The MINNI Project: An Integrated Assessment Modeling System For Policy Making

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Keywords: *Integrated Assessment Modeling; RAINS; Atmospheric Pollution Dispersion; Multiphase Chemical Model; EnvironmentalPolicies.*

EXTENDED ABSTRACT

In 2002, the Italian Ministry of the Environment decided to sponsor the project presented by ENEA for the development of the national Integrated Assessment Modeling system (the MINNI Project). The objective of the project is to support the policy makers in the elaboration and assessment of air pollution policies at international, national and local level, by means of the more recent understandings of atmospheric processes. The MINNI Project consists of two main components (Figure 1).

A multi pollutant eulerian Atmospheric Modeling System (AMS) simulating air pollution dynamics and multiphase chemical transformations, providing hourly concentrations and annual depositions of SO_2, NOx, NH_3, PM_{10} , $PM_{2.5}$ and O_3, with a spatial resolution ranging between 400 and 4 km^2. AMS provides RAINS Italy with the Atmospheric Transfer Matrices (ATM) or "area to grid" transfer matrices.

The RAINS-Italy Integrated Assessment Model, developed within a joint research project ENEA-IIASA, inheriting all the features of the RAINS-Europe model, but comprising the atmospheric transport and chemical transformations, as calculated by AMS, in the ATM. Rains-Italy provides emission scenarios for the mentioned pollutants (plus VOC), as well as estimations of costs associated with the implementation of the abatement technologies and impact assessment.

The two components complement each other, offering a powerful tool which allows to provide the policy makers with detailed analyses, where requested, tailored on the specific national or local needs. AMS may feed RAINS-Italy with fine resolution ATMs and/or different meteorological year based ATMs. RAINS-Italy may feed AMS with a projected emission vector, regarding future scenarios, to develop expected detailed deposition/concentration maps. Eloquent examples are given, about the flexibility and the potential applications of the whole system as scientific underpinning support to the policy makers.

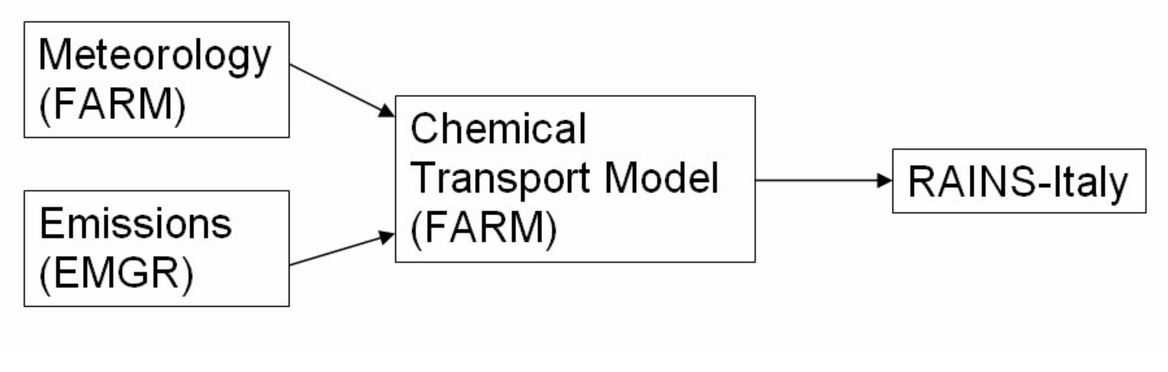

Figure 1. The MINNI project structure and component links**.**

1. INTRODUCTION

The MINNI Project was launched by ENEA at the beginning of 2002 and financed by the Italian Ministry for the Environment and the Protection of the Territory. The conceptual scheme and few test cases will be completed within 2005. The ultimate objective of the Project is the development of an Integrated Assessment Modeling System aimed at both supporting the international negotiation process on Air Pollution and assessing Air Quality Policies at national/local level.

Integrated Assessment Modeling is widely used on continental scale as scientific underpinning for the development of environmental policies. Nevertheless, the accuracy of the continental models in representing pollutant dispersion and chemistry of the atmosphere, at local level, is limited by their resolution. In order to better capture sub-national characteristics, e.g. stagnation inside the Po Valley, a large plane downwind the Alps, the local circulation induced by the complex coastal peculiarities of the Italian Peninsula, both affecting pollutant dispersion and transformation, and to consider an higher resolution land-use definition and consequently a more precise reconstruction of deposition processes, the spatial resolution ranges between 20 x20 km^2 of the whole national domain to 4x4 km^2 for detailed calculation over the northern plane. On the other hand, the need for indipendently developed scenarios, based on the best and detailed national available data, was felt. The MINNI Project was born to fill these gaps, as well as, to provide the Local Authorities with a powerful tool for policy assessment.

2. STRUCTURE OF THE MODELING SYSTEM

The MINNI Project is based upon a double deck system:

- AMS: Atmospheric Modeling System concerning the air pollution dynamics (transport and dispersion) and multiphase chemical transformations. AMS calculates concentration and deposition fluxes of air pollutants;

- RAINS-Italy: a complete Integrated Assessment Model derived from RAINS-Europe (**R**egional **A**ir Pollution **In**formation and **S**imulation). With a built in Atmospheric Transfer Matrix (ATM) calculated by AMS, RAINS-Italy provides emission scenarios, abatement costs, and impact assessment scenarios.

2.1 The Atmospheric Modeling System

The AMS takes into account air pollution dynamics (transport and dispersion), multiphase chemical transformations, wet and dry deposition processes of the pollutants involved in national and international air quality policies (SO_2, NOx, NH_3, VOC**,** O_3, and PM). The modeling system has been applied to estimate deposition and air concentrations fields over Italy, with a spatial resolution of 20x20 km^2. The reference year, hourly simulated, is the 1999, but more recent years are going to be processed. Different simulation models are integrated in a coherent framework: a three-dimensional Eulerian chemistry transport model (CTM), a non-hydrostatic meteorological model and an emission pre-processor to provide emissions from national and international inventories. Boundary conditions for the selected year are provided by the EMEP Unified model (EMEP, 2003) running over the continental-scale for the same simulation period. The atmospheric modeling system includes meteorology, emissions and pollutants dispersion/ chemistry modules over the computational domain (Figure 2) that refers to a 20 km x 20 km grid system.

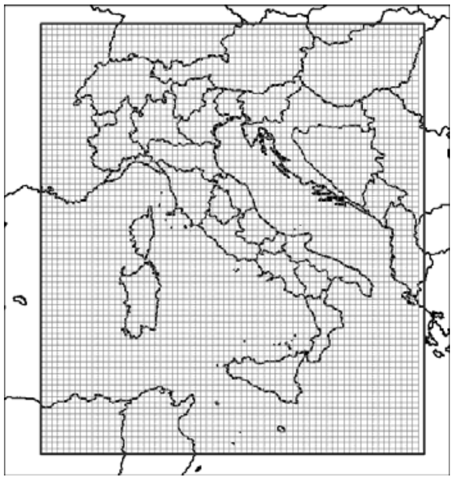

Figure 2. The 20 km x 20 km grid used in the MINNI project

Meteorological fields have been obtained by means of the prognostic and non-hydrostatic model RAMS (Cotton *et al.*, 2003) using a 2 way nested grid system**,** with an outer grid covering large part of the Central Europe and the Mediterranean Sea, with a resolution of 60 km x 60 km and an inner grid including the target area. RAMS has been widely employed as meteorological pre-processor for Chemical Transport Models at continental and national scales (e.g. Zhang *et al*, 2004; Minivielle *et al,* 2004) due to its reliability in decsribing wind fluxes. ECMWF (European Centre for Medium Weather Forecast) analysis fields and surface synoptic observations have been employed as input data for RAMS simulations and the last four-dimensional data assimilation technique (nudging) has been used to force the model output towards the atmospheric reference state, given by experimental data. The emission subsystem is based on the Italian and European emission inventories and includes the maritime emissions also. The hourly input needed by the air quality model, on the computational grid, and for the chemical species of interest, has been provided on the basis of a set of activity specific thematic *layers*, time modulation curves and speciation profiles (NMVOC and PM). A similar procedure was applied to the emissions of the neighbouring countries, starting from the EMEP European inventory. More than 150 Italian large emission sources have been treated as "point sources" taking into account the plume rise effects. The subsystem aimed at simulating the dispersion and the chemical evolution of the pollutants is based on the FARM (Flexible Air Quality Regional Model) model (ARIANET, 2004), derived from STEM (Carmichael *et al.*, 1998). FARM is a three-dimensional Eulerian model dealing with the transport and the multiphase chemistry of pollutants in the atmosphere, including an aerosol module and different chemical schemes, extensively used for air quality assessment studies with overall good results (Silibello *et al*, *2005a and 2005b*). Acid pollutants are treated by means of the (Hov *et al.*, 1988) chemical scheme whereas photochemical reactions will be described by the SAPRC family chemical scheme (Carter, 1990; Carter, 2000). As far as particulate matter is concerned, both the AERO3 Models-3/CMAQ module (Binkowski, 1999) and a simplified PM 'bulk' module (AERO0), considering the ammonia-nitric acid-sulfuric acid-water system, are currently available within the FARM model. The main components of the AMS and their connections with RAINS Italy are shown. (Figure 1). The Atmospheric Transfer Matrices are the link and they are calculated as in the following: the AMS calculates the concentrations as if only one at a time of the considered source areas in RAINS-Italy (see below par. 2.2) had reduced atmospheric emissions (e.g. 30% of the actual rate), while emissions from the other area sources are unchanged. Iterating the process for all the areas, different "area to grid" transfer matrices are obtained, concerning the meteorological pattern and the atmospheric chemical characteristics of the reference meteorological year. In order to capture the inter-annual meteorological variability, model runs should be performed for many different years.

2.1. Structure and functions of the RAINS-Italy Model

The RAINS-Italy has been thought to mirror the features of RAINS-Europe (Amann et al. 2004), which is an Integrated Assessment Model currently adopted by the European Commission and in the frame of the UN-ECE Convention on Long Range Transboundary Air Pollution (CLRTAP) as scientific underpinning to policy assessment. The RAINS-Italy Model has been the subject of a joint research Project ENEA-IIASA (International Institute for Applied Systems Analysis, Laxemburg, Austria). Starting from data concerning the anthropogenic activities (energy consumptions, industrial production, livestock, agriculture etc.) RAINS-Italy computes emissions scenarios, at 5 year intervals, for SO_2, NOx, NH_3, VOCs and PM, on the basis of a long list of applicable abatement technologies, which the user includes in the so called Control Strategy, according to the implementation of measures due to the Current Legislation (CLE Strategy) or alternative Reduction Strategies. Investment and operative costs of the considered technologies are stored in a proper internal database. Therefore, cost curves can be generated to provide a list of possible additional technologies to achieve the desired target in the most cost effective way or to compare alternative strategies costs. The computed emissions are then processed through a proper Atmospheric Transfer Matrix (ATM), which takes into account of the dispersion of the pollutants and the chemical reactions in the atmosphere. The ATM is derived from recursive calculations of the Eulerian Model (AMS), summarizing in exchange coefficients the source-receptor relationship. In RAINS-Europe the ATM is derived by the Unified EMEP Model (Simpson et al, 2003). Through the ATM, yearly average deposition/concentration maps can be generated, concerning the acidification and eutrophication processes, as well as exposure of the population to PM and ozone concentrations. An Health Impact Module has been recently added to the RAINS methodology. Correlations developed by the WHO, on the basis of epidemiological studies, which relate exposure of the population to concentrations of PM and ozone with the occurrence of fatal diseases, have been implemented in the Health Impact Module, so that a statistical estimate of the effects of pollutants on human health is given, in terms of the *Life Expectancy Reduction* and *Premature Deaths* impact indicators. In the RAINS-Italy model, the data processing, described above, is carried out through a modular structure (Figure 3). Some peculiarities characterize the RAINS-Italy Model. The user may select areas of analysis which correspond to different parts of the Italian territory. The user may run the model on the following area sources, individually: the whole national territory, 20 Administrative Regions, 4 Metropolitan Areas, National Sea Traffic, 14 Large Combustion Plants, a group combination of the above areas.

For each one of the above area sources, RAINS-Italy provides the output, as previously described, assuming that activity level data and control strategies are defined properly for each area source.

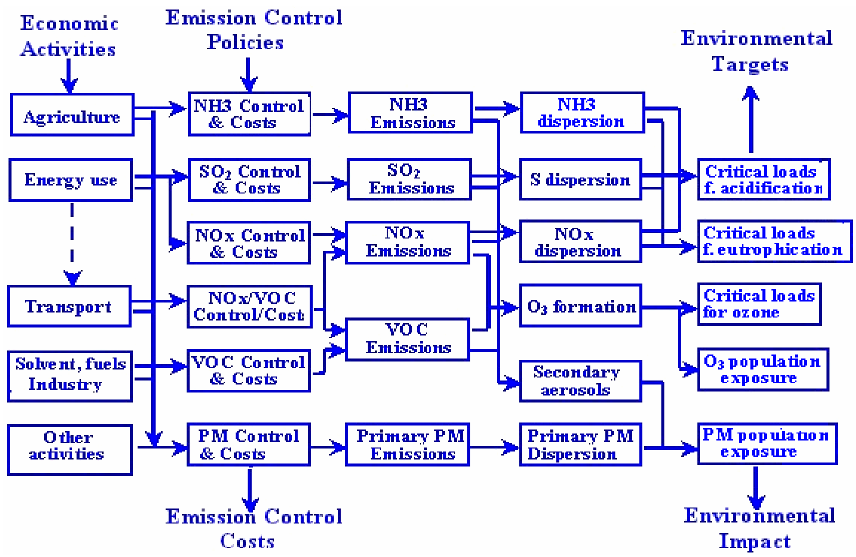

Figure 3. The RAINS methodology modular structure (Amann et al. 2004)

3. THE MINNI PROJECT POTENTIALS IN POLICY ASSESSMENT

For what described above, AMS and RAINS-Italy may develop analyses independently with different features and targets, but they are also complementary each others. AMS generates ATMs (e.g. for different meteorological years) to be embedded in RAINS-Italy, as well as, RAINS-Italy may elaborate emission projections (e.g. at 2020) which can be used as input to AMS, for the deeper and more detailed analyses. Moreover, the potential AMS to analyze Secondary Organic Aerosols, transfers this unique characteristic to RAINS-Italy through the ATMs. In the following paragraph a few meaningful applications will be depicted in order to show the potentiality of the system.

3.1. Applications of AMS

Since the AMS core runs a Chemical Transport Model it is very interesting to simulate the nature of PM in terms of primary or secondary contributions. This possibility allows to develop policies aimed at the reduction even of gaseous pollutants like SOx and NOx. The spatial distributions, in percentage of the primary and secondary PM, are reported (Figure 4).

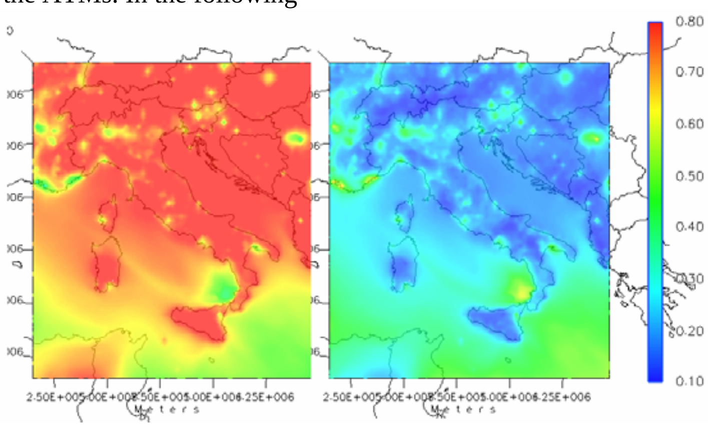

Figure 4. Primary PM (left) and Secondary PM (right) concentrations, (as percentage of total mass) calculated by AMS.

AMS, supporting the non-linear nature of the relationship between PM and its precursors (both gases and particles), allows the simulation of a wide range of policies regarding diverse emission sectors, even apparently “remote”.

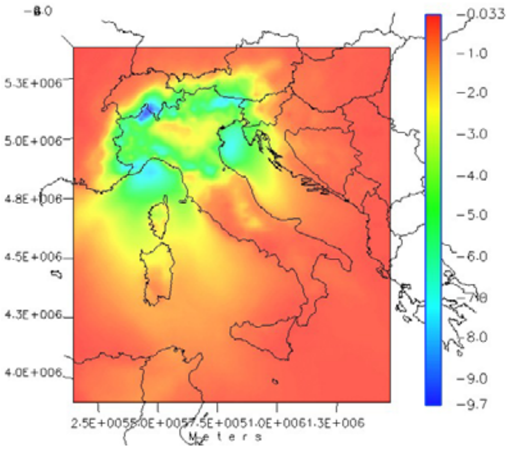

Figure 5. Reduction $PM_{2.5}$ (in percentage), against 30% reduction of NH_3 emissions from agriculture, calculated by AMS.

Impacts on $PM_{2.5}$ concentrations, as a consequence of a 30% reduction in the NH_3 annual emissions from the agricultural sector, in the Northern Italy, are reported (Figure 5).

AMS can also calculate the PM components, both inorganic (Figure 6) and organic (SOA, Secondary Organic Aerosols).

3.2. Applications of RAINS-Italy

The RAINS-Italy Model offers the policy makers with a wide variety of analysis options. Emission scenarios and cost curves are commonly elaborated for the purposes of compliance with the European Commission Directives and other EU environmental programs (e.g. CAFE Program), as well as in the frame of the Gothenburg Protocol of UN-ECE CLRTAP. The scenario comprises emission projections per sector, at 5-year intervals (Figure 7).

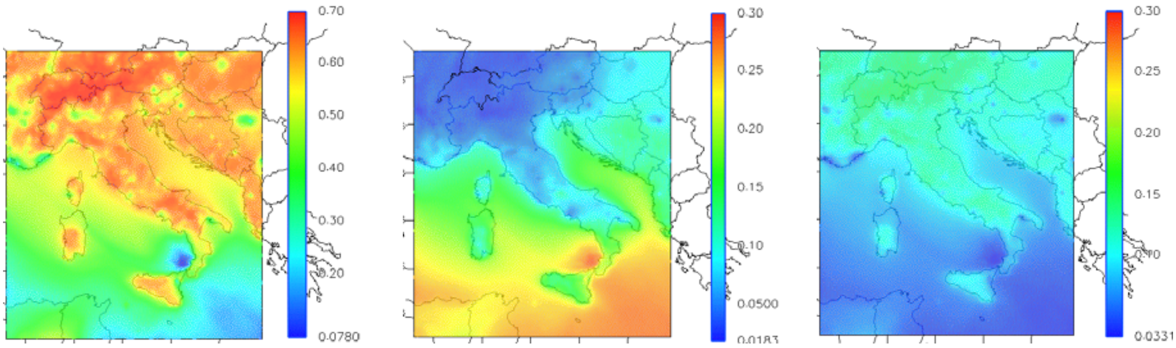

Figure 6. Nitrate (left), Sulphate (center), Ammonium (right), concentrations (as percentage of total mass of inorganic PM) calculated by AMS.

Sector	2000	2005	2010	2015	2020	2025	2030
Energy conversion	89.797	27.666	25.664	25.211	24.059	22.874	23.178
Industry Boilers	29.07	5.18	4.28	3.428	3.103	2.951	2.899
Domestic	29.985	22.753	12.447	10.85	9.923	9.258	8.669
Transport Road	10.98	12.172	0.747	0.758	0.777	0.784	0.773
Transport other	1.571	1.643	0.612	0.661	0.718	0.721	0.78
Transport Ships	11.377	11.377	11.377	11.377	11.377	11.377	11.377
Power Plants Old	338.106	143.298	112.973	96.627	48.125	27.568	27.295
Power Plants New	5.006	30.736	7.64	12.256	17.24	21.907	28.915
Industrial Proces.	116.828	112.064	112.518	114.354	109.633	116.65	129.205
Total	632.72	366.889	288.258	275.522	224.955	214.09	233.091

Figure 7. SOx Emission Scenario (kt/y) calculated by the RAINS-Italy model, with IIASA data.

Emissions assessment usually include a harmonization process between the calculated emissions and the inventory emissions at the base year (2000). Deposition maps (Figure 8) allow assessment of the exceedances of the Critical Loads (CL) and therefore estimations of the level of protection of the ecosystems. Concentration maps (yearly average) are usually compared with the Limit Values (LV) established by the EU Air Quality Directives, both at national and local level.

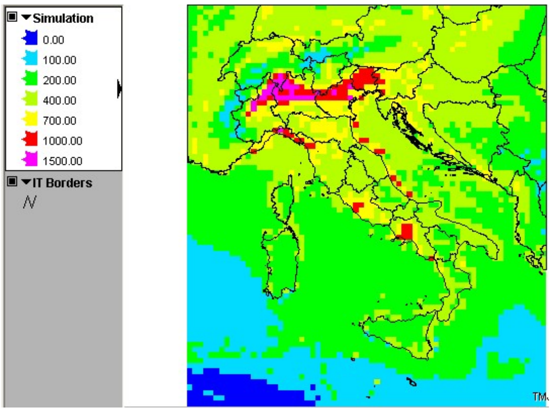

Figure 8. Nitrogen deposition (mg/m^2/y) on the whole Italian territory (test data), calculated by the RAINS-Italy Model.

PM and Ozone concentrations provide a figure of the areas in the country of major exposure for the population and are then further elaborated to evaluate the impact on human health. Sector analyses concerning deposition are allowed for the National Sea Traffic (Figure 9) providing an estimation of the share of shipping on the impact aspects.

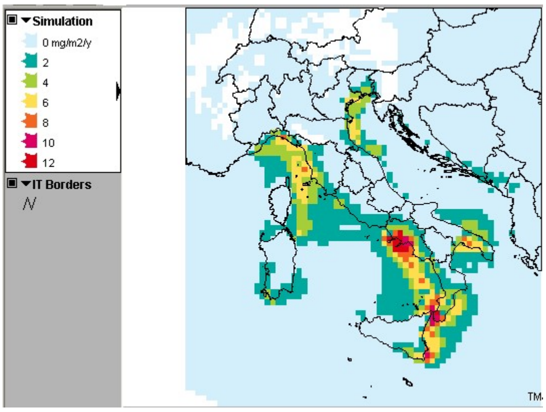

Figure 9. Sulphur deposition (mg/m^2/y) from National Sea Traffic (test data), calculated by RAINS-Italy

In the case of the Large Combustion Plants, considered in the RAINS-Italy Model, a local assessment of the impact on environment and human health, can be also carried out comparing its relative contribution with respect to other sources in the region and in the country (Figure 10). The comparison of different Control Strategies, assuming constant the other input data, provides the user with a tool for ex-ante, ex-post assessment of reduction measures, both at national and local level. This methodology can also be extended to the non technical measures, assuming that the related changes in terms of activity levels are properly estimated and entered as input data.

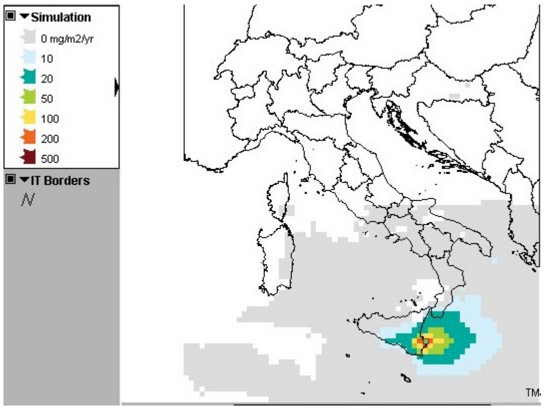

Figure 10. Sulphur deposition (mg/m^2/y) from a local refinery plant, calculated by the RAINS-Italy Model.

4. CONCLUSIONS

The MINNI project has demonstated how an Integrated Assessment Model is an important tool for scenario simulations and for addressing effective air quality and emission control policies. The inclusion of a Chemical Transport Model is necessary to tackle the current air quality problems related to secondary pollutants which do not linearly depend on the emissions. The simulations performed show that PM problems are related to tropospheric ozone, acid rains, eutrophication. MINNI provides an integrated and multi-pollutant approach with many possible outcomes: to forecast both the effectiveness and the costs of the measures, to provide local scale studies with a coherent frame of boundary and background conditions, to assess both technical and non technical measures. In order to routinely support air quality policies a great effort has been devoted in assessing the performances of the model chain.

5. ACKNOWLEDGMENTS

A special acknowledgment is addressed to the Italian Ministry for the Environment for having supported the MINNI Project. We also thank IIASA and EMEP for their great contribution to this project, as well as our colleagues M.Contaldi and R. De Lauretis of APAT (Italian Agency for the Protection of the Environment).

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