Three different paths are possible in the RIAT+ installation:

- The first installation of RIAT+ pack
- The installation of updated RIAT+ pack
- The updating of a previous RIAT+ version

In the case of the first installation of RIAT+ pack, these instructions have to be followed:

- RIAT+ needs the installation of Java virtual machine (uninstall old Java version), Run jre-7u25-windows-i586.exe, MCRInstaller.exe and optionally GoogleEarthSetup.exe;
- Run RiatSetup+.exe.

In the case of the installation of update RIAT+ pack these instructions have to be followed:

- Before installing RiatSetup+.exe, it is mandatory to uninstall the previous version;
- It is supposed that Java virtual machine, MCR and GoogleEarth has been already installed.
- Run new version of RiatSetup+.exe;

In the case of the updating of a previous RIAT+ version these instructions have to be followed:

- Substitute the RIAT.jar file in the installation directory.

All setup files are included in the installation pack.

1.3 RIAT+ directory structure

Generally RIAT+ is organized into two main folders: one dedicated to the installation of the system and a second dedicated to the data of a specific region (and also to more than one region).
RIAT+ installation folder is composed of 3 subfolders:

- *Help*: it contains the .html pages of the user guide;
- *Images*: it contains screen shot figure, project logos and images use in the graphical user interface;
- *Riat_lib*: it contains java libraries used in graphical user interface.

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[1] Optional: useful to display the maps outside RIAT+ environment

RIAT+ data folder is composed of 3 main subfolders:

- ***Logs***: it contains log files related to each run and to each activity made through the GUI; there are three kinds of file: one called "err" concerns the errors related to the various processes integrated in the GUI and the errors related to the GUI itself; the others called "log" and "out" describe log information about the processes and the GUI itself. The user can always examine all these files;
- ***Bin***: it contains .exe files, the core of the system; they are the pre-processors, the post-processors, pre-calculation module and optimization module; the user cannot change these files;
- ***Data region***: it contains all input and output data: subfolders, their contents and their relationship are better explained in the following Paragraph; the system is able to manage more than one region, so data region folder could be more than one.

1.4 RIAT+ data structure

"Data region" folder is made up of 7 sub-folders:

- ***Cfg***
- ***Db***
- ***Input***
- ***Project***
- ***Run***
- ***Shape***
- ***Static***

A general description of these folders, their contents and their relationships is provided below. The contents of some of these folders is better described in the following Paragraphs.

- ○ ***Cfg***: it contains configuration files. They describe the choice made in the main GUI (Domain, Emission Inventory…);
- ○ ***Db***: it contains the measure database in Excel™ format. The user can change this file and can add other databases in these folder using the format described in Paragraph 6.1;
- ○ ***Input***: see the Paragraph 3.1.1;
- ○ ***Project***: all the data pre-processed for each Policy Application Domain (about PAD, see the Paragraph 8.2.1);
- ○ ***Run***: all files related to the run, such as configuration files and output file, are stored in this folders;
- ○ ***Shape***: it contains any shapes to be overlapped to the map visualization in the output section;

o **Static**: it contains the file external_cost_oth_data.csv[2] contains impacts (first column, [cases/year*person*conc]) and costs (second column, [euro/cases]) coefficients, required to compute external costs associated to PM10, and following the ExternE approach (http://www.externe.info).

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[2] In particular the different rows represent:
- Asthmatic/Adults: bronchodilator use
- Asthmatic/Adults: cough
- Asthmatic/Adults: respiratory symptoms
- Asthmatic/Children: bronchodilator use
- Asthmatic/Children: cough
- Asthmatic/Children: respiratory symptoms
- Adults over 65 years: heart attack
- Children: chronic cough
- Adults: Restricted activity days
- Adults: chronic cough
- Total population: chronic mortality
- Total population: Respiratory hospital admissions
- Total population: Cerebrovascular hospital admissions
- Adults over 30 years: Years of Life Lost

2   MAIN ELEMENTS OF RIAT+ GUI

2.1   RIAT+ main menu bar

From the RIAT+ main menu bar the user can select three options:
- *File*
- *Tools*
- *Help*
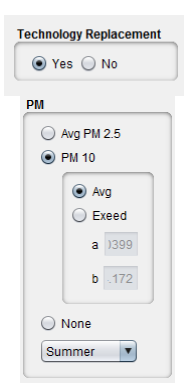
Each of these options offers the user a list of actions: they are summarized in the following table.
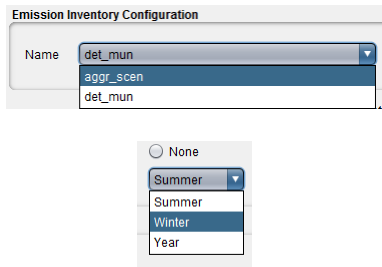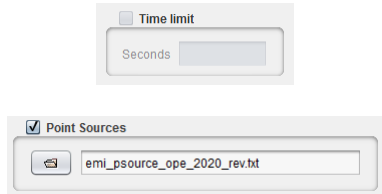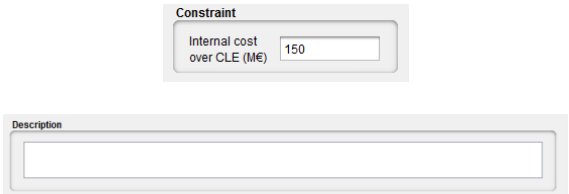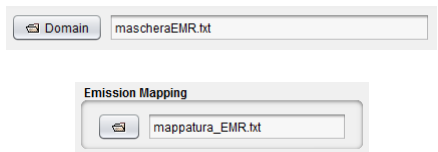
RIAT+ Menu bar options	Functionalities
File	• *Exit*: it closes RIAT+ application • *Exit and switch to region...*: it allows to switch from the current region to another
Tools	• *Log Window*: it opens the log file that records all RIAT+ activities and actions • *Open data directory*: it directly links to RIAT+ data directory • *Show run results*: it directly links to run results GUI (see Paragraph 8.4 and Chapter 10) • Create new region structure (see Paragraph 3.1)
Help	• *Contents*: it is the Help • *About*: some information about the software • *Glossary*: the list of main acronyms and abbreviations

Figure 2-1: RIAT+ main menu options

2.2   Graphical User Interface elements

Below, there is a list of graphical user interface elements available to the user to provide input, query and interact with RIAT+ is presented.

Name	Description	Example
Radio button	This graphical element allows the user to choose only one of a predefined set of options. Radio buttons are displayed on screen as a list of circular holes that can contain white space (unselected) or a dot (selected), accompanied by a label. When the user selects a radio button, any previously selected radio button in the same group becomes deselected.	

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Drop-down list	It is a user interface control GUI element, similar to a list box, which allows the user to choose one value from a list. When a drop-down list is inactive, it displays a single value. When activated, it displays (drops down) a list of values, from which the user may select one. When the user selects a value from the list, the control reverts to its inactive state, displaying the selected value.	
Check box	It is a GUI control that permits the user to make multiple selections. It is shown on the screen as a square box that can contain white space (for false) or a tick mark (for true), accompanied by a label or caption. Inverting the state of a check box is done by clicking the mouse on the box.	
Text box	A text box allows the user to input text information to be used by the program. It is shown on the screen as a rectangle of any size with a border that separates it from the rest of the interface. The user can type in text using the keyboard after clicking with the mouse on the text box. During this operation a text cursor is displayed, indicating the current region of text being edited	
Browse button	This button allows the user to select files to use as input to the software. When the user clicks on it with the mouse, a special window is shown on the screen. This button is composed by a rounded rectangle with the icon of an open folder in its centre (sometimes accompanied by a label). After the selection of the file, the filename is shown in the text box to the right of the button.	
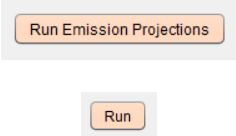
GUI buttons	Each of these buttons opens a special screen that allows the user to select input file for the software. These buttons are shown as rounded rectangles with a descriptive caption in their center. More details about the specific function of each of them will be provided later in the text.	
Run button	This button allows the user to run the program by clicking on it. It is displayed on the screen as a pink rounded rectangle with a descriptive caption in its centre.	

Figure 2-2: Graphical user interface elements used in RIAT+

3   PROJECT SETUP

RIAT+ first screen (named ***RIAT+*** and shown in Figure 3-1) shows the project setup helping the user to save its comments, the description and the configuration of his project (in terms of input). RIAT+ system installation provides sample configurations for the two test-cases of Alsace and Emilia-Romagna Region.
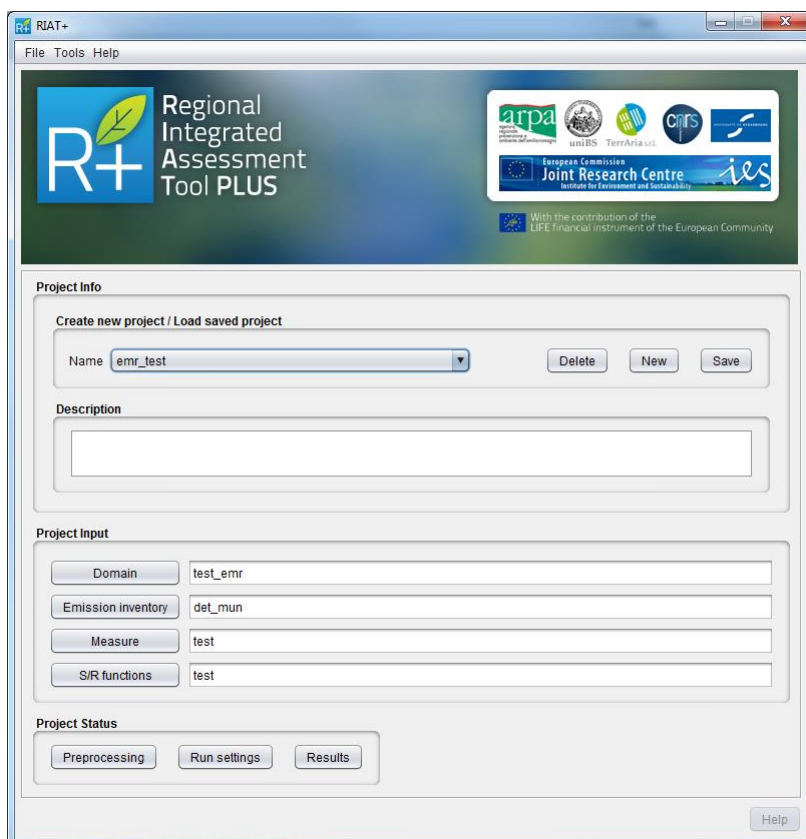
Figure 3-1: RIAT+ GUI: Project set up.

3.1   New region start up

To create a new region data structure, click on ***Tools*** from the menu bar at the top of the main RIAT+ screen and select ***Create a new region structure***. This will open the screen shown in Figure 3-2.
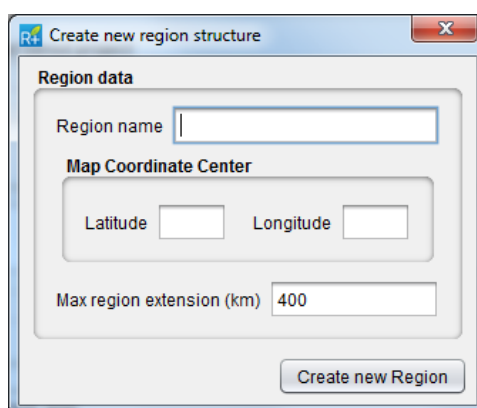
Figure 3-2: Create a new region structure screen.

To create a new region structure the user has to enter:

- ***Region name*** – it concerns only the data structure of the new region, it does not affect the graphical user interface
- Latitude and longitude coordinates map center, used for the GIS mapping
- ***Maximum regional extension*** –the value 400 km is used as default for GIS mapping in output section (see Paragraph 10.6): if the region dimension is larger than this value, the user should enter a higher value (this is only an indicative value to set the GIS view)

When all these fields are completed, the user has to click ***Create a new Region*** button.

The system creates a new input folders structure, where all the user's input data will be saved (see Paragraph 3.1.1).

3.1.1   Input data structure

It contains all the files, mandatory or not, used to create a new project. All subfolder names are fixed. The structure is composed of:

- ***dom_domain***: it contains the ***domain definition*** file (about the format description see Paragraph 4.1);
- ***dom_external_cost***: it contains ***external costs*** file (see Paragraph 4.4);
- ***dom_population***: it contains ***population*** file (see Paragraph 4.4);
- ***dom_sub_domain***: it contains all ***subdomain*** files (see Paragraph 4.4););
- ***emi_as_gridded_region_emission***: it contains ***gridded region emissions*** file (see Paragraph 5.6.3.1);
- ***emi_as_point_source***: it contains ***point sources emissions*** files for the whole domain (see Paragraph 5.6.3.2);
- ***emi_biogenic_emission***: it contains ***biogenic emissions*** files (see Paragraph 5.6.4);
- ***emi_dg_areal_sources_inside_region***: it contains ***areal sources emissions*** files for inside region with activity detail (see Paragraph 5.6.2.1);
- ***emi_dg_outside_region_emission***: it contains ***areal sources emissions*** files from outside the region with macrosector detail (see Paragraph 5.6.2.2);
- ***emi_dg_point_source***: it contains ***point sources emissions*** files for the whole domain (see Paragraph 5.6.2.3);
- ***emi_dm_activity_proxy_assignment***: it contains the ***assignment*** file defining the correspondence between the activities and the proxy disaggregation variables (see Paragraph 5.6.1.4);
- ***emi_dm_areal_source***: it contains ***municipality emissions*** files for inside region with activity detail (see Paragraph 5.6.1.1);
- ***emi_dm_outside_region_emission***: it contains ***areal sources emissions*** files from outside the region with macrosector detail (see Paragraph 5.6.1.3);
- ***emi_dm_point_source***: it contains ***point sources emissions*** files for the whole domain (see Paragraph 5.6.1.2);
- ***emi_dm_proxy_variable***: it contains ***proxy variable*** files for spatial disaggregation (see Paragraph 5.6.1.4);
- ***emi_dm_temporal_disaggregation***: it contains ***proxy variable*** files for temporal disaggregation (see Paragraph 5.6.1.5);

-   ***emi_emission_mapping***: it contains the ***mapping*** file with the correspondence between the regional activity and the classification of the measures (see Paragraph 5.3)
-   ***emi_temporal_horizon***: it contains the ***temporal horizon*** file (see Paragraph 5.5)
    emi_temporal_profile: it contains the ***temporal profile*** file (see Paragraph 5.4)
-   ***pre_emission_level_areal***: it contains emission level scenarios for areal sources (see Paragraph 8.3.1);
-   ***pre_emission_level_point***: it contains emission level scenarios for point sources (see Paragraph 8.3.1);
-   ***pre_total_scenarios***: it contains the file with all different combinations of the emission levels for areal and point sources (see Paragraph 8.3.1);
-   ***srf_model_bias***: it contains ***model bias*** file (see Paragraph 7.2);
-   ***srf_network***: it contains all ***neural networks*** files (see Paragraph 7.1).

3.2 Test-cases

RIAT+ system installation provides two test-cases with standard configuration for:

-   Alsace region – where the emission inventory is detailed for emission activity and cell in the gridded on the domain;
-   Emilia-Romagna region – where the emission inventory is detailed for emission activity and municipality in the domain.

To switch from a test-case to another one the user has to click ***File*** in main menu and select ***Exit and switch to region ...***. The system switches RIAT+ to the selected region.

3.3 New project setup

The initial RIAT+ screen (see again Figure 3-1) consists of three main parts (boxes). The system leads the user through a sequence of steps making some parts and buttons in the ***RIAT+*** screen available or not.
The main functionalities of the three boxes are:

-   ***Project Info*** box: lets the user upload an existing project or create a new one
-   ***Project Input*** box: lets the user go directly to the appropriate module to set any mandatory information files for the system
-   ***Project Status*** box: lets the user go to the "operative" sections of the system and to see the output for an existing project.

When the user creates a new project not all buttons are available in the ***RIAT+*** screen. In the ***Project Input*** box three buttons are active and they are: **Domain**, ***Emission Inventory***, and ***Measures DB***. These buttons connect the user respectively to the screen to enter domain information (Chapter 4), with the screen to upload regional emission inventory (Chapter 5) and the screen to upload the measure database (Paragraph 6). These three buttons can be selected without following a specific order. The S/R configuration depends on the temporal profile that is specified in the ***Emission Inventory*** screen.
In the ***Project Status*** box, at this stage of the project, no button is available because

input is not yet completed.

After the user has completed domain, emission inventory and measure configuration, also the *S/R Functions* button becomes active.

When all the configuration input (Domain, Emission Inventory, Measures and S/R Functions) has been completed, the *Preprocessing* button becomes available in the *Project Status* box. So the user can go to the *Preprocessing* screen providing all the mandatory information and can then execute the *Emissions Projection* run (see Paragraph 8).

Until the *Preprocessing* run is not finished, the *Run Settings* and *Results* buttons are not available in the *Project Status* box.

When the *Preprocessing* run is successfully completed, also the *Run Settings* and *Results* buttons become available and the user can go to the *Run Settings* screen to prepare the run configuration.

The logical sequence just described is the "general" logical sequence, but there is a case in which this sequence is different: when the user selects *Aggregated Scenario* in *Emission Inventory* screen not all buttons are available in the *RIAT+* screen; in the *Project Input* box, three buttons are active: *Domain*, *Emission Inventory*, *S/R Functions* but not *Measures DB*. The rest of the sequence is the same.

In general, the *Results* button in the *Project Status* box links to the *Run Results* screen that shows all the executed (or in progress) runs related to the project. This screen is a sort of mix between the *Pre-run Results* screen and *Run Results* (see Paragraphs 8.4 and 10.1).

Figure 3-3: RIAT+ logical sequence

4   DOMAIN

The **Domain** screen allows the user to enter geographic data, domain info and all the data connected to grid format. The user can use an existent configuration file (uploading all the previously defined information) or create a new domain configuration.
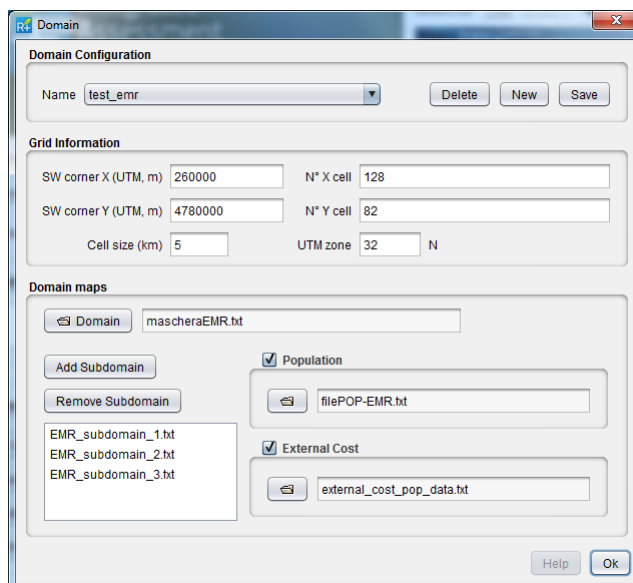
Figure 4-1: RIAT+ GUI: Domain

It is assumed that each cells is identified by its South-West corner. It is mandatory that all input files are consistent with the grid chosen and set.
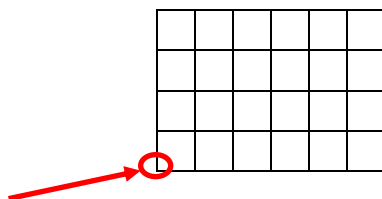
In the first part of the screen, the user sets the gridding data (**Grid Information** box):
- Grid origin: X UTM (m) , Y UTM (m) of the origin (South-West corner of the first cell);
- Cell size (km);
- Number of rows;
- Number of columns;
- UTM zone.

In the second part of the screen (**Domain Maps** box) the user enters txt files:
- Domain;
- Subdomains;
- Population;
- External costs.

Only the **domain** file is required. **Subdomains**, **population** and **external costs** files are optional.

4.1 Domain file

It is a txt file containing information about the whole domain. Domain consists of the region interested in optimization and some area outside the region. The **domain** file contains all the cells involved in the grid domain. They are always divided in: cells inside the region, cells outside the region and boundary (overlapping) cells.

The first line of the file is the header. The second line is equal to 3 and indicates the number of zones in which the domain is divided: inside region, outside region and boundary cells. Then there are 2 columns. In the first column the user has to specify the codes to identify the different classified areas and in the second column the relative names. The codes are:

- 0: outside region;
- 1: inside region;
- 2: boundary cells.

The rest of the lines contains: XUTM and YUTM [m] cell coordinates (South-West corner) and the relative domain code.

Domain		
3		
0	Outside	
1	Inside	
2	Boundary	
XCell	YCell	Code
260000	4780000	0
260000	4785000	0
260000	4790000	0
260000	4795000	0
...	...	

Table 4-1: Example of domain file.
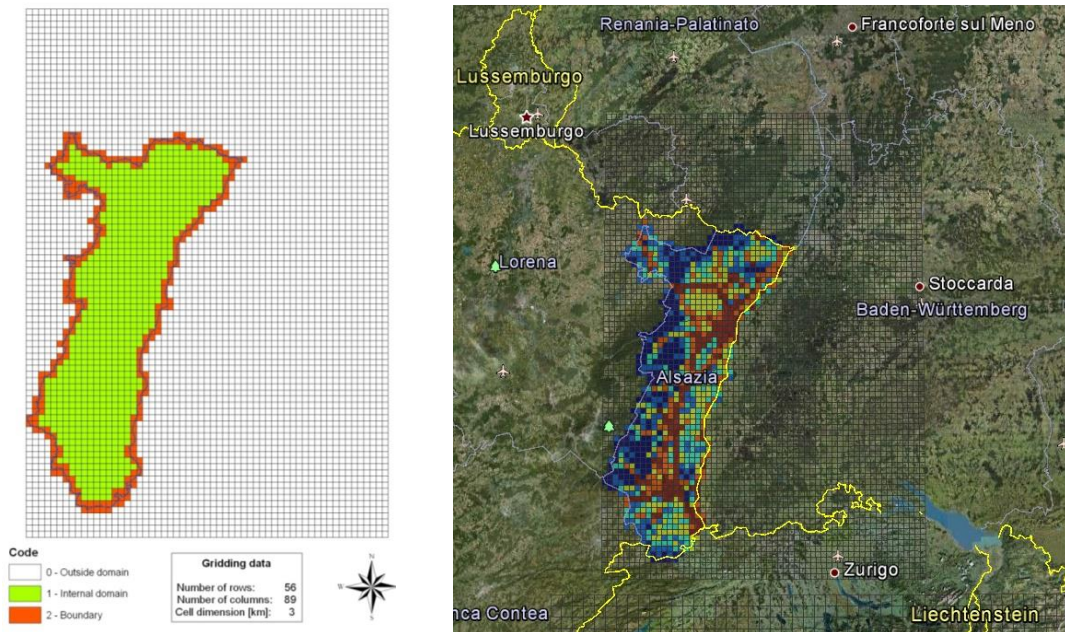
Figure 4-2: Example of region Domain in RIAT+

4.2 Subdomain file

This txt file contains information about a subdomain. It is possible to enter more than one file. By default if no file is entered, the whole region is considered (inside and border cells domain).
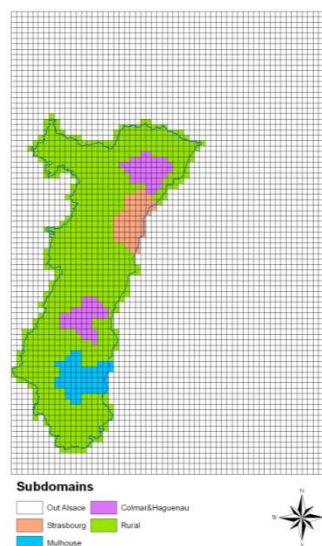
Figure 4-3: Example of subdomain in RIAT+

The first line is the header. The second line contains the number of subdomains plus one (i.e. the number of zones + outside the optimization domain).

Then there are 2 columns. In the first column, the user has to specify the codes to identify the different subdomains areas, the first line must to be 0 and corresponds to the area outside the optimization domain. In the second column, the user specifies the names of the subdomains.

After these lines (their number is variable) there is another header line. The following lines contain:

- XUTM and YUTM [m] cell coordinates (South-West corner);
- SUB_CODE = the code of each cell based on codes specified in the previous lines.

Subdomain		
5		
0	Outside	
3	Strasbourg	
4	Mulhouse	
5	Colmar&Haguenau	
6	Rural	
XCell	YCell	Code
338000	5498000	0
338000	5495000	0
338000	5492000	0
338000	5489000	0
...	...	

Table 4-2: Example of subdomain file

*Each cell outside the considered region must have a code 0 both in **subdomain** files and in the domain file; similarly each cell inside the domain must have a code different from 0 both in **subdomain** files and in the **domain** file.*

4.3   Population

This txt file contains resident population for each cell. The first line is the header. For the following lines, the data format is:

- XUTM and YUTM [m] are cell coordinates (South-West corner);
- POP that is resident population for each cell (number of habitants).

4.4   External cost

This txt file contains information to detail population data, for the different cells; this information is required to compute external costs. In particular, each row corresponds to a cell of the domain. Columns represent (excluding the first 2 columns, that list XUTM and YUTM coordinates):

- Population % per age (first 9 columns, representing the following age ranges):
  - 0-5
  - 6-10
  - 11-14
  - 15-19
  - 20-24
  - 25-29
  - 30-59
  - 60-64

- ▪ >65
  - − mortality rate per age (%), (columns from 10 to 18):
    - ▪ 0-5
    - ▪ 6-10
    - ▪ 11-14
    - ▪ 15-19
    - ▪ 20-24
    - ▪ 25-29
    - ▪ 30-59
    - ▪ 60-64
    - ▪ >65
  - − % asthmatic, per age class over total population (columns from 19 to 21)
    - ▪ 0-14
    - ▪ 15-64
    - ▪ >65
  - − fraction of population > 30 years (column 22)

5   EMISSION INVENTORY

There are two main areas on the screen. The left area concerns details about emission type, pollutants, mapping for measure database correspondence, temporal and horizon profile and reference year. The area on the right deals with the emissions inventory (this area allows to change the required inputs according to the emission type selected by the user).

In this screen, the user can select an existent configuration file (uploading all the previously defined information) or create a new Emission Inventory Configuration.


Figure 5-1: RIAT+ GUI: *Emission inventory – Annual Municipality*.

5.1   Emissions

The system can manage three different kinds of emissions inside the region. They are characterized by different spatial, temporal, and activity or macrosector aggregation. They are:

- Municipalities (polygonal) and annual emissions with regional activity and fuel detail
- Gridded and temporal disaggregated emissions with regional activity and fuel detail
- Gridded and temporal disaggregated emissions with macrosector detail.

According to the kind of the emission chosen, the user can select the proper radio-button located on the top-left side of the screen. The different kinds of emissions aggregation are described below (see Paragraph 5.6).

5.2 Pollutant

By default, precursors considered are:
- Nitrogen Oxide (NO$_x$)
- Volatile Organic Compound (VOC)
- Ammonia (NH$_3$)
- Particular Matter (PM10 and PM2.5)
- Sulfur Dioxide (SO$_2$).

If necessary, the user may modify the pollutant code.

The **Add** button allows the user to enter additional pollutants with the corresponding code.

Pay attention that, regardless of the code entered by the user in this screen, all output files of RIAT+ have the following configuration for pollutant codes:

Pollutant	Code
NO$_x$	1
VOC	2
NH$_3$	3
PM10	4
PM2.5	5
SO$_2$	6

5.3 Emission Mapping

Since the GAINS database[3] is used to describe the activity in terms of costs and application rates, but this database may have different emission regional activity (and fuel) classification, a correspondence between classifications is necessary.

In this box, the user may enter a txt file containing this correspondence. For municipalities, emissions and gridded emissions options this file is required with activity detail; in case of gridded emissions with macrosector detail, the box is disabled.

The format for the input data (first line is the header) is:
- SNAP97 - regional activity and fuel code pair;
- Related GAINS SNAP1-sector-activity triple.

Activity	Fuel_code	SNAP1	Sector	Activity
8	203	1	123	31
8	204	1	123	36
8	301	1	123	23
9	102	1	123	28
13	203	1	20	31
456	301	2	33	23
33	102	2	33	13

Table 5-1: Example of mapping file

---

[3] http://www.iiasa.ac.at/web/home/research/modelsData/GAINS/GAINS.en.html

*All activity-fuel pairs listed in the **municipality/gridded emissions** file must be listed in the **mapping** file. All SNAP1-Sector-Activity triples listed in **mapping** file must be listed in the **DB Measures** file (see Paragraph 6.1).*

5.4 Temporal profiles

By default, an annual profile[4] is considered and the input box is disabled.

To enter another temporal profile, the check box should be selected and the user may enter a txt file.

The format for the input file should be:

- First row: header of temporal profiles
- Following rows: name of temporal profile

Semester
winter
summer

Table 5-2: Example of temporal profile file

The maximum number of temporal profiles that can be entered is 4.

5.5 Temporal horizon

By this button, the user may enter a txt file containing the years of the temporal horizon.

2005
2010
2015
2020

Table 5-3: Example of temporal horizon file

The number of years in the temporal horizons must be 4.

According to the data entered in the txt file, the user may select the reference year in the list box below.

5.6 Emission inventory input

5.6.1 Annual Municipality Input file format

5.6.1.1 Areal sources inside the region

In this input box, the user can enter a txt file containing areal emission data for each municipality/polygonal-shape of the region. The emissions are in tons per year.

The data format is:

- SPAT_COD: spatial (i.e municipality) code
- MS: macrosector code
- ACT: regional activity code
- FUEL: regional fuel code

---

[4] In this guide, with "temporal profile" we refer to time interval.

- POLL: pollutant code
- EMISSION: emission value in tons per year

SPAT_COD	MS	ACT	FUEL	POLL	EMISSION
12001	1	30	10000	2	0.00365
12001	1	30	10000	8	0.01384
12001	1	31	10000	2	0.00032
12001	1	31	10000	8	0.00749
12001	1	33	10000	2	0.0009
12001	1	33	10000	8	0.01317
12001	2	40	10000	8	0.00405

Table 5-4: Example of areal emission file

5.6.1.2 Point sources

Point sources emission data are optional. The user may enter this data type after selecting the appropriate check box.

The emissions have to be annual.

The **point emissions** file contains annual values from point source inside and outside region. Each line (the first is the header) contains data in the following format:

- XUTM: x UTM (m) of the point source
- YUTM: y UTM (m) of the point source
- MS: macrosector code
- ACT: regional activity code
- FUEL: regional fuel code
- POLL: pollutant code
- EMIS: emissions in tons per year
- IN_OUT: source location (IN: inside the region domain, OUT: outside the region domain)
- HGT: point source stack height in meters
- DIAM: point source stack diameter in meters
- TEMP: flue temperature in °C
- VEL: flue velocity in m/s

These files contain emissions from inside and outside the region. Outside emission activity and fuel codes are not mandatory (zero values is allowed).

XUTM	YUTM	MS	ACT	FUEL	POLL	EMIS	IN_OUT	HGT	DIAM	TEMP	VEL
263654	4785988	1	0	0	1	41.256	out	100	2.0	135.0	29.0
263654	4785988	1	0	0	2	4.6846	out	100	2.0	135.0	29.0
263654	4785988	1	0	0	3	0.2581	out	100	2.0	135.0	29.0
263654	4785988	1	0	0	5	44.987	out	100	2.0	135.0	29.0
755350	4930100	9	411	14	1	0.0035	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	2	123.05	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	3	0.0035	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	5	0.0035	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	6	0.0035	in	60	1.2	100.0	10.0
...	...										

Table 5-5: Example of point sources file

User Instructions

5.6.1.3   Outside region emissions

Areal emission data from outside the region are with macrosector detail, one file for each pollutant. These files contain annual emissions.

Format data is:

- XUTM: x UTM (m) cell coordinate (South-West corner);
- YUTM: y UTM (m) cell coordinate (South-West corner);
- EMISSION_MS1: emission value of macrosector 1 in tons per year
- EMISSION_MS2: emission value of macrosector 2 in tons per year
- …
- EMISSION_MS11: emission value of macrosector 11 in tons per year

These files contain all cells in the domain but the inside ones must have zero emission (Figure 5-2). Entering a non-zero value for an inside cell is an error.
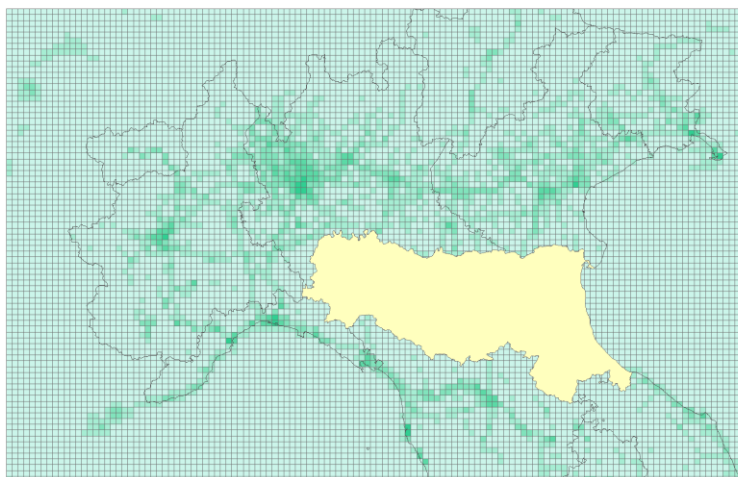
Figure 5-2: Example of outside region emission data

If the user enters separately the biogenic emissions (see Paragraph 5.6.4), the macrosector 11 has to be included in this file. The emission values can be set to zero.

XUTM	YUTM	MS1	MS2	MS3	MS4	MS5	MS6	MS7	MS8	MS9	MS10	MS11
260000	4780000	0.004	0.024	0.002	0	0	0	0.00	0.045	0.012	0	0
260000	4785000	0.003	0.021	0.002	0	0	0	0.001	0.040	0.011	0	0
260000	4790000	0.004	0.027	0.003	0	0	0	0.002	0.051	0.014	0	0
260000	4795000	0.004	0.028	0.002	0	0	0	0.002	0.046	0.014	0	0
260000	4800000	0.410	7.595	0.263	0	0	0	0.485	1.706	2.342	0	0
260000	4805000	0.562	6.351	2.369	0	0	4.52	0.514	1.258	9.658	0	0
…	…											

Table 5-6: Example of outside region emission file

With the **Outside Projected Emission** radio button, it is possible to specify whether the outside region emissions are already projected to the CLE optimization year or not. In case the user selects "No" outside emissions will be projected with a CLE average.

5.6.1.4 Spatial disaggregation

In the ***Spatial Disaggregation*** box, the user has to enter all the necessary parameters for the gridding emissions procedure.

The input data are two txt files. The first (***Activity Proxy Assignment***) contains the correspondence between the regional emission activity code and the gridding indicator code. The second (***Proxy Variables***) contains the gridding indicator value for each cell/municipality/gridding indicator triple.

The ***Activity Proxy Assignment*** file has in each line (the first is the header):
- ACT: activity code
- IND_CODE: gridding indicator code

ACT	IND_CODE
2	2
4	2
5	2
7	2
30	11
31	11
40	12
41	3
...	...

Table 5-7: Example of activity proxy assignment file

*All activities listed in the **municipality emission** file should be listed in the **activity proxy assignment** file.*

Each line of ***Proxy Variables*** file contains data in the following format (the first line is the header):
- XUTM and YUTM [m] cell coordinates (South-West corner);
- MUN_CODE: municipality code;
- IND_CODE: gridding indicator code;
- VAL_IND: the gridding disaggregation value depending on cell (x and y coordinates), municipality and of course gridding indicator code.

XUTM	YUTM	MUN_CODE	IND_CODE	VAL_IND
515000	4935000	33030	15	0.00275
515000	4940000	33047	2	0.00004
515000	4940000	33030	2	0.01871
515000	4940000	33030	12	0.36942
515000	4940000	33030	13	0.00704
515000	4940000	33030	15	0.19341
515000	4945000	33041	1	1.00000
...	...			

Table 5-8: Example of proxy variables file

Proxy variables file has the following requirements:

- *All gridding indicator codes should be listed in the* **activity proxy assignment** *file;*
- *The gridding disaggregation value should be between 0 and 1;*
- *The sum of the gridding disaggregation value for each municipality and for each gridding indicator code should be 1.*

5.6.1.5   Temporal disaggregation

The input txt file contains the parameters for temporal disaggregation. The box is disabled for annual profile.

The first line is the header and then the following lines contain data in the format:

- MS: macrosector code;
- MM: number of temporal profiles;
- $PV_{p,t}$: coefficients for temporal disaggregation (t) and for each pollutant (p) .

MS	MM	NOx	COV	NH3	PM10	PM25	SO2
1	1	0.4498	0.4591	0.444	0.4514	0.4514	0.4491
1	2	0.5503	0.5411	0.556	0.5485	0.5485	0.551
2	1	0.0781	0.0801	0.079	0.0803	0.0803	0.0784
2	2	0.9219	0.92	0.921	0.9198	0.9198	0.9216
3	1	0.4586	0.1056	0.5022	0.4574	0.4574	0.4013
3	2	0.5414	0.5945	0.4976	0.5427	0.5427	0.5988
…	…						

Table 5-9: Example of outside region emission

The sum of temporal coefficients for each pollutant and temporal profile should be 1.

The order of the pollutants from NO_x to SO_2 is mandatory. Any other pollutant entered by user should be listed in the same order after SO_2 values.

5.6.2   Detailed Gridded emission inventory

Figure 5-3: RIAT+ GUI: *Emission Inventory – Detailed Gridded*.

5.6.2.1   Areal sources inside the region

In this input box, the user can enter a txt file for each temporal profile containing areal emission for each cell inside the region. The data format is (the first line is a header):

- XUTM and YUTM [m] cell coordinates (South-West corner)
- MS: macrosector code
- ACT: regional activity code
- FUEL: regional fuel code
- POLL: pollutant code
- EMISSION: emission value in tons

XUTM	YUTM	MS	ACT	FUEL	POLL	EMISSION
338000	5297000	2	43	204	1	0.00365
338000	5297000	2	43	204	2	0.01384
338000	5297000	2	43	204	3	0.00032
338000	5297000	2	43	204	4	0.00749
338000	5297000	2	43	204	5	0.0009
338000	5297000	2	43	204	6	0.01317
338000	5297000	2	456	12	1	0.005462
338000	5297000	2	456	12	2	0.01562
338000	5297000	2	456	12	3	0.07548
...	...					

Table 5-10: Example of areal emission

Pay attention that these files contain only the cells inside the domain (border ones included).

5.6.2.2 Outside region emissions

Outside region areal emission data are with macrosector detail, one file for each pollutant, and for each temporal profile.

The data format is:

- XUTM: x UTM (m) cell coordinate (South-West corner)
- YUTM: y UTM (m) cell coordinate (South-West corner)
- EMISSION_MS1: emission value of macrosector 1 in tons
- EMISSION_MS2: emission value of macrosector 2 in tons
- …
- EMISSION_MS11: emission value of macrosector 11 in tons

These files contain all cells in the domain, but the inside ones must be with zero emission. Enter non-zero emission for an inside cell is an error.

XUTM	YUTM	MS1	MS2	MS3	MS4	MS5	MS6	MS7	MS8	MS9	MS10	MS11
260000	4780000	0.004	0.024	0.002	0	0	0	0.002	0.045	0.012	0	0
260000	4785000	0.003	0.021	0.002	0	0	0	0.001	0.040	0.011	0	0
260000	4790000	0.004	0.027	0.003	0	0	0	0.002	0.051	0.014	0	0
260000	4795000	0.004	0.028	0.002	0	0	0	0.002	0.046	0.014	0	0
260000	4800000	0.410	7.595	0.263	0	0	0	0.485	1.706	2.342	0	0
260000	4805000	0.562	6.351	2.369	0	0	4.521	0.514	1.258	9.658	0	0
…	…											

Table 5-11: Example of outside region emission

If the user enters separately the biogenic emissions (see Paragraph 5.6.4), the macrosector 11 has to be included in these files. The emission value can be set to zero.

With the **Outside Projected Emission** radio button, it is possible to specify whether the outside region emissions are already projected to the CLE optimization year or not. In case the user selects "No" outside emissions will be projected with a CLE average.

5.6.2.3 Point sources

Point sources emission data are optional. The user may enter this data type after selecting the appropriate check box.

The system requires a file for each temporal profile. Each file contains point source emission data inside and outside the region.

The format required (the first line is a header) is:

- XUTM: x UTM (m) of the point source
- YUTM: y UTM (m) of the point source
- MS: macrosector code
- ACT: regional activity code
- FUEL: regional fuel code
- POLL: pollutant code

- EMIS: emissions in tons
- IN_OUT: the source location (IN: inside the domain, OUT: outside the domain)
- HGT: point source stack height in meter
- DIAM: point source stack diameter in meter
- TEMP: flue temperature in °C
- VEL: flue velocity in m/s

Pay attention that all these files contain emissions inside and outside the region. When a point source is outside the region, it has only macrosector detail so regional activity and fuel code are set to zero.

XUTM	YUTM	MS	ACT	FUEL	POLL	EMIS	IN_OUT	HGT	DIAM	TEMP	VEL
263654	4785988	1	0	0	1	41.256	out	100	2.0	135.0	29.0
263654	4785988	1	0	0	2	4.6846	out	100	2.0	135.0	29.0
263654	4785988	1	0	0	3	0.2581	out	100	2.0	135.0	29.0
263654	4785988	1	0	0	4	1.258	out	100	2.0	135.0	29.0
263654	4785988	1	0	0	5	44.987	out	100	2.0	135.0	29.0
263654	4785988	1	0	0	6	369.68	out	100	2.0	135.0	29.0
755350	4930100	9	411	14	1	0.0035	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	2	123.05	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	3	0.0035	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	4	0.0035	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	5	0.0035	in	60	1.2	100.0	10.0
755350	4930100	9	411	14	6	0.0035	in	60	1.2	100.0	10.0
…	…										

Table 5-12: Example of outside region emission

5.6.3   Gridded macrosector
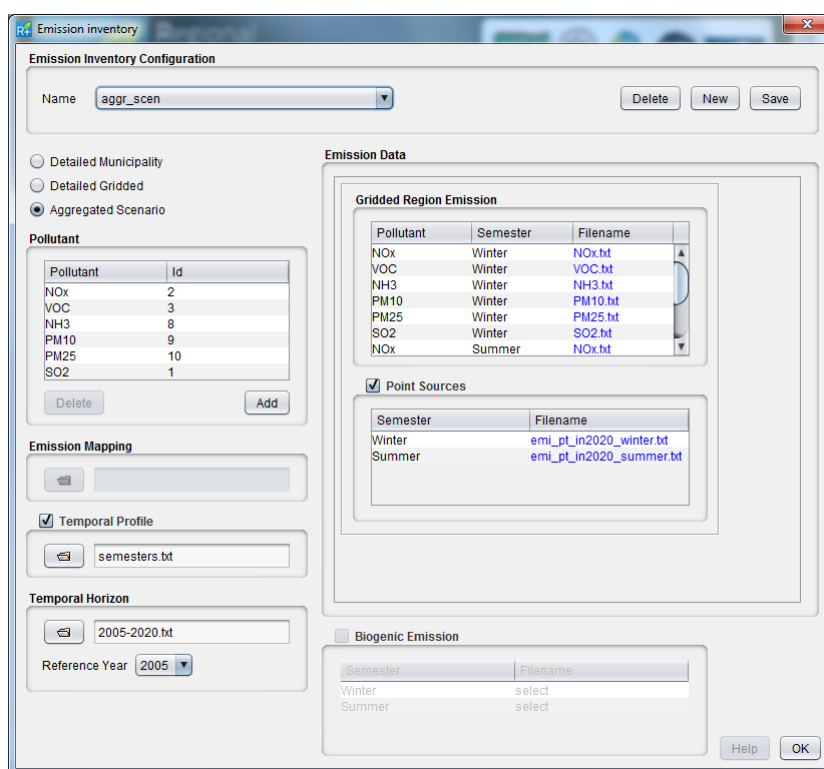
Figure 5-4: RIAT+ GUI: *Emission Inventory – Aggregated Scenario*.

5.6.3.1   Gridded Region Emission

Emission data are in macrosector detail, one file for each pollutant and temporal profile.

The data format is:

- XUTM: x UTM (m) cell coordinate (South-West corner);
- YUTM: y UTM (m) cell coordinate (South-West corner);
- EMISSION_MS1: emission value of macrosector 1 in tons
- EMISSION_MS2: emission value of macrosector 2 in tons
- …
- EMISSION_MS11: emission value of macrosector 11 in tons.

Pay attention that these file has to contain all cells in the domain.

XUTM	YUTM	MS1	MS2	MS3	MS4	MS5	MS6	MS7	MS8	MS9	MS10	MS11
260000	4780000	0.004	0.024	0.002	0	0	0	0.002	0.045	0.012	0	0
260000	4785000	0.003	0.021	0.002	0	0	0	0.001	0.040	0.011	0	0
260000	4790000	0.004	0.027	0.003	0	0	0	0.002	0.051	0.014	0	0
260000	4795000	0.004	0.028	0.002	0	0	0	0.002	0.046	0.014	0	0
260000	4800000	0.410	7.595	0.263	0	0	0	0.485	1.706	2.342	0	0
260000	4805000	0.562	6.351	2.369	0	0	4.521	0.514	1.258	9.658	0	0
…	…											

Table 5-13: Example of gridded region emission (areal source).

5.6.3.2 Point sources

These files have the same format of ***Detailed Gridded Point Sources*** Files. See Paragraph 5.6.2.3.

5.6.4 Biogenic Emissions

In the lower part of the ***Emission Inventory*** screen, the ***Biogenic Emissions*** check box is located: it allows the user to enter separately the biogenic emission. One file for each temporal profile is required.

Pollutant considered are: NO_x, VOC, PM10, PM2.5 and SO_2.

The data format is:

- XUTM: x UTM (m) cell coordinate (South-West corner)
- YUTM: y UTM (m) cell coordinate (South-West corner)
- Following columns: Biogenic Emission respectively for NO_x, VOC, PM10, PM2.5 and SO_2

Pay attention that these file should contain all cells in the domain.
The order of the pollutants from NO_x to SO_2 is mandatory.

XUTM	YUTM	NOX	VOC	PM10	PM2.5	SO2
260000	4780000	0.0042	0.0246	0.0027	0	0
260000	4785000	0.0037	0.0218	0.0024	0	0
260000	4790000	0.0047	0.0277	0.0030	0	0
260000	4795000	0.0044	0.0289	0.0028	0	0
260000	4800000	0.4103	7.5954	0.2638	0	0
260000	4805000	0.5621	6.3512	2.3695	0	0
...	...					

Table 5-14: Example of biogenic emission file.

6   MEASURES

In the **Measures** screen, the user has to enter the Measures Database. Again, the user can select an existent configuration file (uploading all the previously defined information) or create a new measure configuration.
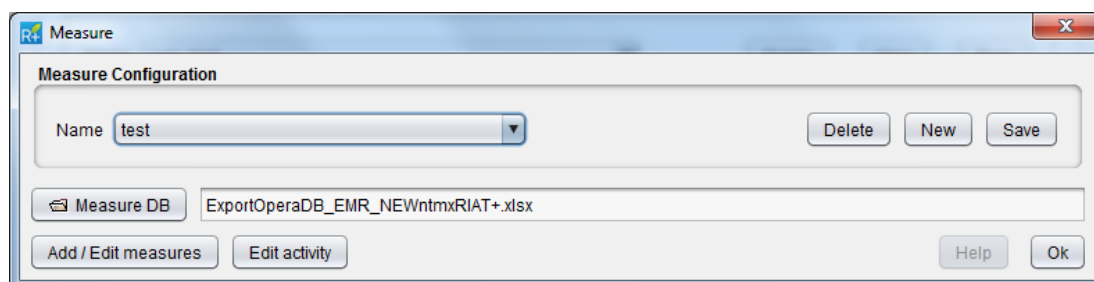
Figure 6-1: RIAT+ GUI: *Measure data*.

From this screen, the user could also decide to modify activities (***Edit Activity*** button) and to modify or create new measures (***Add/Edit Measure*** button): these buttons link to specific screens where also the DB sheet could be opened and measures and activity data could be edited directly.

6.1   Measures DB format

The measures DB is integrated in the system through an Excel file. The measures DB provided for test cases has been downloaded from GAINS database. It is organized in 7 different work sheets.

The name of the sheets and the name of the labels in each sheet is fixed (see test cases).

The 7 sheets of the measures DB are described below:
- UM: defines Activity Level Unit through their name and their associated code
- SNAP: establishes the name/description, the abbreviation and the associated code for each SNAP
- Sector: contains the description, the abbreviation and the associated code for each sector
- Activity: establishes the description, the abbreviation and the associated code for each activity
- Technology: establishes the description, the abbreviation and the associated code for each technology
- Sector – Activity: fixes the association between sector and activity and the code associated to this combination. Others columns represent activity data in this format:
    - Unabated emission factor for the pollutants (PM10, PM2.5, NO_X, SO_2, VOC and NH_3 and for GHG: CO_2, CH_4, N_2O and Fgases), [kton/Act.Lev.Unit];
    - Activity level for the years considered (on the basis of temporal horizon), [unit depends on the type of activity];

- o   Activity Level Unit;
- o   Predominant pollutant in terms of emission for each activity;
- Sector – Activity – Technology: fixes the association between activity and technology and the code associated to this combination. Others columns represent technology data in this format:
  - o   Removal Efficiency (for each pollutant and GHG) expressed as percentage;
  - o   Application rate (CLE and potential, for the years considered in the temporal horizon) expressed as percentage;
  - o   Unit Cost [Meuro/Act.Lev.Unit];
  - o   Flag column that represents if the measure could be replaced or not in a following year by a more efficient one (Replaceable = 0, Not Replaceable = 1);
  - o   Flag column that represents if measure is technical or non technical (Non Technical Measure = 0, Technical Measure = 1).

These requirements are mandatory for measures DB:
- *all measures should have a code between 1 and 9998;*
- *the code 9999 should be assigned to the NOC measure (No Control);*
- *all activities should have at least the NOC measure.*

There are some constraints on the values entered in the measures DB and they are also explained in the following Paragraphs.

To ensure the emission mass balance for each precursor, the sum of the technologies Application Rates for each activity cannot be greater than 100%. This constraint should be valid for each pollutant with Removal Efficiency different from zero.

From **Edit Activities** screen, the user can select any activity and change its parameters. Activities can be modified but not added or deleted.

Figure 6-2: RIAT+ GUI: *Edit Activities*.

Through the **Edit Activities** screen, the user can select a particular measure from the first part of the screen choosing the macrosector (SNAP), the sectors and the activity itself. The main features of the selected activity are shown: Unabated

Emission Factors for each of the 6 precursors and 4 greenhouse gases, Activity Level for all the temporal horizons uploaded in **Emission Inventory** screen and Activity Level Unit (ALU).

The user can enter the desired Unabated Emission Factor and Activity Level in the text boxes. After making the changes, the user has to save the new data with the **Save** button. Otherwise, the **Close** button has to be clicked.

*If changes have been made and saved, when the user comes back to **Measures** screen, s/he is asked if the measures DB has to be changed or the previous one has to be restored.*

Through **Edit All** button the user could edit directly the measure database sheet (Figure 6-3).

Figure 6-3: RIAT+ GUI: *Edit All – measure DB sheet.*

6.2 Edit measures

From **Edit Measures** screen, the user selects all the measures and changes its parameters. Measures can be modified but also created or deleted. All the technologies in the measure database are available for changes.

Figure 6-4: RIAT+ GUI: *Edit Measures.*

From **Edit Measures** screen the user can select a particular measure from the first part of the screen choosing the macrosector (SNAP), the sectors and the activity and the measure itself. The main feature of the technology selected are shown: RE, CLE and Potential AR, UC, if the technology is a technical measure or not, and if it is replaceable or not.

After making the changes, the user has to save the new data with **Save** button. Otherwise, **Close** button has to be clicked.

Clicking the **New** button, it is possible to add a measure to an already existent activity. The **Technology** screen appears (Figure 6-5) and the user has to click **Create New** and to enter the name and the abbreviation. The technology code is assigned by the system and it is a progressive number over the existent technology codes.

Figure 6-5: RIAT+ GUI: *Technology*

*If changes have been made and saved, when the user comes back to the **Measure** screen, s/he is asked if the measures DB has to be changed or the previous one has to be restored.*

Also in **Edit Measures** screen, through **Edit All** button, the user can edit directly the measure database sheet (Figure 6-3).

Only the expert user is suggested to modify the values in the measure DB. Removal Efficiency and Application Rate are expressed as percentage. CLE and Potential Application Rate are between 0 and 100%. As explained before, for each precursor, the sum of the technologies Application Rates for each activity cannot be greater than 100%.

7   SOURCE/RECEPTOR FUNCTIONS

In the *S/R Function* screen, the user may upload the *neural network/model* files. The user can use an existent configuration file (uploading all the previously defined information) or create a new S/R function configuration.

It is mandatory to upload at least one *neural network/model* file. The temporal profile is the same already uploaded in the *Emission Inventory* screen. Each *neural network/model* file for a particular AQI can have a different temporal profile.

In case the user has not yet trained the networks, s/he has the possibility to select the first radio button *Create input for training*. So in *Preprocessing* screen it will be possible to create the emission scenarios useful to train the networks (see Paragraph 8.3).

If networks are already available, it is necessary to indicate the years of the emission scenarios used to train the networks (inside and outside region).

Both Year Inside Region and Year Outside Region available for the selection must be greater than the reference year set in **Emission Inventory** *screen.*
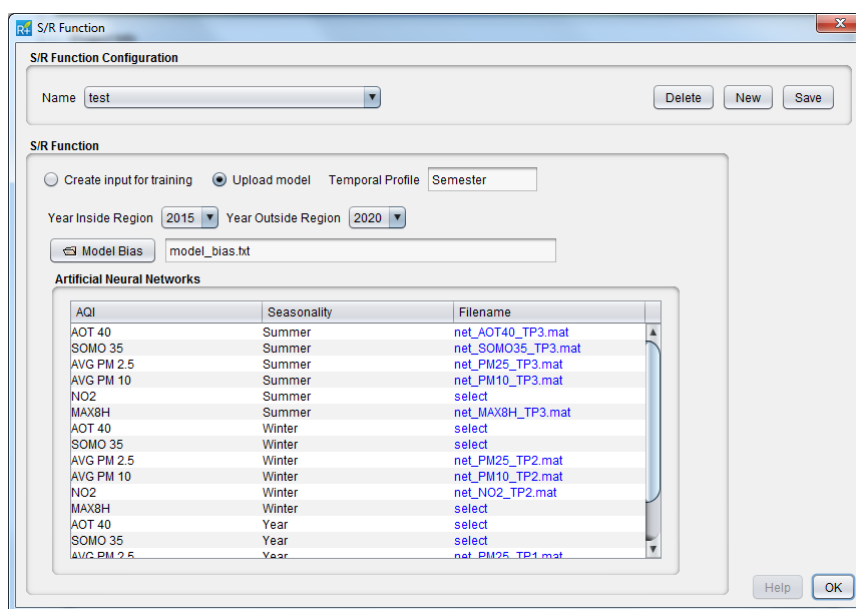
Figure 7-1: RIAT+ GUI: *S/R Function*

Furthermore, the user has to enter the *model bias* file (see Paragraph 7.2). This because, in some cases the CTM simulations are known to be biased. If a bias can be derived for each AQI and cell of the simulation domain, it can be used to "unbias" the ANNs simulation results. In practice, after the RIAT+ optimization is finished, the optimal AQI results (both maps and Pareto curve) can be post-processed to be unbiased, summing the bias available in this file (i.e. the bias is assumed to be additive). The final AQI value (sum of the original one and of the bias) is saved, and replaces the original AQI.

The optimization analysis will be possible only for the networks/models uploaded.

7.1   Neural network files

In the **Network** box, the user should enter the Air Quality models: linear model or Artificial Neural Networks (for more details see Annex I).

In both cases, the model has to be saved in a .mat file, containing:

- icells: scalar that specifies the emission quadrant dimension, used to train the model
- net: it contains the model:
  - In case of a linear approach, it is a vector [nx1], in which n represents the number of input to the model. In particular n=48 for PM, and n=16 for gases, considering the product of these variable values:
    - 6 (in case of PM) or 2 (in case of gases) precursor emissions
    - 2 emission levels (low and high emissions)
    - 4 quadrants.
  - In case of artificial neural network (ANNs), it is the neural network model itself
- ps_input: it contains the values applied to normalize input of the ANNs (in case of linear approach, it is an empty variable).
- ps_target: it contains the values applied to denormalize the output of the ANNs (in case of linear approach, it is an empty variable).

7.2   Model bias files

The **model bias** file contains the bias for the 7 AQIs and the temporal profile considered (also for annual profile), using the format listed below (to better exemplify winter and summer are used as temporal profiles).

In case of annual profile, only the first 9 columns are required.

The data format is:

1. XUTM [m] cell coordinate (South-West corner)
2. YUTM [m] cell coordinate (South-West corner)
3. Bias to correct yearly mean PM10
4. Bias to correct yearly mean PM2.5
5. Bias to correct yearly ozone concentrations accumulated dose over a threshold of 40 ppb - AOT40
6. Bias to correct yearly ozone concentrations accumulated dose over a threshold of 35 ppb - SOMO35
7. Bias to correct yearly mean of daily maximum 8-hour running average - Max8h
8. Bias to correct yearly mean NO_2
9. Bias to correct yearly number of exceedances of the PM10 daily threshold (this is the bias to be applied to the average PM10, that is the initial value considered to compute, through linear relation, the number of daily PM10 threshold exceedances)
10. Bias to correct winter mean PM10
11. Bias to correct winter mean PM2.5

12. Bias to correct winter ozone concentrations accumulated dose over a threshold of 40 ppb - AOT40
13. Bias to correct winter ozone concentrations accumulated dose over a threshold of 35 ppb - SOMO35
14. Bias to correct winter mean of daily maximum 8-hour running average - max8h
15. Bias to correct winter mean NO_2
16. Bias to correct winter number of exceedances of the PM10 daily threshold (see the note for the yearly correction, for this AQI)
17. Bias to correct summer mean PM10
18. Bias to correct summer mean PM2.5
19. Bias to correct summer ozone concentrations accumulated dose over a threshold of 40 ppb - AOT40
20. Bias to correct summer ozone concentrations accumulated dose over a threshold of 35 ppb - SOMO35
21. Bias to correct summer mean of daily maximum 8-hour running average - max8h
22. Bias to correct summer mean NO_2
23. Bias to correct summer number of exceedances of the PM10 daily threshold (see the note for the yearly correction, for this AQI)

*If the ANN required to compute a particular AQI is not available, the related bias information is not used. If no model bias has to be applied, the **model bias** file should contain 0 for each AQI and cell.*

User Instructions

8 RUN PREPROCESSING

The **Run Preprocessing** button is available only if all mandatory data input are entered in the system.

The **Preprocessing** screen is shown in the following figure and allows the user to:

- validate the input data (see Paragraph 8.1)
- set the Pre-run Configuration (see Paragraph 8.2)
- set the CTM and ANNs Scenario Configuration (see Paragraph 8.3).

Figure 8-1: RIAT+ GUI: Preprocessing.

8.1 Validation data input

All input data entered in the screens described above are validated by clicking the **Run Input Validation** button. The data validation process checks all files entered and identifies all incorrect or missing values. The validation procedures are described at Annex II.

Identified errors are displayed in **Pre-Run Results** screen by clicking the **Last Phase Log** button (for details see Paragraph 8.4). Every message reports the file name, the line number and the error or warning description.

The system does not allow the user to proceed if the input validation process checks one or more errors. In this case, it is necessary to correct the errors found and revalidate all the input data. If warnings are present the system allows the user to proceed.

*If "aggregated scenario" has been set in Emission Inventory only Run Input Validation is enabled in **Preprocessing** screen.*

8.2   Pre-run configuration

This part of the system lets the user introduce mandatory input to pre-process emissions entered in **Emission Inventory** screen. The pre-computed emissions are required to speed up the optimization procedure (this is not applied in the "aggregated scenario" evaluation); these pre-computed emissions have to be recreated each time one of the input data (domain, emissions and measure database, S/R functions) and the information set in this screen is modified.
Pre-processors involved in this part produce pre-computed quadrant emissions and emission input to the optimizer (see Paragraph 8.2.4); these files contain virtual pollutant emissions and virtual activity level (see Paragraph 15.1), representing the starting point for the optimization.
The **Pre-run Configuration** box lets the user:

- select the Policy Application Domain (see Paragraph 8.2.1);
- select the year for optimization analysis inside the region (see Paragraph 8.2.2);
- select the use of Non Technical Measures (see Paragraph 8.2.3);

8.2.1   Policy Application Domain

In the **PAD** box, the user can indicate the Policy Application Domain. By default the PAD is the whole region.
To define a different PAD, the following steps are necessary:

- click on the **Subdomain** drop-down list and select a subdomain (of course this is possible only if **subdomain** files were entered in the **Domain** screen);
- select one or more areas;
- click on the **Add** button;
- enter a PAD name.

All PADs defined will be shown in the **PAD Selected** box and, for each of these PADs, the system will produce quadrant emissions and the emission data needed for the optimizer.

---

*The **PAD** box is disabled for "Aggregated Scenario" emissions option. It is possible to choose the Policy Application Domain for "aggregated scenario" emissions option in the **Run Settings** screen.*
*By clicking on **Remove** button in **PAD** box, all pre-computed quadrant emissions already created for the selected PAD will be deleted.*
Region PAD is mandatory and it is computed as default configuration.

8.2.2   Optimization year selection

In the **Year** box, the user can select the optimization year (inside the region). The chosen year is used to calculate virtual emissions. Available years are strictly dependent on the year selected in **S/R Functions** screen: user can select the optimization year (inside the region) starting from the training year for neural networks inside the region. By default, the system sets also the optimization year outside the region: this year is the same set for the training year for neural network inside the region in **S/R Functions** screen.

*The **Year Selection** box is disabled for "aggregated scenario" emissions option.*

8.2.3   Optimize the non-technical measures

With this radio button the user can decide to include in the optimization process the non-technical measures.

*The **Non Technical** radio button is disabled for "Aggregated Scenario" emissions option.*

8.2.4   Emissions Projection

The **Run Emissions Projections** button lets the user start the sequence of processes to produce pre-computed quadrant emissions and emissions input to the optimizer.

The "Run Emissions Projections" button is disabled for "Aggregated Scenario" emissions option.

8.3   CTM & ANNs Scenario configuration

When the user has selected in the **S/R Functions** screen the option **Create input for training**, the usual configuration of **Preprocessing** screen changes and becomes the one shown in Figure 8-2: the actual Pre-Run is blocked and only Validation and CTM & ANNs Scenario Configuration are available.

Figure 8-2: RIAT+ GUI:CTM & ANNs Scenario Configuration.

*The CTM & ANNs Scenario Configuration part is not available only when the Scenario Aggregated has been selected in the **Emission Inventory** screen.*

This part of RIAT+ is dedicated to the creation of the input for Chemical Transport Model (CTM) and for Artificial Neural Networks (ANNs). It means that, in general, to support the training of the ANNs to reproduce quickly the results of CTM two sets of emissions are necessary:

- The projected emissions in the format required as input to CTM
- The projected emissions in the format required as input to ANNs

The emissions produced are the same, what changes is only their format. The projections of the emissions are explained in detail in Paragraphs below. It is also necessary to say that the emissions format described in this Paragraph is not an "universal" format, it is the typical format used in Opera project, more in general it could be a "possible" format for chemical transport models and to train others source receptor models.

Apart from the format, the emission projections could be very useful to the user to analyze the trend of CLE projected emissions and MFR projected emissions, also comparing different projection to the reference emission inventory.

In detail, the creation of the input for Chemical Transport model (CTM) and for Artificial Neural Networks (ANNs) means the production of a combination of different emission levels (the combination is also called emissions "scenarios").

8.3.1   Emission levels

The emissions levels are obtained projecting emission inventory applying CLE and MFR (see Paragraph 15.3) and using a multiplicative factors to enlarge or not the emission range for the ANNs training.

The emissions levels are three and they are different for the cells inside or outside the region.

Emissions levels inside the region are:

- Level 1: $EMI\_CLE_{t=year\_scen\_IN} * \frac{100+CLE_{rate}}{100}$

- Level 2: $\frac{[(EMI\_CLE_{t=year\_scen\_IN})+(EMI\_MFR_{t=year\_scen\_IN})]}{2}$

- Level 3: $EMI\_MFR_{t=year\_scen\_IN} * \frac{100-MFR_{rate}}{100}$

where

EMI_CLE: are the emissions [in tons] referred to the indicated year for scenarios inside region (Year Scen In), remaining after the application of a set of technologies of CLE;

EMI_MFR: are the emissions [in tons] referred to the indicated year for scenarios inside region (Year Scen In), remaining after the application of a set of technologies of MFR;

CLE_{rate}: multiplicative factor to enlarge the emissions *EMI_CLE*

MFR_{rate}: multiplicative factor to reduce the emissions *EMI_MFR*

For outside region cells the emissions have a unique level that is the CLE projection at the year chosen by the user:

$$EMI\_CLE_{t=year\_scen\_Out}$$

where

EMI_CLE: are the emissions [in tons] referred to the indicated year for scenarios outside region (Year Scen Out), remaining after the application of the average reduction factor (see Paragraph 15.3.1);

From the ***CTM & ANNs Scenario Configuration*** part in the ***Preprocessing*** screen, the user can set:

- ***CLE Rate*** text box: it is a multiplicative factor to enlarge or not the emission range for the ANNs training; it is referred to the CLE projected emissions, it is expressed as percentage and it has to be between 0 and 100%;
- ***MFR Rate*** text box: it is a multiplicative factor to enlarge or not the emission range for the ANNs training; it is referred to the MFR projected emissions, it is expressed as percentage and it has to be between 0 and 100%.

And also:

- ***Year Scen In*** drop box: the user has to chose the year for projecting emissions inside the region;
- ***Year Scen Out*** drop box: the user has to chose the year for projecting emissions outside the region.

---

*The available years in the **Year Scen In** drop list depend on the temporal horizon and the reference year declared in the **Emission Inventory** screen: they are greater than the reference year.*

*The available years in the **Year Scen Out** drop list depend on the selection made in the **Year Scen In** drop list: they are greater than the year chosen for inside region projection.*

It is mandatory to establish the emissions level for each pollutant. This is made through two files: one for the areal and one for the point emissions.

The data format is shown in the following table where (Table 8-1):

- the first line is the header;
- the first row is the identifier of emissions scenarios: it means a progressive number to identify the independent combination of different emissions levels for different pollutants; "independent" means that the code is unique for each combination, without repetition;
- the following rows contain the emissions level code for each pollutant.

It is also possible to introduce a faked emissions level code, level 4, that means the there is no projection for the emission inventory for a particular pollutant: like CO in this case.

ID_SCEN	NOX	VOC	NH3	PM10	PM2.5	SO2	CO
1	1	1	1	1	1	1	4
2	2	2	2	2	2	2	4
3	3	3	3	3	3	3	4
4	3	2	2	2	2	2	4
5	2	3	2	2	2	2	4
6	2	2	3	2	2	2	4
…	…						

Table 8-1 Example of areal or point emission levels file.

*Pollutants in Areal and Point Emission levels are the same entered in the **Pollutant** box in the **Emission Inventory** screen.*

From the **CTM & ANNs Scenario Configuration** part in the **Preprocessing** screen, the user has to upload these files:
- **Areal Emission Levels** button: lets the user upload the file that contains the emissions levels for each pollutant –areal independent scenarios - in the format explained above
- **Point Emission Levels** button: lets the user upload the file that contains the emissions levels for each pollutant –point independent scenarios - in the format explained above

*Emission levels can be different for areal and point sources. If the user has not uploaded point emissions in the **Emission Inventory** screen, the **Point Emission Levels** button is not available*

8.3.2   Total scenarios

All the independent areal end point emissions levels are combined to provide the total scenarios, used for CTM and ANNs simulations. An example of the total scenario is shown in the first column of the following table.

TOTAL SCENARIOS	INDIPENDENT SCENARIOS	AREAL EMISSIONS							POINT EMISSIONS							OUTSIDE REGIONAL DOMAIN
		NOX	VOC	N33	PM10	PM25	SO2	CO	NOX	VOC	N33	PM10	PM25	SO2	CO	
0	1	1	1	1	1	1	1	4	1	1	1	1	1	1	4	CLE2020
1	2	2	2	2	2	2	2	4	1	1	1	1	1	1	4	CLE2020
2	3	3	3	3	3	3	3	4	1	1	1	1	1	1	4	CLE2020
3	4	3	2	2	2	2	2	4	1	1	1	1	1	1	4	CLE2020
4	5	2	3	2	2	2	2	4	1	1	1	1	1	1	4	CLE2020
5	6	2	2	3	2	2	2	4	1	1	1	1	1	1	4	CLE2020
6	7	2	2	2	3	3	2	4	1	1	1	1	1	1	4	CLE2020
7	8	2	2	2	2	2	3	4	1	1	1	1	1	1	4	CLE2020
8	9	3	3	2	2	2	2	4	1	1	1	1	1	1	4	CLE2020
9	10	3	2	3	3	3	3	4	1	1	1	1	1	1	4	CLE2020
10	11	3	2	3	2	2	2	4	1	1	1	1	1	1	4	CLE2020
11	12	3	2	3	2	2	3	4	1	1	1	1	1	1	4	CLE2020
12	1	1	1	1	1	1	1	4	2	2	2	2	2	2	4	CLE2020
13	1	1	1	1	1	1	1	4	3	3	3	3	3	3	4	CLE2020
14	1	1	1	1	1	1	1	4	3	2	2	3	3	3	4	CLE2020
15	1	1	1	1	1	1	1	4	2	2	2	2	2	3	4	CLE2020
16	1	1	1	1	1	1	1	4	3	2	2	2	2	3	4	CLE2020
17	3	3	3	3	3	3	3	4	3	3	3	3	3	3	4	CLE2020
18	10	3	2	3	3	3	3	4	3	2	2	3	3	3	4	CLE2020
19	8	2	2	2	2	2	3	4	2	2	2	2	2	3	4	CLE2020
20	12	3	2	3	2	2	3	4	3	2	2	2	2	3	4	CLE2020
21	9	3	3	2	2	2	2	4	3	3	2	2	2	2	4	CLE2020

Table 8-2 Example of total scenario

From the CTM & ANNs Scenario Configuration part in the **Preprocessing** screen, the user has to upload the total scenarios by clicking the **Scenarios combinations** button. The format is the one shown in the table below.

ID_SCEN_Areal	ID_SCEN_Point
1	1
2	1
2	2
3	1
3	2
3	3
...	...

Table 8-3 Example of Scenario combinations file

To run the processes that produce CTM and ANNs emissions set, the user has to push the **Run Scenarios Creation** button. All the files produced are described in Paragraph below.

8.3.3   Output

The system produces the scenarios in different formats and detail. The output data are saved in folder:
RIAT\Data_Region\project\"Project_Name"\"Pad_Name"\emis_proj_out\SCE
and are divided in subfolders:

- EMI_AR_ACT_IN: areal gridded emissions with activity-fuel detail for inside cells. One file for each temporal profile and CLE/MFR projection;
  Files format is:
  - XUTM and YUTM [m] cell coordinates (South-West corner);
  - MS_SNAP: macrosector code
  - ACT: regional activity code
  - FUEL: regional fuel code
  - POLL: pollutant code
  - EMI: emission value in tons
  - EMI_CLE\MFR: projected emissions in tons

- EMI_AR_MS_IN: areal gridded emissions with macrosector detail for inside cells. One file for each temporal profile, CLE/MFR projection and pollutant;
  The files format is:
  - XUTM and YUTM [m] cell coordinates (South-West corner);
  - EMI_MS1: macrosector 1 emissions in tons
  - EMI_MS2: macrosector 2 emissions in tons
  - ...
  - EMI_MS11: macrosector 11 emissions in tons

- EMI_AR_MS_OUT: areal gridded emissions[5] with macrosector detail for outside cells. One file for each temporal profile and pollutant;
  The files format is:
  - XUTM and YUTM [m] cell coordinates (South-West corner);
  - EMI_MS1: macrosector 1 emission in tons
  - EMI_MS2: macrosector 2 emission in tons
  - ...

---

[5] Emissions [in tons] referred to the indicated year for scenarios outside region (Year Scen Out), remaining after the application of the average reduction factor (see Paragraph 15.3.1)

- o   EMI_MS11: macrosector 11 emission in tons

- EMI_PT_IN: point emissions with activity-fuel detail for inside sources. One file for each temporal profile and CLE/MFR projection;
  The format required (first line is a header) is:
    - o   XUTM: x UTM (m) of the point source
    - o   YUTM: y UTM (m) of the point source
    - o   MS_SNAP: macrosector code
    - o   ACT: regional activity code
    - o   FUEL: fuel code
    - o   POLL: pollutant code
    - o   EMI: emission in ton
    - o   EMI_CLE\MFR: projected emission in tons
    - o   IN_OUT: source location (IN: inside the domain)
    - o   HGT: point source stack height in meter
    - o   DIAM: point source stack diameter in meter
    - o   TEMP: flue temperature in °C
    - o   VEL: flue velocity in m/s

- EMI_PT_OUT: point emissions[6] with activity-fuel detail for outside sources. One file for each temporal profile.
  The format required (first line is a header) is:
    - o   XUTM: x UTM (m) of the point source
    - o   YUTM: y UTM (m) of the point source
    - o   MS_SNAP: macrosector code
    - o   ACT: regional activity code
    - o   FUEL: fuel code
    - o   POLL: pollutant code
    - o   EMI: emission in tons
    - o   IN_OUT: source location (OUT: outside domain)
    - o   HGT: point source stack height in meter
    - o   DIAM: point source stack diameter in meter
    - o   TEMP: flue temperature in °C
    - o   VEL: flue velocity in m/s

8.4   Pre Run Results

The *Pre Run Results* screen in Figure 8-3 helps the user to manage different pre-run simulations and to see their progress.
The screen is divided into 2 parts:
- *Run Results* box
- *Configuration info*

The *Run Results* box shows a list (only one line or a series of lines) containing: the name of the pre-run, the name of the Project to which the pre-run refers to, and the execution info. In this last part of the line, the user finds three kinds of

---

[6] Emissions [in tons] referred to the indicated year for scenarios outside region (Year Scen Out), remaining after the application of the average reduction factor (see Paragraph 15.3.1)

information about the pre-run: Status, concerning the whole run (if the run is in progress, completed successfully or not); Phase shows what process is running – or the last when the run is finished; for each phase, "Progression" shows the progress of the process.

The list of the pre-run contains pre-run executed, pre-run in progress and also pre-run in the queue. RIAT+ is able to manage a queue of different pre-runs.

Runs stored, in progress or in queue could be deleted using the ***Delete Selected*** button. The ***Last Phase Log*** button shows the log of the last procedure processed: it is very useful in general, but above all when the run has not completed successfully because it contains the information to understand the errors and the type of issue.

Also for "Input validation" procedure, it is possible see the log files created. In this case, two log files are shown: the first lists all file checked while the second reports the description and the details of the error or warning found.

Show Selected button in ***Pre-Run Results*** screen is disabled.
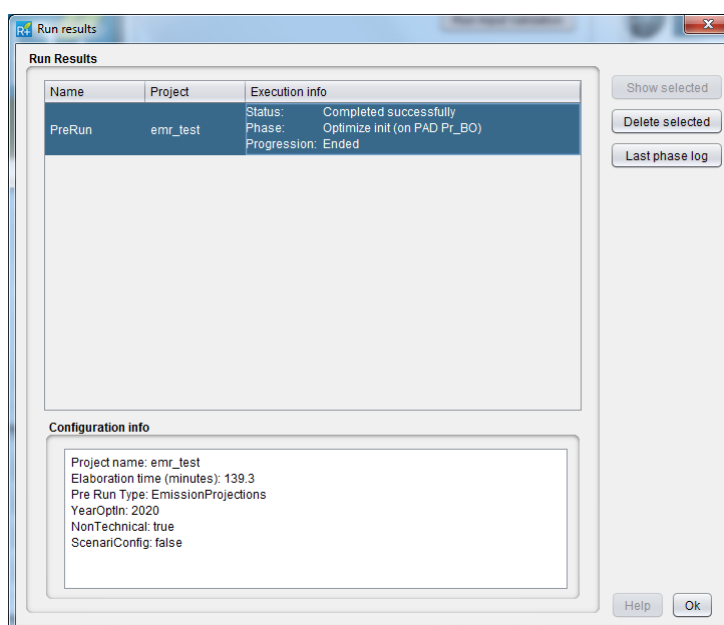
Figure 8-3: RIAT+ GUI Pre Run Results.

In the ***Configuration Info*** box the user can visualize all the information concerning the pre-run selected from the pre-run list. It is a summary of the all settings recorded from the ***Preprocessing*** screen.

9   RUN SETTINGS

Figure 9-1 shows *Run Settings* window where the user can select the decision approach (Air Quality Indexes, costs) and can set all the mandatory parameters to perform a run. Four decision approaches are available and they are:
- Multi Objective (single or combined AQI)
- Cost Effectiveness (single or combined AQI)
- Scenario Detailed approach
- Scenario Aggregated approach

Figure 9-1: RIAT+ GUI: *Run Settings*.

Each of these four approaches requires a particular set of parameters and information. In the **Run Settings** screen, some parts are common to the four computation approaches and they are listed below:
- **Run Name** box
- **Run** button
- **Run Results** button

The user has to fill in the **Run Name** box with a name to easily identify the run.

The **Run** button starts the run or puts it in a queue. The **Run Results** button leds the user to the screen containing the summary of the run already completed or its progress (see Paragraph 10.1).

On the right side of the **Run Setting** screen there is a scrollbar to visualize the entire screen.

The **Run Settings** screen changes according to the decision approach selected: it

means that for each approach only some parts of the entire **Run Setting** screen are available. In the following Paragraphs all the four configurations will be described in detail.

If "Aggregated Scenario" has been set in **Emission Inventory** *only Scenario Aggregated approach is available in* **Run Settings** *screen.*

The table below shows what kinds of settings are available for each decision approach.

Settings \ Decision Approach	Cost Effectiveness	Multi Objective	Scenario Detailed	Scenario Aggregated
Measure Selection	X	X		
Air Quality Objective	X	X		
Budget Constraint	X			
Weight	X	X		
Spatial AQI Aggregation	X	X		
Tecnology Replacement	X	X		
PAD Selection	X	X	X	
PAD Scenarios Selection				X
AQI Target Domain Selection	X	X		
Time Limit		X		
SNAP1 budget constraint	X	X		
Scenario Application Rate			X	
Traffic splitting	X	X		
Scenario Settings				X

Table 9-1: Table of the available settings for each decision approach

Multi Objective has more options and information to be set: so the bigger part of the functionalities of the **Run Settings** screen are described in the Multi Objective Paragraph and in the description of the other approaches there will be references to it to avoid repetitions.

9.1   Multi Objective approach

All the options and parameters available in the Multi Objective approach are presented in the figure below (highlighted in yellow) and are described in the following sub-paragraphs.

In the **Year Opt In** box, the year chosen as starting point for CLE application rate is visualized (it is the same year used to produce pre-computed emissions in Preprocessing run). "IN" is referred to cells inside the region.

Figure 9-2: RIAT+ GUI: *Multi Objective approach*

9.1.1   *Air Quality Objective*

In **Air Quality Objective** box, the user has to choose the Air Quality Index to optimize. This box is made up of other 3 boxes, each concerning particulate matter, ozone and nitrogen oxides. Each AQI in these boxes has also a temporal definition: it could be annual or seasonal. Yearly, winter and summer are used in the following as typical examples of temporal definition.

The user has to choose at least one AQI but can also select more than one AQI: the only constraint is that each AQI has to belong to a different box (i.e. particulate matter, or ozone, or nitrogen oxides).

The AQI available in the **Air Quality Objective** box are the following:
1.   Yearly/winter/summer mean PM2.5

2. Yearly/winter/summer mean PM10
3. Yearly number of exceedances of the PM10 daily threshold
4. Yearly/winter/summer ozone concentrations accumulated dose over a threshold of 40 ppb - AOT40
5. Yearly/winter/summer ozone concentrations accumulated dose over a threshold of 35 ppb - SOMO35
6. Yearly/winter/summer mean of daily maximum 8-hour running average - MAX8H
7. Yearly/winter/summer mean NO_2

To obtain yearly PM10 exceedances the user has to fill in the two text boxes with the two coefficients (*a* and *b*), that allows to implement the following linear relation linking yearly PM10 exceedances and yearly PM10 average:

- (Number of times PM10 threshold is exceedances) = a * (mean PM10) – b

*All AQIs available in the **Air Quality Objective** box are the same for which the neural networks/models and their seasonality has been uploaded in **S/R Functions** screen. The yearly PM10 exceedances AQI is available only if the yearly PM10 model has been uploaded.*

9.1.2 Weights

The **Weight** box is available only if more than one AQI has been selected in **Air Quality Objective** box. The user can choose two different ways to weight different AQIs (in the drop list):

- User defined: text box available are the same of the AQIs chosen. The user must enter a value for each AQI chosen in the **Air Quality Objective** box. These weights must be between 0 and 1, for each of the AQIs to be considered simultaneously; the sum of the weights cannot be greater than 1
- Fairness: the user lets the algorithm decide the weights

9.1.3 Technology Replacement

This radio button allows the user to decide if technologies are replaceable or not for the optimization module: "yes" means that technologies are replaceable (their application rates can go down below the corresponding CLE application rate), "no" means they are not replaceable (their application rates cannot go below the corresponding CLE application rate); this flag is applied only to technical measures.

9.1.4 PAD Selected

The **PAD Selected** box lets the user choose which policy application domain is used for the optimization. This box is strictly related to the **Policy Application Domain** box in **Preprocessing** screen (see Paragraph 8.2.1). In this box only the list of PADs for which the Pre-run process has been made appears. So the user can always choose the whole region domain (that is the default PAD) or a subdomain for which pre-computed emissions are ready from Pre-run process.

9.1.5   AQI Target Domain

The **AQI Target Domain** box lets the user choose which domain is used to compute the AQI. This box is strictly related to the **PAD Selected** box. The AQI Target Domain is always a smaller or equal part of the selected PAD. So in the upper part of the **AQI Target Domain** box, there is **Subdomain** box that visualizes the PAD selected. In the lower part of the **AQI Target Domain** box, there is the list of the zones of the subdomain selected. The user can choose the AQI Target Domain from this box, also using multiple selection.

9.1.6   Spatial AQI Aggregation

In **Spatial AQI Aggregation** box, the user can decide which method to use to compute the AQI by aggregating single cell values. It can also set the local thresholds to be applied to cell values.
Spatial AQI Aggregation box is available only for Multi Objective and Cost Effectiveness approaches.
The Spatial AQI Aggregation method is selectable only for the AQI chosen in the **Air Quality Objective** box. They are:

- spatial average
- total number of cells whose local value exceeds the corresponding threshold
- population weighted spatial average

The AQI aggregation method can be different for the different AQIs to be considered simultaneously; all the aggregation methods work on the same computation domain.
The local value thresholds to enter in the text box are always available and do not depend on the previous choice in the **Air quality Objective** box. When these threshold values are set, the algorithm disregards the cells with lower local values.
The following limit values can be set:

- local PM10 threshold [μg/m3];
- local PM2.5 threshold [μg/m3];
- local AOT40 threshold [μg/m3];
- local SOMO35 threshold [μg/m3];
- local MAX8H threshold [μg/m3];
- local NO_2 threshold [μg/m3];
- number of exceedances of the PM10 daily threshold.

9.1.7   Time Limit

The **Time Limit** check box is available only when Multi Objective mode is set and allows the user to enter a value T>0 that is the maximum CPU time (in seconds) to compute the Pareto curve. When this time is reached, the computation stops, whatever its stage. If the user does not select this check box, a five points Pareto curve is computed independently of the time required to perform the computation.

9.1.8   SNAP1 Budget Constraint

The **Budget Constraint** check box is available only when multi objective or cost effectiveness mode are set and allows the user to constrain the budget for each

macrosector; that is to say, to establish a maximum budget that can be accepted for a particular macrosector. When the user activates the **Budget Constraint** check box, the **SNAP1 Budget Constraint** button becomes active and the user has to enter one value for each macrosector having a constrained budget; the sum of these parameters can't be greater than 1.

9.1.9 Traffic Splitting

The **Traffic Splitting** radio button offers the user the possibility to generate consistency constraints for the variables representing the application rates of the technologies related to traffic.

The Traffic Splitting option is available only when Multi Objective or Cost Effectiveness mode are set.

When "yes" is selected, it means that constraints are required; because the measure DB has been generated in such a way that quadruples SNAP1-HIGHWAY-activity-technology, SNAP1-EXTRA_URBAN-activity-technology and SNAP1-URBAN-activity-technology are associated with the same activity-technology pair. This means that the same technology can be applied to HIGHWAY, EXTRA_URBAN and URBAN traffic, respectively. For such a technology the penetration level has to be kept consistent while acting on HIGHWAY, EXTRA_URBAN and URBAN traffic.

If the user selects "yes", the sectors button becomes active and the user has to select:

- highway code: code of the HIGHWAY sector in the SNAP1-sector-activity-technology quadruples listed in measure DB;
- extra_urban code: code of the EXTRA_URBAN sector in the SNAP1-sector-activity-technology quadruples listed in measure DB;
- urban code: code of the URBAN sector in the SNAP1-sector-activity-technology quadruples listed in measure DB.

If the user selects "no" sectors, the button becomes inactive and no particular constraint is applied.

9.1.10 Measure selection

The **Optimize Activities** screen allows the user to choose the activities to be considered by the optimization procedure. The user can use an existent configuration file (uploading all the previously defined information) or create a new configuration.

In case of a new configuration, to select the activities to be optimized the user has to drag and drop the activities from the left side of the screen (**Activity**) to the right side (**Optimized Activities Selected**). It is possible to select single or multiple activities but also single and multiple sectors and macrosectors to make the operation faster.

If the user does not select any configuration or does not create a new one, the system provides a default configuration containing all the activities in the measures DB.
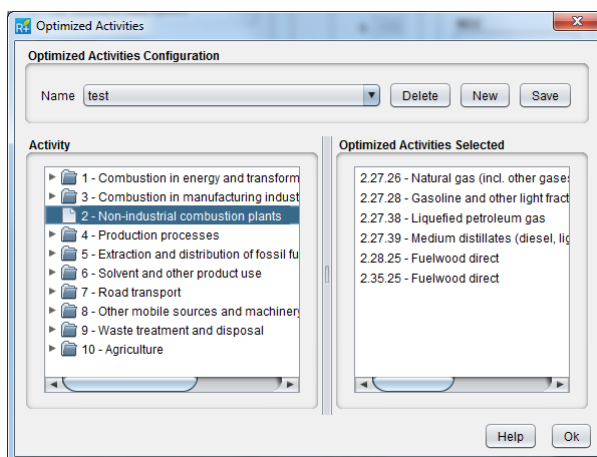
Figure 9-3: RIAT+ GUI: *Optimized Activities*.

The ***Measure Selection*** option is available only when Multi Objective or Cost Effectiveness mode are set.

In the activities list, only those with emissions greater than zero are listed.

9.2 Cost Effectiveness approach

All the options and parameters available in the Cost Effectiveness approach are presented in the figure below (highlighted in green) and they are briefly described in this Paragraph and in detail in the following sub-Paragraphs.

Except for the ***Time Limit*** check box, all the settings of Multi Objective approach are available for the Cost Effectiveness approach. Only another setting is mandatory in this kind of optimization: the budget constraint (see Paragraph 9.2.1).
Also in this case, in the ***Year Opt In*** box, the year chosen as starting point for CLE application rate is visualized (it is the same year used to produce pre-computed emissions in Pre-processing run). "IN" refers to cells inside the region.

Figure 9-4: RIAT+ GUI: *Cost Effectiveness approach*

9.2.1   Constraint

The **Constraint** text box is available only when Cost Effectiveness mode is set and allows the user to enter a value C>0 that is the maximum cost assumed in the optimization process: as shown in the methodology part, the Cost Effectiveness case is a "simplified" implementation of the multi objective optimization in which a unique point of the Pareto curve, given a budget of technologies application, is computed.
The value C is an internal cost over CLE and is expressed in Meuro.

9.3   Scenario detailed approach

The scenario detailed approach allows the user to introduce the application rates of a subset of measures (or of the whole set of measures too). Only few settings are available in the scenario detailed approach, they are presented in the figure below (highlighted in blue) and briefly described in this Paragraph and in detail in the following sub-Paragraphs.

Among all settings in common with Multi Objective approach, the user has to select

the policy application domain in **PAD selected** box (see Paragraphs 9.1.4), but in this case the AQI Target Domain is automatically set equal to the selected PAD. Only another setting is mandatory in this kind of analysis: the user has to enter the application rate for each measure involved in the computation (see Paragraph 9.3.1).

Also in this case, in the **Year Opt In** box, the year chosen as starting point for CLE application rate is visualized (it is the same year used to produce pre-computed emissions in Preprocessing run). "IN" refers to cells inside the region.

Figure 9-5: RIAT+ GUI: *Scenario detailed approach*

9.3.1   Scenarios AR

From **Scenarios AR** *screen* the user can introduce the measures application rate to evaluate the impacts of this penetration in terms of AQI and costs. The information shown in this screen is the same listed in **Edit Measure** screen (see Paragraph 6.2): the user can select a particular measure from the first part of the screen choosing the macrosector (SNAP1), the sectors and the activity and the measure itself. The main feature of the technology selected are shown: RE, CLE and Potential AR, and UC.

The user can enter the desired application rate in the ***AR*** text box. To ensure the emission mass balance for each precursors, the sum of the application rates for each precursor, updated in real time, is shown in the ***Total User AR*** box. The sum cannot be greater than 100%. When the user pushes the ***Save*** button to confirm the new application rate, a check on the sum is done; if it is greater than 100% a Warning messages appears, and the user cannot save the new data.

The starting point of each application rate is the application rate at CLE of the optimization year chosen for the Project: this information in shown in ***Year Opt In*** box.

User can also export a txt file with the list of all measures and application rates. Then it is possible to modify data input and import the same file.

Total User AR is the sum for each precursor of the application rate entered by the user and cannot be greater than 100% to ensure the emission mass balance.

For non-replaceable measures, the application rate entered cannot be less than the application rate of the optimization year.

The check on the sum of the application rate described before is not performed on the imported AR.

Figure 9-6: RIAT+ GUI:*Scenarios AR*.

9.4   Scenario aggregated approach

The scenario aggregated approach is the unique analysis integrated in the system that uses aggregated input emissions. If "Aggregated Scenario" has been set in ***Emission Inventory*** screen, only scenario aggregated approach is available in ***Run Settings*** screen. "Aggregated" in this case means that emissions are detailed by macrosector.

The scenario aggregated approach allows the user to enter emissions reduction percentages to an entire macrosector to estimate the AQIs obtained by their application.

Settings available in the scenario aggregated approach are presented in the figure below (highlighted in pink) and briefly described in this Paragraph and in detail in the following sub-Paragraphs.

Figure 9-7: RIAT+ GUI: *Run Settings*.

None of the settings employed in the other three approaches is used in aggregated configuration: to run the aggregated scenario analysis, the user has to set the domain or subdomain for the computation and to enter the emission reduction percentages (see Paragraphs 9.4.1 and 9.4.2).

In this case, a default year is visualized in the **Year Opt In** box but it is not connected to the aggregated scenario analysis.

About the year used in the aggregated scenario approach: if "aggregated scenario" has been set in **Emission Inventory** screen, the reference year for the emission is that declared in **Emission Inventory** screen (in the **Temporal Horizon** box); if detailed emissions have been entered in **Emission Inventory**, the aggregated emissions used as starting point are projected at CLE of the year declared in the **S/R Functions Configuration** screen – **Year Outside Region** drop list (see Paragraph 9.1.4).

9.4.1   *Policy Application Domain Scenario*

The **Policy Application Domain Scenario** box lets the user choose which policy application domain is used for the aggregated analysis. This box is strictly related to

the ***Domain*** screen (see Paragraph 4.2): the drop list shows the subdomains uploaded in the ***Domain Maps*** box in addition to the domain that is always present as a default configuration.

The user has to select the Policy Application Domain Scenario from the drop list and then one or more of the available zones for the subdomain chosen.

The main difference between ***Policy Application Domain Scenario*** selected here and ***PAD Selected*** box is that the second one requires the Pre-run process, while the aggregated scenario approach does not need pre-computed emissions.

9.4.2   Scenarios Settings

The ***Scenarios Settings*** screen allows the user to enter the emissions reduction percentages to adopt in the aggregated estimation procedure. The user can use an existent configuration file (uploading all the previously defined information) or create a new configuration.

In case of a new configuration, the user has to enter the emissions reduction percentage in the ***Scenarios Settings*** box.
The emissions reduction percentage are different for each precursor and each macrosector and also for areal or point source emissions.

The entered values cannot be smaller than one and for the currently available ANNs (for Emilia Romagna and Alsace) the integrated aggregated scenario analysis have some limitations: the values cannot be greater than 30% for each precursor and for each macrosector; no reduction for SO_2 is allowed.

SNAP	Areal						Point					
	NOx	VOC	NH3	PM10	PM25	SO2	NOx	VOC	NH3	PM10	PM25	SO2
ms1	30	30	30	30	30	0	30	30	30	30	30	0
ms2	30	30	30	30	30	0	30	30	30	30	30	0
ms3	30	30	30	30	30	0	30	30	30	30	30	0
ms4	30	30	30	30	30	0	30	30	30	30	30	0
ms5	30	30	30	30	30	0	30	30	30	30	30	0
ms6	30	30	30	30	30	0	30	30	30	30	30	0
ms7	30	30	30	30	30	0	30	30	30	30	30	0
ms8	30	30	30	30	30	0	30	30	30	30	30	0
ms9	30	30	30	30	30	0	30	30	30	30	30	0
ms10	30	30	30	30	30	0	30	30	30	30	30	0
ms11	0	0	0	0	0	0	0	0	0	0	0	0

Figure 9-8: RIAT+ GUI:*Scenario Settings*

10 RIAT+ OUTPUT

The output section of RIAT+ is the part of the system dedicated to the visualization of the results of the optimization/scenarios modules.

The system offers different kinds of output; there are:
- Graphs – like Pareto curve containing a set of solutions
- Tables: they show the optimized solution in detailed and aggregated way (technology and macrosector)
- Maps: a GIS interface inspired by Google Earth provides the user with basic and well known GIS navigation functions and good cartographic information
- Summary of the optimization output

Like the run settings, also the outputs depend on the approach used for the computation of AQIs. So the following Paragraphs describe in detail each kind of output and then the kind of output available for each of the four analysis approaches is explained.

Output \ Decision Approach	Cost Effectiveness	Multi Objective	Scenario Detailed	Scenario Aggregated
Pareto Curve		X		
Summary Results	X	X	X	
Activity Details	X	X	X	
SNAP1 Details	X	X	X	
Spatial Details:				
- Total Emission Maps	X	X	X	X
- Macrosector Emission Maps	X	X	X	
- AQI Maps	X	X	X	X
- Total Cost Maps	X	X	X	
- Macrosector Cost Maps	X	X	X	

Table 10-1: Table of the available output for each decision approach

10.1 Run Results

This **Run Results** screen in Figure 10-1 helps the user to manage different simulation runs and see their progress and above all it is the way to enter the output section of the system.
The screen is divided into 2 parts:
- **Run Results** box with 3 buttons on the right side
- **Configuration info**

The **Run Results** box shows a list (only one line or a series of lines) containing: the name of the run, the name of the Project which the run is referred to, and the

execution info. In this last part of the line, the user finds 3 kinds of information about the run: Status - concerning the whole run (says if the run is in progress, completed successfully or not); the whole run is made up of a serious of processes - like–Phase shows which process is running (pre-processors, optimization, post-processors) or the last when the run is finished; "Progression" shows the progress of the current process.

The list of the runs contains those executed, in progress and in the queue. As already explained, RIAT+ is able to manage a queue of different runs.

From the list of runs, the user can select a run and visualize the results using the **Show Selected** button; run stored, in progress or in queue could also be deleted using the **Delete Selected** button. The **Last Phase Log** shows the log of the last procedure processed: it is very useful in general, but above all when the run has not completed successfully because it contains the information to understand the errors and the type of issue.
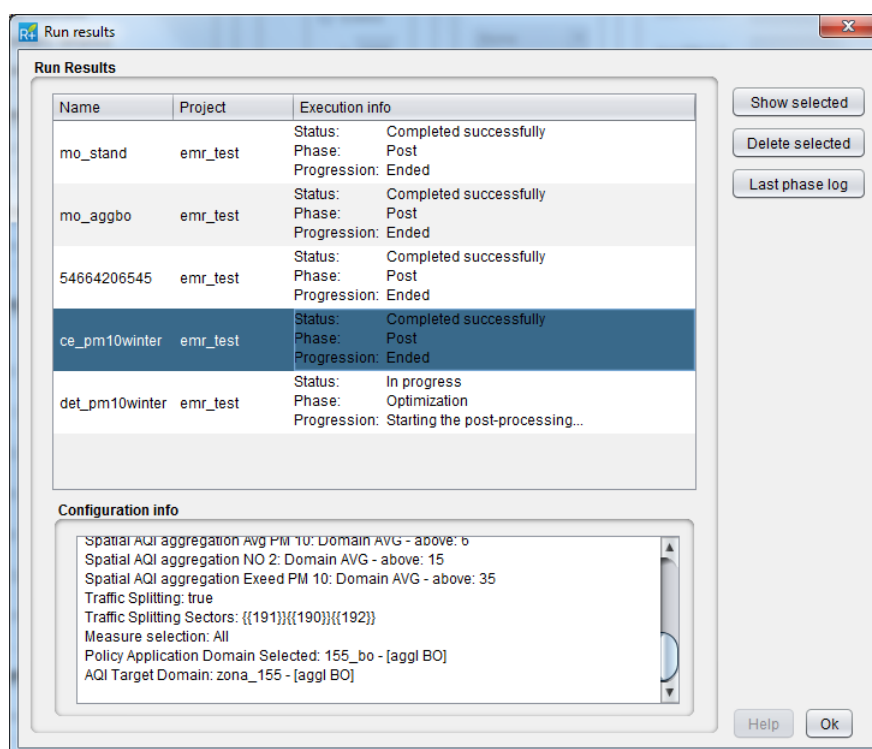
Figure 10-1: RIAT+ GUI Run Results.

In the **Configuration Info** box the user can visualize all the information concerning the run selected from the runs list. It is a summary of the all settings recorded from the **Run Settings** screen: the run and project names, the chosen approach, the AQIs and temporal horizon and so on. Also the computation time is shown (in minutes).

To go to the output section of the system the user has to select a run from the **Run Results** and push **Show Selected** button.

10.2 Pareto curve

The Pareto curve is a graph available only when a Multi Objective run has been executed. It represents the set of solution obtained by the optimization module and shows the optimal trade-offs between AQI and internal costs.

When a Multi Objective run has been successfully completed, through the **Show Selected** button, the screen in Figure 10-4 appears. Then the user can choose one of the points with a cross to display the specific results (see Paragraph 10.3).
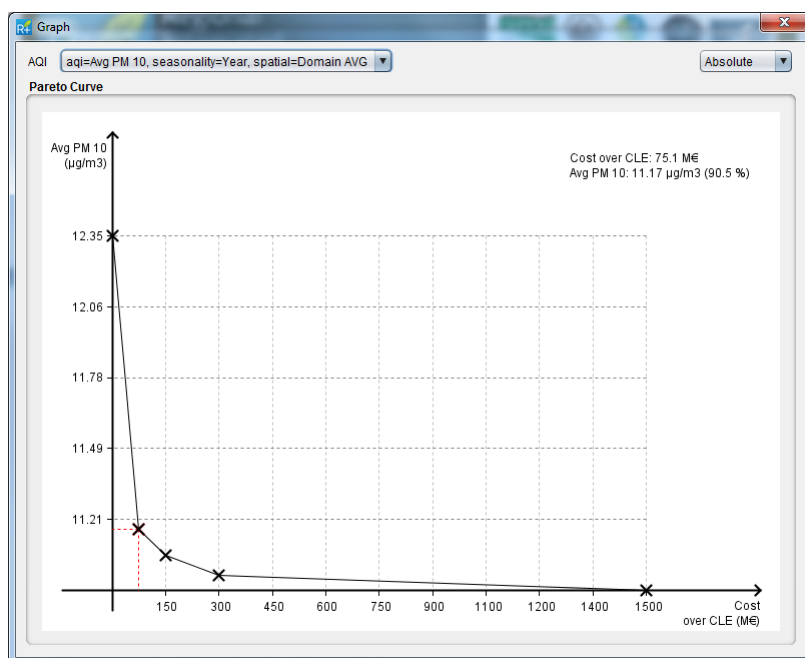
Figure 10-2: RIAT+ GUI: Pareto curve.

On the horizontal axis of the graph there are internal costs, considered over CLE and expressed in Meuro. On the vertical axis there is the AQI value, with the temporal definition and spatial domain aggregation, chosen in the run settings of the optimization analysis. The AQI and information about it are visualized in the drop box on top (left side). In the case of a multi pollutant optimization, the drop box lets the user choose the AQI and the vertical axis changes accordingly.

On the right side of the top of the screen, there is another drop box that lets the user chose the kind of visualization for the AQI: it is possible to visualize the absolute value (in the AQI unit) or the percentage value with respect to CLE.

If the user chooses a point of Pareto curve different from those with the cross, another optimization starts in Cost Effectiveness mode using the same AQI value and entering (or maintaining) a particular cost value and the name for the new run (Figure 10-3). This new run let the user obtain all the run results (tables and maps) illustrated in the following paragraphs.
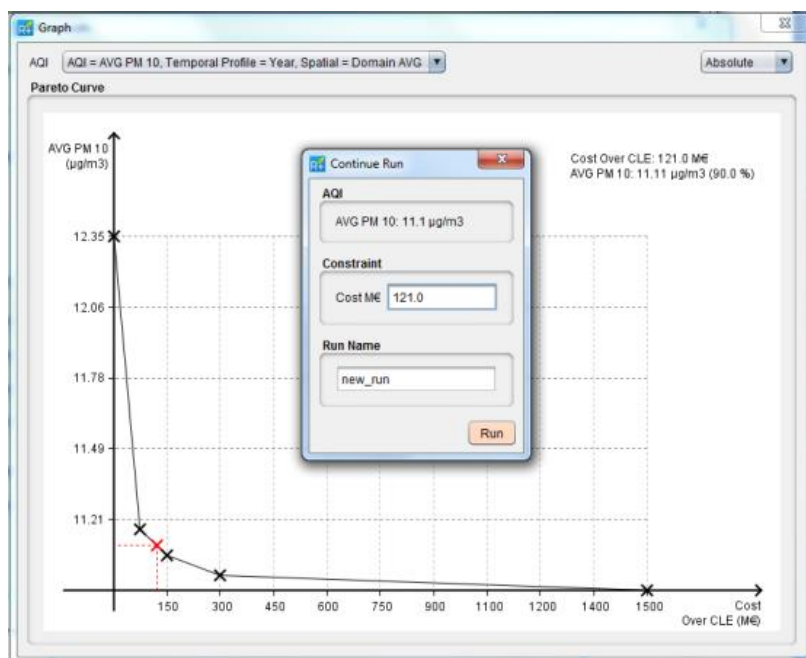
Figure 10-3: RIAT+ GUI: Pareto Curve, starting another optimization in Cost Effectiveness mode.

10.3 Results

The ***Results*** screen shows a summary of the optimization output. It appears in case of a Multi Objective run (clicking on a point with the cross of the Pareto Curve) or in case of Cost Effectiveness and detailed scenarios analysis run (clicking the ***Show Selected*** button in ***Run Results*** screen).
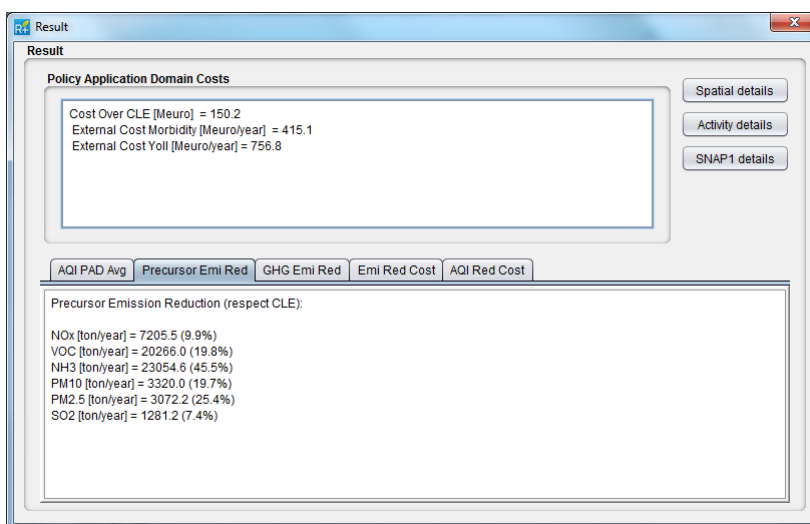
Figure 10-4: RIAT+ GUI: *Output* – summary of final results.

The screen is divided into two main parts: the upper part concerning information about costs and the lower one that contains some information about emissions reduction and AQI values.

The upper part, ***Policy Application Domain Costs***, shows the total cost respect to CLE over all the policy application domain, in Meuro. When in ***Domain*** screen the

External Cost check box is active, also the External Cost Morbidity and the External Cost YOLL are visualized here (in Meuro per year).

In the lower part there are 5 tabs:

- *AQI PAD Avg* that contains: all the AQIs computed (it means all the AQI for which the ANN has been uploaded), the temporal profile and the spatial aggregation of the AQI is the same set in *Run Settings* screen; the spatial aggregation is computed on the whole PAD;
- *Precursor Emi Red*: for each precursor the emission reduction is shown (respect the application of CLE); it was shown in tons per year and also as a percentage of the CLE;
- *GHG Emi Red*: for each greenhouse gas the emission reduction is shown in tons per year;
- *Emi Red Cost*: for each precursor, the cost of emission reduction is shown (above the application of CLE) in thousand euro per tons per year;
- *AQI Red Cost*: for each AQI the cost of AQI reduction is shown (respect the application of CLE) in thousand euro per tons per AQI unit.

On the right side there are three buttons:

- *Spatial Details* button that leads to the map section (see Paragraph 10.6);
- *Activity Details* button that leads to activity and technology table (see Paragraph 10.4);
- *SNAP1 Details* button that leads to macrosector table (see Paragraph 10.5).

10.4 Activity Details

The *Activity Details* table shows the optimization results with activity and technology detail. It can be seen in case of a Multi Objective run or in case of Cost Effectiveness or detailed scenarios analysis run (clicking the *Activity Details* button in *Results* screen).

The screen contains 17 columns of data and a legend to better understand the table.

The first four columns describe the measure (macrosector, sector, activity and technology names); the LowHigh column indicate only if the measure is referred to an areal emission (1) or point source emission (2); the Application Rate columns represent application rates obtained with the optimization process referred to the CLE and potential application rate, in particular: green represents CLE AR, grey represents Potential AR and pink is the optimized rate above CLE application rate; the red indicator points to the optimized application rate. The same value are shown numerically in the three following columns (respectively: CLE, optimized and potential application rates); the following 6 columns are the emission reduction for each precursor: emission reduction is calculated on the basis of the optimized application rate respect to the CLE application rate. The last two columns represent the total cost and the incremental cost (above CLE). All these values are shown with technology detail and computed on PAD.

The table contains all the measure involved in the optimization process: those highlighted in blue have been optimized and their application rate is above CLE, those highlighted in orange have been optimized and their application rate is below

CLE (technologies replacement is active).

The system offers the possibility to export the **Activity Details** table in Excel format.
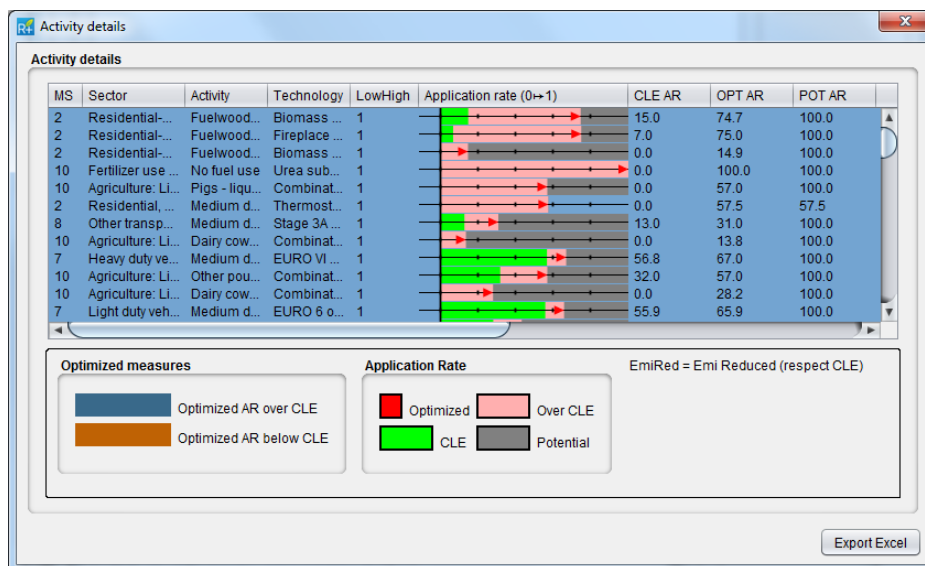
Figure 10-5: RIAT+ GUI: Activity and Technology table.

10.5 SNAP1 table

The **SNAP1** table shows the optimization results with macrosector detail. As the **Activity** table, SNAP1 table can be seen in case of a Multi Objective run or in case of Cost Effectiveness or detailed scenarios analysis run (clicking the **SNAP1 Details** button in **Results** screen).

The screen contains 14 columns of values and a legend to better understand the table.
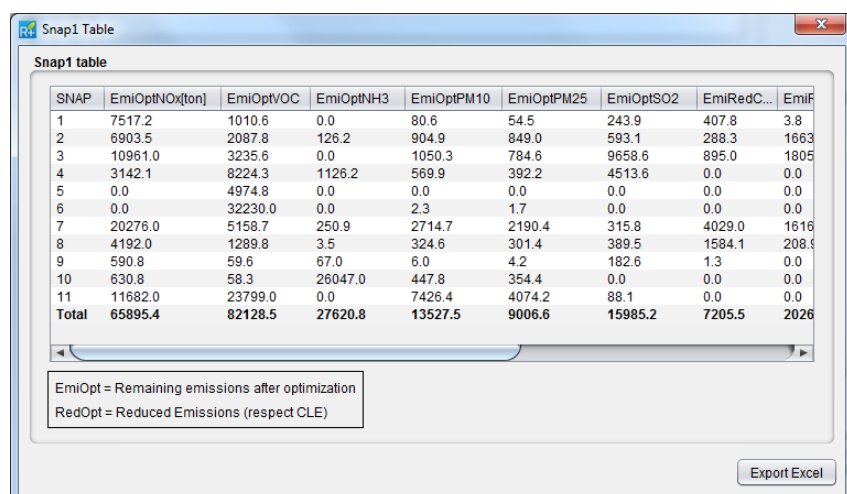
Figure 10-6: RIAT+ GUI: SNAP1 table.

The first column lists all the macrosectors; the following 6 columns are the remaining emissions after the optimized measure application; the others 6 columns are the reduced emissions for each precursor for each macrosector. Reduced emission is calculated on the basis of the optimized application rate respect to the

CLE application rate. The last column represents the incremental cost (above CLE). All these values are computed on PAD.

The system offers the possibility to export the **SNAP1 Details** table in Excel format.

10.6 Maps

The **Maps** screen shows the optimization results with grid detail on a cartographic basis. The system allows the user to visualize emissions, AQIs and costs maps. The map section is available for each of the four decision approaches, but not all the maps are available for each of them, as explained below.

To reach the Maps section in multi objective run or in case of Cost Effectiveness or detailed scenarios analysis run the user has to click the **Spatial Details** button in **Results** screen. In case of aggregated scenario approach the **Result** screen is not available and so the user has to click on the **Show Selected** button in **Run Results** screen.
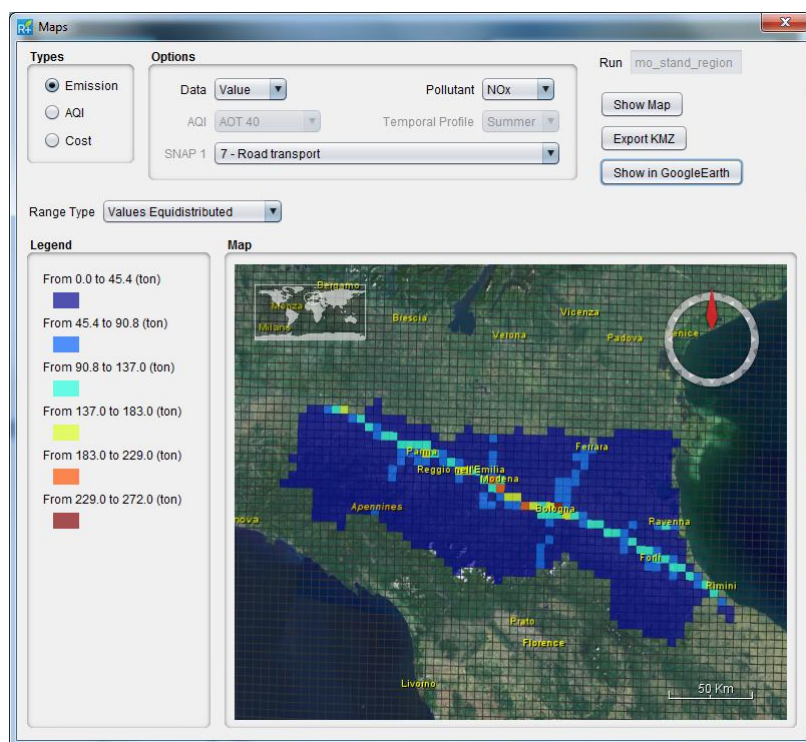
Figure 10-7: RIAT GUI: *Maps* screen

After a brief description of the **Maps** screen structure, available maps and related options are detailed.

In the upper part of the **Maps** screen there are:

- **Types** box: the user can visualize emissions maps or AQI maps or costs maps
- **Option** box: the user can chose the available options for that current map, like to visualize the actual value, the delta value or percentage delta value, what precursor, what AQI and the temporal profile, and what macrosector
- **Show Map** button lets the user visualize the chosen map
- **Export KMZ** button lets the user to export the chosen map in KMZ format

- **Show in GoogleEarth** button lets the user to visualize the chosen map directly in Google Earth, with all its functionalities.
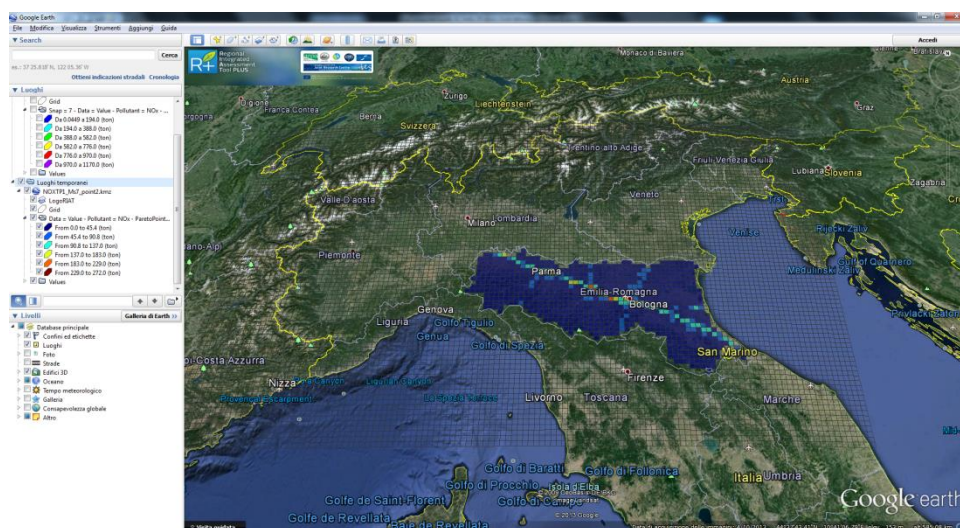
Figure 10-8: Maps can be also visualized in Google Earth.

In the **Run** box, the name of the run selected in **Run Results** screen is visualized.

The **Range Type** drop box contains different ranges to visualize the results in the most appropriate way. Four range types are available:

- Equidistributed values
- Linear progression
- Numerosity equidistributed
- Legislation limit (only for AQI maps)

The main part of the screen is dedicated to the map visualization and to its legend.

RIAT+ GIS interface is implemented using NASA World Wind and it has all the typical GIS functionalities.

In the Table 10-1, the maps available for each of four decision approach are summarized.

10.6.1 Emission maps

For all four decision approaches, it is possible to select emission in the **Types** box. The options available for the emission maps are:

- **Data**: value, delta and delta percentage are available for Multi Objective, Cost Effectiveness and detailed scenarios analysis; but only values of emission are available in the case of aggregated scenario analysis
- **Precursor**: all 6 pollutants - PM10, PM2.5, NO_X, SO_2, VOC and NH_3 - are always available
- **Macrosector**: 11 macrosectors and the total values are available for multi objective, Cost Effectiveness and detailed scenarios analysis; but only total emissions are available in the case of aggregated scenario analysis

The value of emission is the annual value. The delta value is computed as the difference with respect to the CLE emission; the delta percentage value is computed as a percentage of CLE emission.

10.6.2 AQI maps

For all four decision approaches it is possible to select AQI in the Types box. The options available for the AQI maps are:

- Data: value, delta and delta percentage are always available
- AQI: the number of available AQIs depends on the ANNs uploaded and used for the selected run. The maximum number of AQIs is 8 - annual mean PM10 and PM2.5 concentration and PM10 exceedances, SOMO35, AOT40 and maximum on 8 hours and annual mean NO_x concentration.
  PM10 exceedances and YOLL are available only when the annual PM10 ANN has been uploaded
- AQI Temporal profile: depends on the ANNs uploaded; the annual profile is always available.

The value of AQI is the annual or selected temporal profile value. The delta value is computed as the difference with respect to the CLE situation; the delta percentage value is computed as a percentage of CLE situation.

10.6.3 Cost maps

For Multi Objective, Cost Effectiveness and detailed scenarios analysis it is possible to select Cost in the *Types* box. The options available for the Cost map are only:

- Macrosector: cost for each macrosector and total values are available

PART II: RIAT+ METHODOLOGY

11 IA – INTEGRATED ASSESSMENT

The methodology foresees two possible decision pathways, which can be easily interpreted in the light of the classical DPSIR (Drivers-Pressures-State-Impacts-Responses) scheme, adopted by the EU:

- open-loop, or scenario analysis. This is the approach mainly used nowadays to design "Plans and Programmes" at regional/local scale. Emission reduction measures (Policies) are selected on the basis of expert judgment or Source Apportionment and then they are tested through simulations of an air pollution model. This approach does not guarantee that Cost Effective measures are selected, and only allows for "ex-post evaluation" of costs and other impacts.
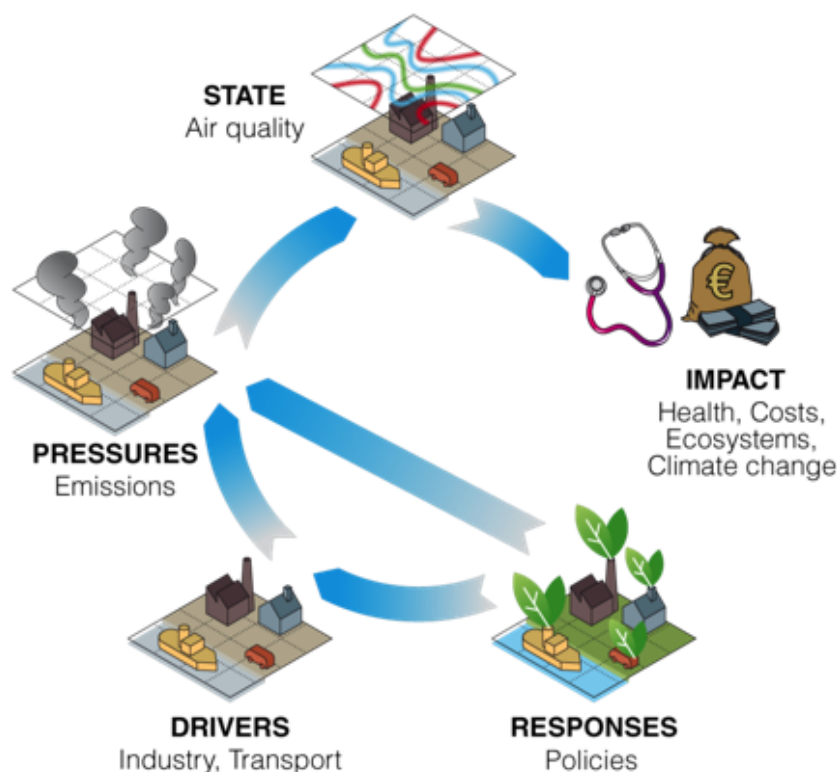
- closed loop, or optimization. This pathway indicates the most Cost Effective measures for air quality improvement by solving an optimization problem. In other words, the approach allows for the computation of the efficient set of technical (end-of-pipe) and non technical (energy efficiency) measures/policies to be encouraged and/or introduced to reduce pollution, explicitly considering their impacts and costs.

Methodology
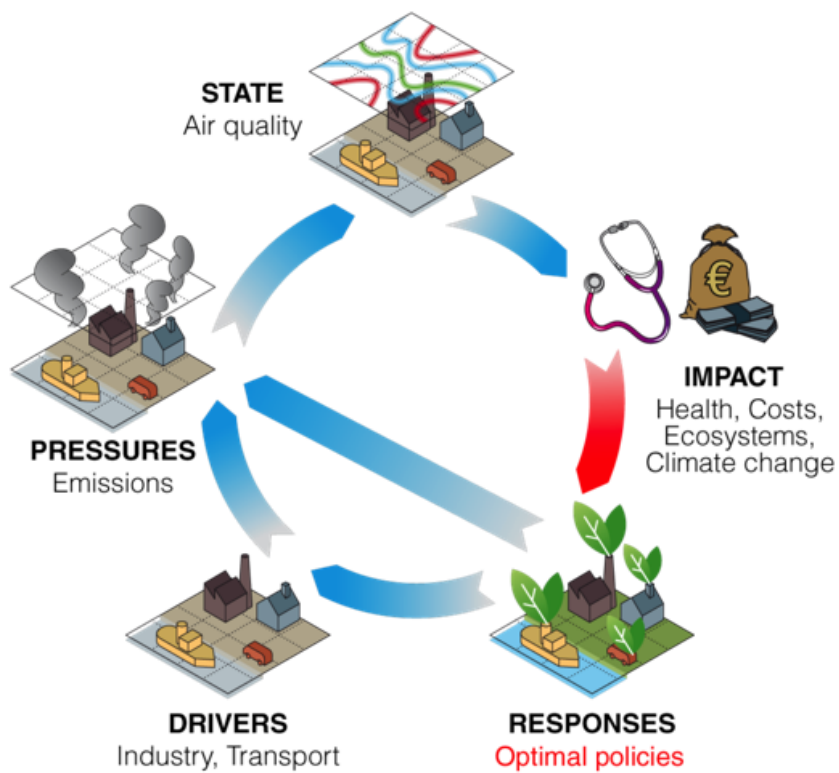
12 SCENARIO ANALYSIS

The scenario analysis case allows to assess the variations of the air quality indexes due to the application of a set of policies chosen a priori by the user. The problem can be formalized as follows:

$$AQI_n = f\big(E(\theta)\big) \ \ with \ n = 1,..,N$$

where:

E represents the precursor emissions;

$AQI_n\big(E(\theta)\big)$ are the Air Quality Indexes concerning different pollutants. Each Index depends on precursor emissions through emission reductions;

θ is the decision variable set constrained to assume values in the feasible set. The decision variable set includes:

- for the *detailed approach*, the application rates for each reduction measure. They are constrained to assume values between CLE and MFR values. In this case the AQI computation is similar to an evaluation of the objective function performed during the optimization procedure (see the following section)
- for the *lumped approach*, the emission reductions for each pollutant in each macrosector. These variables are constrained to assume values in the emission range of the surrogate models.

For the detailed approach, the scenario analysis can also estimate the costs associated to the application of the selected reduction measures (see Paragraph 13.3) and, for both approaches, the population exposure costs (see Paragraph 13.6).

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13 OPTIMIZATION APPROACH

In this section the Multi Objective optimization methodology is formalized. The Cost Effectiveness case is a particular case of the Multi Objective optimization, in which a unique point of the Pareto curve, given a budget for technologies application, is computed; for this reason, it does not deserve a separate formalization.

13.1 Decision problem

A **Multi Objective** problem consists of a number of objectives to be simultaneously optimized while applying a set of constraints. The problem can be formalized as follows:

$$\min_{\theta}[f_o(\theta)], \;\; with \; o = 1, \dots, O_{obj}$$

subject to:

$$\theta \epsilon \Theta$$

where f_o is the o-th objective function,
O_{obj} is the number of the objectives,
θ is the decision variable set (namely the emission reduction measures) constrained to assume values in Θ (the feasible decision variable set).

The target of this problem is to control secondary pollution at ground level. The solutions of the Multi Objective problem are the efficient emission control policies in terms of air quality and emission reduction costs. The problem can be formalized as follows:

$$\min_{\theta} J\big(E(\theta)\big) = \min_{\theta}\big[AQI_n\big(E(\theta)\big) \; inC(E(\theta))\big], \;\; with \; n = 1, \dots, N$$

where
E represents the precursor emissions;
$AQI_n\big(E(\theta)\big)$ are (maximum N) Air Quality Indexes concerning different pollutants;
$inC\big(E(\theta)\big)$ represents the internal (emission reduction) costs.

All the objectives depend on precursor emissions through, as already said, emission reductions. The decision problem complexity can then be reduced to two objectives, considering just a single Air Quality Index (AQI) obtained as a linear combination of the various Air Quality Indexes AQI_n (plus the Cost index). These various AQIs can be aggregated through linear combination of normalized[7] AQIs, using these two configurations:

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[7] Normalization is performed applying the following equation: $\frac{AQI - AQI_{mfr}}{AQI_{cle} - AQI_{mfr}}$, in which AQI_{cle} and AQI_{mfr} represent, respectively, the AQI at Current Legislation and Maximum Feasible Reduction levels. The linear combination of normalized AQIs is then re-written to simplify the denominator, that can give rise to computational problems during the optimization phase.

- with "user-defined" weights (the user defines the relative importance of the AQIs, providing weight values between 0 and 1 for each AQI);
- with the so-called "fairness" approach (an automatic approach that balances the relative importance of the AQIs).

Finally, the previous equation can be re-written as:

$$\min_{x \in X} J(x) = \min_{x \in X}[AQI(x) \ inC(x)]$$

where *x* is a vector containing the application rates of the reduction measures, constrained to be included in the feasible set X.

The Multi Objective optimization problem is solved following the ε-*Constraint Method*: just the Air Quality objective is minimized, while the Internal Cost objective is included in the set of constraints. In this configuration, the Multi Objective approach has the same features of the *Cost Effectiveness analysis,* where the Figure of Merit is

$$\min_{x \in X} J(x) = \min_{x \in X} AQI(x)$$

and the second objective is included in the constraints:

$$inC(x) \leq L \qquad 0 \leq L \leq \bar{L}$$

where L can assume different values in the defined range. In this way a set of effective solutions is computed and a Pareto curve can be drawn.

The **Cost Effectiveness** approach is thus the solution of the above problem for a specific value of L.

13.2 Air Quality objective

The Air Quality objective may consider the following indexes:
- mean PM10 concentration;
- mean PM2.5 concentration;
- SOMO35: ozone concentrations accumulated dose over a threshold of 35 ppb;
- AOT40: ozone concentrations accumulated dose over a threshold of 40 ppb;
- MAX8H: maximum 8-hour running average ozone concentrations;
- NO_x mean value;
- number of times that PM10 daily threshold is exceeded (this index is computed applying a linear relation that transforms the "PM10 yearly average" in "daily number of exceedances").

All the indexes can be computed over different domains, and can be related to i.e. yearly, winter or summer periods. More in general, the implemented approach considers the use of different temporal profiles for AQI temporal aggregation.

The relationship between the decision variables and the indexes is modelled by

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linear models or Artificial Neural Networks – ANNs (except for the "number of times that PM10 daily threshold is exceeded"), identified processing long-term simulations of a CTM model. Starting from the local value, computed cell by cell, an aggregation function is applied, to get the scalar variable (AQI) that has to be optimized. Such an aggregation function has to be selected among the following:
- spatial Average;
- population weighted average;
- number of cells over threshold.

13.3 Emission reduction costs

The emission reduction costs are calculated first for each sector-activity:

$$C_{k,f} = \sum_{t \in T_{k,f}} C_{k,f,t} \cdot A_{k,f} \cdot X_{k,f,t}$$

where:

- $C_{k,f,t}$ are the technology unit costs [Meuro/year] for sector, activity, technology *k,f,t*;
- $C_{k,f}$ are the total cost [Meuro/year] for sector, activity *k,f*;
- $A_{k,f}$ is the activity level for the defined sector-activity;
- $T_{k,f}$ are the technologies that can be applied in a defined sector activity;
- $X_{k,f,t}$ are the application rates of the technologies acting in the sector-activity *k,f*.

Then, the total internal costs [Meuro/year] is computed as:

$$C = \sum_{k,f} C_{k,f}$$

13.4 Decision variables

The decision variables are the application rates of the emission reduction measures. In particular, the two possible decision variables considered in this formalization are technical measures (as i.e. end-of-pipe technologies) and efficiency/non-technical measures (as i.e. behavioural changes).
More in detail, the following definitions (for technical and non-technical measures) are adopted:
- technical measures are the so-called "**end-of-pipe-technologies**", i.e. filters that are applied to power plant emissions, to cars, etc.. These measures neither modify the driving forces of emissions nor change the structural composition of energy systems or agricultural activities, but are applied to reduce emissions before being released in the atmosphere;

- non-technical measures or **energy efficiency measures** are measures that reduce anthropogenic driving forces that generate pollution. Such measures can be related to people behavioural changes (for instance: the use of bicycle instead of cars for personal mobility, the reduction of temperature in buildings) or to technologies that aim to reduce the energy demand (urban/regional structural planning like densification, road management, building renovation), or to abate the fuel consumption (for instance: the use of high efficiency boilers, of building thermal insulating coats).

Applying these measures,the reduced emissions is computed as follows[8]:

$$E_{k,f,p} = \sum_{t \in T_{k,f}} (A_{k,f} \cdot ef_{k,f}^{p}) X_{k,f,t} \cdot eff_{k,f,t}^{p} + \sum_{t \in Z_{k,f}} (A_{k,f} \cdot ef_{k,f}^{p}) Z_{k,f,t} \cdot eff_{k,f,t}^{p}$$

where:
- variable $X_{k,f,t}$: is the application rate (bounded in $[\bar{X}_{k,f,t}; \underline{X}_{k,f,t}]$) of technical measure t to sector k and activity f;
- variable $Z_{k,f,t}$: is the application rate (bounded in $[\bar{Z}_{k,f,t}; \underline{Z}_{k,f,t}]$) of non-technical measure t to sector k and activity f;
- $A_{k,f} \cdot ef_{k,f}^{p}$: is the pollutant p emission due to sector k and activity f;
- $X_{k,f,t} \cdot eff_{k,f,t}^{p}$: is the overall technical measure t removal factor with respect to sector k, activity f and pollutant p;
- $Z_{k,f,t} \cdot eff_{k,f,t}^{p}$: is the overall non-technical measure t removal factor with respect to sector k, activity f and pollutant p.

The total emission reduction for a pollutant p, due to the application of a set of measures, can be calculated as the sum of the emission reductions over all the <sector-activity> pairs:

$$E_p = \sum_{k,f} E_{k,f,p}$$

The Air Quality objective is a function of the emission reductions and, thus, of the technical and non-technical measure application rates.

The emission reductions are computed beyond the CLE scenario. It is important to note that the CLE scenario is estimated starting from the emissions at an initial year if no technology had been applied. Such "no technology" scenario is defined in this report as "virtual emissions".

The selection of the technologies to be optimized is done through a dedicated flag (for each technology, in fact, the user can select if they must be kept fixed at the Current Legislation level, or if they can be optimized). Furthermore, to speed up the

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[8] This equation should also consider a nonlinear term due to combined use of end-of-pipe and efficiency measures; however, in order to simplify it, the nonlinear term is neglected.

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computations, "not efficient" technologies are automatically excluded by the optimization, and kept fixed to CLE[9].

13.5 Constraints

The first constraint concerns the internal cost (for emission reduction implementation), which cannot be greater than the available budget *L*.

The Internal Cost objective is the total cost to apply the selected measures at the selected rates. As previously introduced, $c_{k,f,t}$ is the internal cost of applying measure $t \in T_{kf} \cup NT_{kf}$ to a unit of sector-activity *k, f*. The total units of activity to which technology *t* can be applied is given by $A_{k,f} X_{k,f,t}$ and $A_{k,f} Z_{k,f,t}$ for technical and non-technical measures, respectively.

Thus, the internal costs [Meuro/year] are calculated as:

$$inC(X,Z) = \sum_{k \in K}\sum_{f \in F_k}\sum_{t \in T_{k,f}} (X_{k,f,t}A_{k,f})c_{k,f,t} + \sum_{k \in K}\sum_{f \in F_k}\sum_{t \in NT_{k,f}} (Z_{k,f,t}A_{k,f})c_{k,f,t}$$

The constraint is thus the following:

$$inC(X_{k,f,t}; Z_{k,f,t}) \leq L$$

The following constraints hold for technical measures.

1. When no technological substitution is admitted, the following constraints are defined:
   - to ensure the application feasibility:

   $$X_{k,f,t}^{CLE} \leq X_{k,f,t} \leq \bar{X}_{k,f,t} \quad \forall k \in K, f \in F_k, t \in T_{k,f};$$

   - to ensure the mutual exclusion of the technical measures application (for each activity and each primary pollutant, i.e. for each activity and each precursor, the sum of all the application rates must be less than one):

   $$\sum_{t \in T_{k,f}:eff_{kft}^p>0} X_{k,f,t} \leq 1 \quad \forall k \in K, f \in F_k, p \in P ;$$

   it is worth observing that these constraints imply the so called "conservation of mass" associated with the application of the technical measures (for each activity and each primary pollutant, i.e. for each activity and each precursor):

   $$\sum_{t \in T_{k,f}:eff_{kft}^p>0} X_{k,f,t}eff_{kft}^p \leq 1 \quad \forall k \in K, f \in F_k, p \in P .$$

---

[9] Technologies are defined as "not efficient": a) when the maximum feasible emission reduction associated to a technology is less than 10^{-6} tons; b) when CLE and MFR for that technology assume the same value.

2. When technological substitution is admitted, the following constraints are applied:
   - to ensure the application feasibility:

$$0 \leq X_{k,f,t} \leq \bar{X}_{k,f,t} \quad \forall\, k \in K, f \in F_k, t \in T_{k,f};$$

   - to ensure the mutual exclusion of technical measures application (for each activity and each primary pollutant, i.e. for each activity and each precursor):

$$\sum_{t \in T_{k,f}:eff^p_{kft}>0} X_{k,f,t} \leq 1 \quad \forall\, k \in K, f \in F_k, p \in P;$$

   - to ensure that the emission reduction achieved according to the optimal solution are at least those guaranteed by the application of the technologies imposed by the Current LEgislation (for each activity and each primary pollutant):

$$\sum_{t \in T_{k,f}:eff^p_{kft}>0} X_{k,f,t} \cdot eff^p_{k,f,t} \geq \sum_{t \in T_{k,f}:eff^p_{kft}>0} X^{CLE}_{k,f,t} \cdot eff^p_{k,f,t}$$

$$\forall\, k \in K, f \in F_k, \mathrm{p} \in \mathrm{P};$$

   - to ensure that the emissions controlled according to the optimal solution are at least those controlled applying the technologies at the lower bounds imposed by the Current LEgislation:

$$\sum_{t \in T_{k,f}:eff^p_{kft}>0} X_{k,f,t} \geq \sum_{t \in T_{k,f}:eff^p_{kft}>0} X^{CLE}_{k,f,t} \quad \forall\, k \in K, f \in F_k, \mathrm{p} \in \mathrm{P};$$

Concerning non-technical measures:
   - to ensure the application feasibility:

$$Z^{CLE}_{k,f,t} \leq Z_{k,f,t} \leq \bar{Z}_{k,f,t} \quad \forall\, k \in K, f \in F_k, t \in NT_{k,f};$$

Moreover, when both technical and non-technical measures are applied, the global conservation of mass constraints have to be stated explicitly (for each activity and each primary pollutant):

$$\sum_{t \in T_{k,f}:eff^p_{kft}>0} X_{k,f,t}\, eff^p_{kft} + \sum_{t \in NT_{k,f}:eff^p_{kft}>0} Z_{k,f,t}\, eff^p_{kft} \leq 1$$

$$\forall k \in K, f \in F_k, \mathrm{p} \in \mathrm{P}$$

When required, additional constraints are added to manage macrosector budget constraints, and to keep consistency for traffic measures applied to different road types (highway, extraurban, urban).

When macrosector budget constraints have to be imposed, the following inequalities are added to the model:

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$$inC(X_{k,f,t}^{i};Z_{k,f,t}^{i}) - inC(X_{k,f,t}^{CLE,i};Z_{k,f,t}^{CLE,i}) \leq \phi_i(inC(X_{k,f,t};Z_{k,f,t}) - inC(X_{k,f,t}^{CLE};Z_{k,f,t}^{CLE})) \quad i \in \tilde{M},$$

Where

$M = \{1,...,\mu\}$ is the index set for the macrosectors, and

$\tilde{M} \subseteq M$ identifies the macrosectors whose budgets have to be bounded.

In order to keep consistency for traffic measures applied to different road types (highway, extraurban, urban) the following constraints are imposed:

$$X_{k',f,t} = X_{k'',f,t} \qquad k'=H, k''=E, f \in F_{k'} \cup F_{k''}, t \in T_{k',f} \cup T_{k'',f}$$

$$X_{k',f,t} = X_{k'',f,t} \qquad k'=E, k''=U, f \in F_{k'} \cup F_{k''}, t \in T_{k',f} \cup T_{k'',f}$$

$$X_{k',f,t} = X_{k'',f,t} \qquad k'=H, k''=U, f \in F_{k'} \cup F_{k''}, t \in T_{k',f} \cup T_{k'',f}$$

where *H, E, U* are the identifiers of the highway, extraurban and urban sectors, respectively. In this way, the values of the variables $X_{k,f,t}$ must be the same when these variables are associated with the same technical measure *t*, applied to the same activity *k*, which is performed in at least two sectors among highway, extraurban and urban.

13.6 Ex-post analysis: External Cost computation

The ExternE approach (Bickel et al., 2005) has been applied to compute health impacts and external costs, due to PM10 exposure. More in detail, considering the PM10 maps resulting from optimal air quality policies, the following health impacts/external costs have been considered:

- Asthmatic adults and children
    - o Bronchodilator usage
    - o Cough
    - o Respiratory problems
- Over 65 years-old
    - o heart attack
- Children
    - o chronic cough
- Adults
    - o reduced activity
    - o chronic bronchitis
- Total population
    - o chronic mortality
    - o hospital admission for respiratory problems
    - o hospital admission for cardiovascular problems
- Over 30 years
    - o Years of life lost

The equation to compute impacts is as follows:

$$h^m = \sum_{x,y} \gamma^m \cdot P_{x,y} \cdot \chi_{x,y}$$

Where:

o h^m is the morbidity indicator (m) cost;

o γ^m is the incidence of the indicator m;

o $P_{x,y}$ is the population exposed to PM10 pollution (population of children, adults …, depending on the selected health impact), at cell x, y;

o $\chi_{x,y}$ indicates the mean PM10 concentrations, at cell x, y.

Coefficients used to compute impacts and related economic values are shown in the next Figure.

receptors	impact indicator	pollutant	impact coefficient		economic value	
ASTHMATIC						
Adults						
	Bronchodilator usage	PM 10	0.163	cases/(year*person*mg/m3)	40	euro$_{2000}$/case
	cough	PM 10	0.335	cases/(year*person*mg/m3)	45	euro$_{2000}$/case
	Respiratory problems	PM 10	0.061	cases/(year*person*mg/m3)	8	euro$_{2000}$/case
Children						
	Bronchodilator usage	PM 10	0.078	cases/(year*person*mg/m3)	40	euro$_{2000}$/case
	cough	PM 10	0.267	cases/(year*person*mg/m3)	45	euro$_{2000}$/case
	Respiratory problems	PM 10	0.103	cases/(year*person*mg/m3)	8	euro$_{2000}$/case
OVER 65						
	heart attack	PM 10	1.85E-05	cases/(year*person*mg/m3)	3260	euro$_{2000}$/case
CHILDREN						
	chronic cough	PM 10	0.00207	cases/(year*person*mg/m3)	240	euro$_{2000}$/case
ADULTS						
	reduced activity	PM 10	0.025	cases/(year*person*mg/m3)	110	euro$_{2000}$/case
	chronic bronchitis	PM 10	0.000049	cases/(year*person*mg/m3)	169330	euro$_{2000}$/case
TOTAL POPULATION	chronic mortality	PM 10	0.26	[% of change in yearly mortality ratedi/(µg/m3)]		
	hospital admission for respiratory problems	PM 10	2.07E-06	cases/(year*person*mg/m3)	4320	euro$_{2000}$/case
	hospital admission for cardiovasculary problems	PM 10	5.04E-06	cases/(year*person*mg/m3)	16730	euro$_{2000}$/case
OVER 30						
	years of lost life	PM 10	0.0004	Years Of Life Lost (YOLL)	50000	euro$_{2000}$/case

Figure 13-1: Data used to compute health impacts and related economic costs.

The outputs produced by this ex-post analysis are (for each point of the Pareto curve):

- maps of impacts (years of life lost);
- total cost (over the domain) computed separately for morbidity and mortality.

13.7 Ex-post analysis: Greenhouse Gases computation

Also the GHG budget is computed ex-post, as a result of the optimal Air Quality policies application. Starting from the optimal application rates of emission reduction measures and from the activity level for each sector-activity, reduced GHG (beyond CLE) are computed. The GHG considered are the Kyoto protocol

regulated ones, that is to say: CO_2, CH_4, N_2O, Fgas.

Starting from estimated activity level (*A*) for each sector-activity (*k,f*) the removed GHG emissions (*g*), due to optimal air quality policies, are computed as:

$$GHG_{k,f,g} = \sum_{t \in T_{k,f}} (A_{k,f} \cdot ef^g_{k,f}) \cdot X_{k,f,t} \cdot eff^g_{k,f,t}$$

Where all the various equation ingredients have already been explained. Finally, the total GHG reduced emissions (for GHG emission *g*) are defined as:

$$GHG_g = \sum_{k,f} GHG_{k,f,g}$$

14 DISAGGREGATION METHODOLOGY

In case of municipal emissions, RIAT+ computes a spatial disaggregation allocating emission in the cells of the domain inside the region and a temporal disaggregation on the entire domain.

Spatial (Paragraph 14.1) and temporal (Paragraph 14.2) disaggregation processes are described below.

14.1 Emission spatial disaggregation

Emission spatial disaggregation is carried out using "activity proxy assignment" and **proxy variable** files (see the Paragraph 5.6.1.4).

Through the first file, a suitable indicator is assigned to each inventory's activity to represent the spatial location of the emission phenomenon.

For example, emissions of "residential heating plants" are spread on urban land, which represents the land portion where it is more likely that there will be emissions.

Through the second file, the fraction of spatial indicator of the municipalities that intersects a generic cell "i" is indicated (term in brackets in the following formula).

Then the spatial disaggregation per cell is calculated by the formula:

$$E\_cell_{i,a,p} = \sum_{m} E\_mun_{m,a,p} \left(\frac{ind_{m,i}}{ind_m} \right)$$

where:

i = cell

a = emission activity

m = municipality

p = pollutant

E_cell = emission of the pollutant *p* and the activity *a* in the cell *i*

E_mun = emission of the pollutant *p* and the activity *a* in the municipality *m*

Ind = spread proxy variable

14.2 Emission temporal disaggregation

The temporal disaggregation is carried out for each cell in the whole domain.

The temporal proxy variables are detailed for each macrosector, pollutant and, of course, temporal profile.

The used formula is:

$$E\_cell_{i,a,p,t} = E\_cell_{i,a,p} \cdot P_{ms(a),p,t}$$

where:

i = cell

a = emission activity

ms(a) = macrosector of activity a

p = pollutant

t = specific temporal profile (e.g. semester, season …)

E_cell = emission of the pollutant *p* and the activity *a* in the cell *i*

P = temporal profile of macrosector *ms*, pollutant *p* and temporal period *t*

15 VIRTUAL EMISSION AND CLE AND MFR PROJECTION

15.1 Virtual emission definition

Virtual emissions are the starting point for the projection of emissions and for the optimization process. As suggested by the name, virtual emission is not a real one, but it is a concept strictly related to the concept of the application rate: it represent the emission that there would be without any technology applied (all technologies ARs set to zero). This guarantees that applying the CLE to the reference year we obtain exactly the regional emission inventory data.

To better understand the virtual emission definition, it is necessary to show the general formulation used to obtain the emission in a particular year (called scenario year - SCEN_YEAR) when the emission inventory refers to (another) reference year (REF_YEAR):

$$
\begin{aligned}
E_{SCEN\_YEAR\ i,j,k,p} = E_{BC\ REF\_YEAR\ i,j,k,p} \\
* \left[\sum_{t=1}^{T_{i,j,k}} \left[(1 - eff_{i,j,k,t,p}) * AR_{SCEN\_YEAR\ i,j,k,t} \right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR_{SCEN\_YEAR\ i,j,k,t} \right) \right] \\
* \frac{AL_{SCEN\_YEAR\ j,j,k}}{AL_{REF\_YEAR\ j,j,k}}
\end{aligned}
$$

Where:
- $E_{SCEN\_YEAR\ i,j,k,p}$ are the emissions [in tons] referred to a particular year (SCEN_YEAR) of the pollutant p, in macrosector, sector, activity *<i,j,k>* triple, remaining after the application of a set of technologies;
- $T_{i,j,k}$ are the technologies that can be applied in the macrosector, sector, activity *<i,j,k>* triple;
- $eff_{i,j,k,t,p}$ represents the removal efficiency (between 0 and 1) of a particular technology t (in the macrosector, sector, activity *<i,j,k>* triple), for a selected pollutant p;
- $AR_{SCEN\_YEAR\ i,j,k,t}$ represents the application rate of a particular year -SCEN_YEAR- (between 0 and 1) of a macrosector, sector, activity, technology *<i,j,k,t>* quadruple (0 means no technology use, 1 means maximum application of the technology);
- $AL_{SCEN\_YEAR\ i,j,k}$ is the activity levels of a particular year -SCEN_YEAR- of a macrosector, sector, activity *<i,j,k>* triple;
- $AL_{REF\_YEAR\ i,j,k}$ is the activity levels of a particular year -REF_YEAR- of a macrosector, sector, activity *<i,j,k>* triple;

In this equation the part into the square brackets represents the application of the set of technologies taking also in account the emission not reduced due to the NOC technologies for that macrosector, sector, activity *<i,j,k>* triple; the ratio between the $AL_{SCEN\_YEAR\ i,j,k}$ and the $AL_{REF\_YEAR\ i,j,k}$ represents the evolution of the emission activity in the two years considered (in terms of increase or decrease).

$E_{BC\ REF\_YEAR\ i,j,k,t,p}$ are the "base case" emissions [in tons/year] of the pollutant p, in macrosector, sector, activity *<i,j,k>* triple. The year to which the emissions refer is the reference year of the emission inventory, but these emissions are not the actual

emissions of the regional emission inventory. It is necessary to take into account that the measure application rate are not incremental. So to apply the set of technologies of the macrosector, sector, activity *<i,j,k>* triple for the scenario year it is mandatory to bring back the regional emission inventory to a "virtual" state in which no technologies are applied. The emissions corresponding to this state are the "virtual" ones, and thus they may be different from those in the regional emission inventory for the same year.

The virtual emission value - $E_{BC\ REF\_YEAR\ i,j,k,t,p}$ – is obtained using the general formulation, but referred to the reference year:

$$E_{REF\_YEAR\ i,j,k,p} = E_{BC\ REF\_YEAR\ i,j,k,p}$$
$$* \left[\sum_{t=1}^{T_{i,j,k}} \left[(1 - eff_{i,j,k,t,p}) * AR_{REF\_YEAR\ i,j,k,t} \right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR_{REF\_YEAR\ i,j,k,t} \right) \right]$$
$$* \frac{AL_{REF\_YEAR\ j,j,k}}{AL_{REF\_YEAR\ j,j,k}}$$

So the virtual emission - $E_{BC\ REF\_YEAR\ i,j,k,t,p}$ – is:

$$E_{BC\ REF\_YEAR\ i,j,k,p} = \frac{E_{REF\_YEAR\ j,jk,p}}{\sum_{t=1}^{T_{i,j,k}} \left[(1 - eff_{i,j,k,t,p}) * AR_{REF\_YEAR\ i,j,k,t} \right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR_{REF\_YEAR\ i,j,k,t} \right)}$$

From all the equations shown the final formulation of the emission in a particular year (scenario year - SCEN_YEAR) when the emission inventory refers to reference year (REF_YEAR) is:

$$E_{SCEN\ YEAR\ i,j,k,p} = E_{REF\_YEAR\ j,jk,p}$$
$$* \frac{\left[\sum_{t=1}^{T_{i,j,k}} \left[(1 - eff_{i,j,k,t,p}) * AR_{SCEN\_YEAR\ i,j,k,t} \right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR_{SCEN\_YEAR\ i,j,k,t} \right) \right]}{\sum_{t=1}^{T_{i,j,k}} \left[(1 - eff_{i,j,k,t,p}) * AR_{REF\_YEAR\ i,j,k,t} \right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR_{REF\_YEAR\ i,j,k,t} \right)}$$
$$* \frac{AL_{SCEN\_YEAR\ j,j,k}}{AL_{REF\_YEAR\ j,j,k}}$$

15.2 Computing MFR

As explained in Paragraph 6.1, the measure database contains the CLE and Potential application rates. To calculate the emissions for ANNs training, also Maximum Feasible Reduction (MFR) application rate is used. The MFR emission defines the upper reduction limit to be computed by the CTM module for the neural network training.

To estimate MFR application rates for each activity, the first step is the sorting of the removal efficiency of the technologies, for each pollutant, considering the macrosector-sector-activity triples.

Then the technology with the highest RE is applied until the potential level of application of the technology itself. If the potential value is less than 100%, then the technology with the second highest RE is applied within the potential limit, until the sum of the two technologies application rates reaches the value of 100%. If this limit is not reached, the system goes on with the technology with the third highest RE value until the total AR of 100% is reached.

Through this procedure the maximum reduction of emissions is guaranteed for each

activity and pollutant.

15.3 CLE and MFR projection

The CLE and MFR emission projection are computed to define the minimum and maximum limit to be computed by the CTM module for the neural network training. The formulation of CLE and MFR emission is the same shown in Paragraph 15.1.

The remaining emissions after the application of CLE of the scenario year - SCEN_YEAR - when the emission inventory refers to the reference year (REF_YEAR) are:

$$E\_CLE_{SCEN_{YEAR} i,j,k,p} = E_{REF\_YEAR\ j,jk,p}$$

$$* \frac{\left[\sum_{t=1}^{T_{i,j,k}}\left[(1 - eff_{i,j,k,t,p}) * AR\_CLE_{SCEN\_YEAR\ i,j,k,t}\right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR\_CLE_{SCEN\_YEAR\ i,j,k,t}\right)\right]}{\sum_{t=1}^{T_{i,j,k}}\left[(1 - eff_{i,j,k,t,p}) * AR_{REF\_YEAR\ i,j,k,t}\right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR_{REF\_YEAR\ i,j,k,t}\right)}$$

$$* \frac{AL_{SCEN\_YEAR\ j,j,k}}{AL_{REF\_YEAR\ j,j,k}}$$

Where all the terms of the equation are the same shown in the Paragraph 15.1:
- *E_CLE* $_{SCEN\_YEAR\ i,j,k,p}$ are the emissions [in tons] referred to a particular year (SCEN_YEAR) of the pollutant *p*, in macrosector, sector, activity *<i,j,k>* triple, remaining after the application of the set of technologies of CLE;
- *AR_CLE* $_{SCEN\_YEAR\ i,j,k,t}$ represents the CLE application rate of a particular year - SCEN_YEAR- (between 0 and 1) of a macrosector, sector, activity, technology *<i,j,k,t>* quadruple (0 means no technology use, 1 means maximum application of the technology).

The remaining emissions after the application of MFR of the scenario year - SCEN_YEAR - when the emission inventory refers to the reference year (REF_YEAR) are:

$$E\_MFR_{SCEN_{YEAR} i,j,k,p} = E_{REF\_YEAR\ j,jk,p}$$

$$* \frac{\left[\sum_{t=1}^{T_{i,j,k}}\left[(1 - eff_{i,j,k,t,p}) * AR\_MFR_{SCEN\_YEAR\ i,j,k,t}\right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR\_MFR_{SCEN\_YEAR\ i,j,k,t}\right)\right]}{\sum_{t=1}^{T_{i,j,k}}\left[(1 - eff_{i,j,k,t,p}) * AR_{REF\_YEAR\ i,j,k,t}\right] + \left(1 - \sum_{t=1}^{T_{i,j,k}} AR_{REF\_YEAR\ i,j,k,t}\right)}$$

$$* \frac{AL_{SCEN\_YEAR\ j,j,k}}{AL_{REF\_YEAR\ j,j,k}}$$

Where all the terms of the equation are the same shown in the Paragraph 15.1:
- *E_MFR* $_{SCEN\_YEAR\ i,j,k,p}$ are the emissions [in tons] referred to a particular year (SCEN_YEAR) of the pollutant *p*, in macrosector, sector, activity *<i,j,k>* triple, remaining after the application of the set of technologies of MFR;
- *AR_MFR* $_{SCEN\_YEAR\ i,j,k,t}$ represents the MFR application rate of a particular year -SCEN_YEAR- (between 0 and 1) of a macrosector, sector, activity, technology *<i,j,k,t>* quadruple (0 means no technology use, 1 means maximum application of the technology).

15.3.1 Average CLE and MFR projection for outside region emissions

It is also possible to project emissions applying the reduction not with technology detail but with macrosector detail using CLE and MFR average values. This is the

approach used for the emission projection outside region.

To simplify the explanation the following formula are referred only to CLE reduction, but they are exactly the same considering MFR reduction.

The CLE and MFR reduction with technology detail concerning only the emissions inside region, so in the following formulation every emissions terms is to be considered inside region.

The computation of average CLE reduction factor is:

$$AVG\_CLE_{SCEN\_YEAR\ i,p} = \frac{E\_CLE\_areal_{SCEN\_YEAR\ i,p} + E\_CLE\_PS_{SCEN\_YEAR\ i,p}}{E\_areal_{REF\_YEAR\ i,p} + E\_PS_{REF\_YEAR\ i,p}}$$

Where:

- $AVG\_CLE_{SCEN\_YEAR\ k,p}$ is the average CLE reduction factor referred to a particular year (SCEN_YEAR) of the pollutant *p* for the macrosector *i*; it should be included between 0 and 1;
- $E\_CLE\_areal_{SCEN\_YEAR\ k,p}$ are the areal emissions [in tons] referred to a particular year (SCEN_YEAR) of the pollutant *p*, for the macrosector *i* remaining after the application of a set of technologies related to the *i* macrosector (see the Paragraph below);
- $E\_CLE\_PS_{SCEN\_YEAR\ k,p}$ are the point source emissions [in tons] referred to a particular year (SCEN_YEAR) of the pollutant *p*, for the macrosector *i* remaining after the application of a set of technologies related to the *i* macrosector (see the Paragraph below);
- $E\_areal_{REF\_YEAR\ k,p}$ are the areal emissions [in tons] referred to the reference year (REF_YEAR) of the pollutant *p*, for the macrosector *i* (areal emission inventory);
- $E\_PS_{REF\_YEAR\ k,p}$ are the point source emissions [in tons] referred to the reference year (REF_YEAR) of the pollutant *p*, for the macrosector *i* (point source emission inventory);

All the emission listed above are inside region emission.

Then the CLE emission projection outside region is computed with:

$$E\_AVG\_CLE\_areal_{SCEN\_YEAR\ i,j,k,p} = AVG\_CLE_{SCEN\_YEAR\ i,p} * E\_areal_{REF\_YEAR\ i,p}$$

Where:

- $E\_AVG\_CLE\_areal_{SCEN\_YEAR\ k,p}$ are the areal emissions [in tons] referred to a particular year (SCEN_YEAR) of the pollutant *p*, for the macrosector *i* remaining after the application of the average reduction factor;
- $AVG\_CLE_{SCEN\_YEAR\ k,p}$ is the average CLE reduction factor referred to a particular year (SCEN_YEAR) of the pollutant *p* for the macrosector *i*; it should be included between 0 and 1;
- $E\_areal_{REF\_YEAR\ k,p}$ are the areal emissions [in tons] referred to the reference year (REF_YEAR) of the pollutant *p*, for the macrosector *i* (areal emission inventory).

All the emission listed above are outside region emission.

The same formulation is used for point emissions outside region.

ANNEXES: RIAT+ MODEL ALGORITHMS

ANNEX I: SOURCE RECEPTOR MODELS

The methodology foresees the use of source-receptor models, both linear and nonlinear (Artificial Neural Networks) ones.
In this ANNEX a description of the ANNs identification and use is given.

ANNs structure

ANNs are known to be suitable to describe nonlinear relationship between data, such as those theoretically involved in the formation of air pollution. Given a class of surrogate models, the identification procedure requires two steps: the definition of the specific structure, and the calibration of the parameters to the specific application. These two steps, however, are not completely independent and the definition of the structure is often constrained by available data, while the output of the calibration step obviously depends on the structure adopted. Furthermore, the structure of the ANNs must be able to retain what are considered to be the essential features of the original model. So models formalized and identified in this work have to retain spatial information, linking emission values to local air quality indexes, that later could be processed to obtain a single global value.
In terms of ANNs structure, a feed-forward neural structure has been adopted in this study (Figure 1).
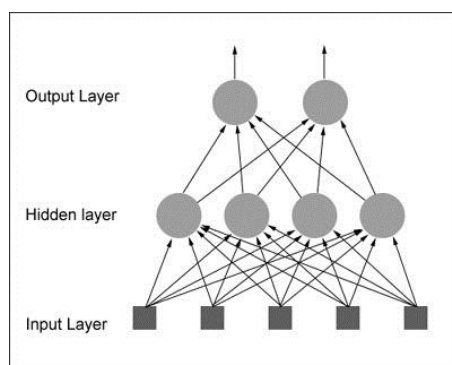
Figure 1: Scheme of the Feed Forward Neural Network.

This network computes a vector function $f_{NN} : R^Q \to R^L$ where Q and L are the dimensions of the net input and output vectors, respectively; the l-th element of the vector function f_{NN} is defined as (M is the number of the neurons in the hidden layer):

$$f_{NN}(v) = f_2 \left(\sum_{m=1}^{M} (O_{lm} \cdot a_m) + g_l \right)$$

where:

$$a_m = f_1 \left(\sum_{q=1}^{Q} (W_{mq} \cdot v_q) + b_m \right)$$

in which f_1 and f_2 are real continuous functions, called activation functions of the hidden layer (f1) and of the output layer (f2). The matrices W (M x Q) and O (L x M)

are the input and output matrix respectively, and b (M x 1) and g (L x 1) vectors are the bias terms. Neural networks are trained on available data, tuning the parameters W, O, b and g by means of a back-propagation algorithm.

ANNs identification

The steps to be implemented are as follows:

- LOAD EMISSIONS. For each pollutant to be used as input of the source-receptor models (NH_3, NO_x, PM10, PM2.5, SO_2, VOC) it is necessary to provide an emission value for each:
    - o Domain cell
    - o Emission reduction scenario (i.e. basecase + emission reduction scenarios)
    - o Time horizon (i.e. yearly, winter, summer)
    - o Type of emission (areal or point)
- AGGREGATE EMISSIONS. In the current version of RIAT+, to consider the influence of the surrounding cell emissions and the influence of the prevalent wind directions on the study domain, emissions have to be aggregated in "quadrants", as shown in Figure 2 (see also Carnevale et al.,2012), and in the methodological part of the RIAT+ User Guide. This aggregation takes a long time, so a pre-processor (see paragraph 10) has been provided in order to perform an off-line aggregation and speed up the optimization process.

ANNs inputs:
quadrant precursor emissions

ANNs output:
AQI

Figure 2: Quadrant shape input/output configuration.

At the end of this procedure, each input pattern contains up to 48 values, that is to say the emission of:

- o 4 quadrants (left, up, right, down)
- o 6 precursor emissions (NH_3, NO_x, PM10, PM2.5, SO_2, VOC)
- o 2 types of emissions (areal or point, if considered separately)

In practice, the input pattern contains at first the 4 quadrants of areal NH_3 emissions, the 4 quadrants of areal NO_x, of areal PM10… and after these 24 patterns of areal emissions (in the order specified above), the same is repeated for point emissions (to reach the 48 input). In case of particular

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AQIs (as i.e. in the case of ozone) the user can decide to consider only NO_x and VOC as input, and in this case the following input order is adopted:

- o 4 quadrants (left, up, right, down)
- o 2 precursor emissions (NO_x, VOC)
- o 2 types of emissions (areal or point)

- LOAD TARGET. For each AQI to be considered as target (i.e. meanPM10, meanPM2.5, …), it is necessary to provide an emission value for each:

  - o Domain cell
  - o Emission reduction scenario (i.e. basecase + emission reduction scenarios)
  - o Time horizon (i.e. yearly, winter, summer)

- SELECT TRAINING AND VALIDATION DATA. This step allows for the creation, starting from the input and target patterns, of two different dataset, to be used for identification and validation of source-receptor models.

- CHOOSE MODEL CONFIGURATION. Both linear regression and Artificial Neural Networks model can be used in RIAT+. In the case of ANNs (the most complex one) also "Transfer Functions", "number of neurons" and "number of epochs" should be configured (see Mathworks, 2011b).

- TRAIN AND VALIDATE THE MODELS. This step is required to obtain the final SR models, and to test their capabilities. In particular, for the linear case it is possible to use the REGRESSION Matlab command, while for ANNs one should use the commands MAPMINMAX (for normalization/denormalization of input/target), TRAIN (for ANNs training) and SIM (for ANNs validation) (see Mathworks, 2011b),

- PACK THE FINAL RESULT. The structure of the final Matlab object, to be loaded in the RIAT+ GUI, is as follows:

  - o Linear model. It contains the following variables:
    - ▪ PS_INPUT: empty variable
    - ▪ PS_TARGET: empty variable
    - ▪ NET: coefficients of the regression model
    - ▪ ICELLS: area of influence of the quadrants (see Carnevale et al., 2012)
  - o ANNs. It contains the following variables:
    - ▪ PS_INPUT: normalization factors for the input variables
    - ▪ PS_TARGET: denormalization factors for target variables
    - ▪ NET: ANN object
    - ▪ ICELLS: area of influence of the quadrants (see Carnevale et al., 2012)

ANNEX II: INPUT VALIDATION PROCESS

The input validation process validates all data entered in the input project screens. In the following table, all validation procedures used for each input file are listed. All procedures are described below.

Input Data	Data type	Number of columns	Number of rows	Coherence of coordinates with grid	Coherence of zones codes	Coherence with the domain	Macrosector code	Precursors code	Macrosector-activity pair	Municipality code	Spatial disaggregation value	Numbrer of temporal profile	Temporal disaggregation value	Activity-Fuel mapping
Domain file	X	X	X	X	X									
Temporal profile file	X	X												
Population file	X	X	X	X										
Sub-domain files	X	X	X	X	X	X								
External costs file	X	X	X	X										
Model bias file	X	X	X	X										
Emission mapping file							X		X					X
Detailed municipality emission files:														
- Areal sources inside region	X	X					X	X	X	X	X			
- Point sources	X	X		X		X	X	X	X					
- Outside region emissions	X	X	X	X		X								
- Spatial disaggregation file	X	X		X		X	X		X	X	X			
- Temporal disaggregation file	X	X	X									X	X	
Detailed gridded emission files:														
- Areal sources inside region	X	X		X		X	X	X	X					
- Point sources	X	X		X		X	X	X	X					
- Outside region emissions	X	X	X	X		X								
Aggregated scenarios emission files:														
- Areal sources	X	X	X	X										
- Point sources	X	X	X	X		X								
Biogenic Emissions	X	X	X	X										

Procedures

Data type

Checks the data type of the input value and gives an error message if the input data does not match with the chosen data type.

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Number of columns

This procedure counts the number of columns and returns an error message or a warning message depending if the number is smaller or greater than the number of columns required.

Number of rows

As the previous one, this procedure counts the number of rows and returns an error message if the number of rows is incorrect.

Coherence of coordinates with grid

Checks all input coordinates and returns an error if the point does not match with the South-West coordinates of a grid cell.

Coherence with the domain

Checks the consistency of the domain file and the emissions data input. For example, the cells of inside the region must have an emission greater than or equal to 1 in the file domain.

Macrosector code

Checks that the macrosector value is an integer between 1 and 11.

Precursors code

Checks that the precursors value is the same entered in the "emission inventory" screen.

Macrosector-activity pair

Checks that all activities are associated with a unique macrosector value. Returns an error message if there is an activity associated with different macrosectors.

Municipality code

Checks that all municipalities codes in the emission inventory are listed in the spatial disaggregation files.

Spatial disaggregation value

Checks that the sum of disaggregation values for each municipality and each disaggregation index is 1.

Temporal disaggregation value

Checks that the proxy variable for temporal disaggregation is between 0 and 1 and that the sum of temporal proxy variable for each precursors and for each macrosector is 1.

Activity-Fuel mapping

Checks that all activity-fuel pairs listed in emission inventory file are present in emissions mapping file.

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Output

In the folder:

RIAT\Data_region\project\"Project_name"\"Pad_name"\input_validation_out the process saves the file "error.log" where all output messages are reported.

In this file every message is listed with:

- the file name;
- the line number;
- the error or "warning" description.

The system does not allow the user to proceed if the input validation process checks one or more errors. In this case ,it is necessary to correct the errors found and revalidate all the input data. If warnings are present, the system allows the user to proceed.

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ANNEX III - RIAT+ GLOSSARY

Acronym/Abbreviation	Description
AL	Activity Level
ALU	Activity Level Unit
ANN	Artificial Neural Network
AOT40	The sum of the differences between hourly ozone concentration and 40 ppb
AQI	Air Quality Index
AR	Application Rate
AVG	Average
CLE	Current LEgislation
CTM	Chemical Transport Model
EMIOPT	Remaining Emissions after Optimization
GHG	Greenhouse Gas
MAX8H	Daily Maximum Eight-Hour Ozone Averages
MFR	Maximum Feasible Reduction
MS	Macrosector
PAD	Policy Application Domain
POT	Potential
RE	Removal Efficiency
REDOPT	Reduced Emissions
SOMO35	For ozone, the sum of average daily values above 35 ppb
SW	South West
THR	Threshold
UC	Unit Cost
UNEF	Unabated Emission Factor
YEAR OPT IN	Optimization year
YEAR SCEN IN	Scenario emissions year inside the region
YEAR SCEN OUT	Scenario emissions year outside the region

Annexes

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