Belgian Science Policy

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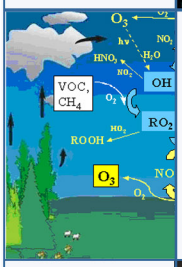
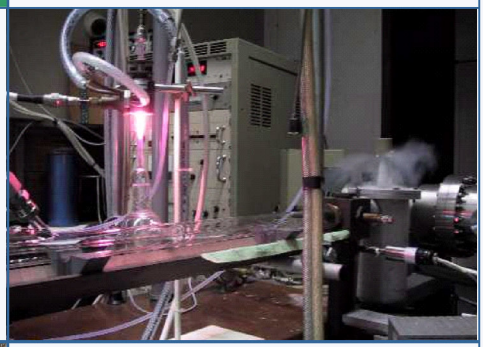
Scientific support to the tropospheric ozone reduction strategy



Contribution of the Belgian Science Policy in the framework of the "Federal plan against acidification and tropospheric ozone"



Information dossier

Belgian Science Policy

Scientific support to the tropospheric ozone reduction strategy

Contribution of the Belgian Science Policy
in the framework of the
"Federal Plan against acidification and tropospheric ozone"

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OZON

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Foreword

The Belgian Science Policy has been entrusted with producing the present report in the framework of the "Federal Plan against acidification and tropospheric ozone". Focusing on ozone and the issues it raises, this report presents a summary and the main results of relevant research activities supported by the Belgian Science Policy, including research conducted within the federal scientific institutions.

In the early nineties, the Belgian Science Policy launched the "Global Change" and "Transport and Mobility" impulse programmes. Later, from 1996 to 2001, these two research areas were integrated into the "Scientific Support Plan for a Sustainable Development" (SPSD I). A second plan bearing the same name (SPSD II) will extend to the end of 2005. SPSD I and SPSD II were implemented in the framework of a cooperation agreement between the federal authorities, the Regions, and the Communities.

In recent years the Belgian Science Policy has taken various initiatives aimed at facilitating access to and exploitation of research results related to ozone policy: it has published reports, report summaries, and project information sheets, organised symposia, and set up steering structures at programme and project level.

In particular, the Belgian Science Policy and the 'Flemish Institute for Technological Research' (Vlaamse Instelling voor Technologisch Onderzoek (Vito)) co-organised the one-day workshop "Ozone in Ambient Air and Ozone Precursors: Scientific Instruments and Policy" in June 2004.

In addition, the Belgian Science Policy has prepared an assessment report analysing the results and (potential) applications of twelve years of Global Change research. One chapter of this report deals specifically with tropospheric ozone issues.

The objective of these various initiatives is to provide scientific bases supporting Belgium's capacity to contribute to the development and assessment of measures, and particularly ozone-related measures, at the national, European, and international levels.

This document presents an overview of the (expected) results of the research projects funded by the Belgian Science Policy as well as a list of relevant publications, websites, workshops, etc.

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1. Introduction

1.1. Context

The concentration of ozone in the troposphere (lowest layer of the atmosphere from 0 to 15 km) is said to have at least doubled in the northern hemisphere in the last 100 years. The increase in ozone concentration is connected to anthropogenic emissions of volatile organic compounds (VOC), carbon monoxide (CO) and nitrogen oxides (NO_x). Aerosols also partially have the same precursors and are therefore linked to tropospheric ozone. In the summertime, the intense sunrays activate photochemical reactions that cause ozone to be produced. That is why there are ozone episodes/ozone peaks.

Thanks to the Geneva Protocol (1991) for the reduction of VOCs the amount of ozone episodes with peak values above the alarm threshold has decreased in the EU. However, background concentration keeps growing, alarmingly, and not only in Belgium but also in large parts of the planet in such a way that one can certainly speak of a 'global' problem. Moreover, an enormous increase in emissions in developing countries is expected in the 21st century and therefore one needs to place this problem in an international context.

Ozone is a highly oxidative gas. It affects especially the lung function and is therefore harmful for people with lung, heart and vascular problems. It causes damage to forests and other ecosystems and decreases the yields of agricultural crops. Moreover, the irritation of the mucous membrane caused by ozone is suspected of causing increased sensitivity with respect to some allergens such as pollen. It erodes materials such as paints and all types of plastic. In conjunction with aerosols, ozone is seriously suspected of increasing mortality from respiratory illnesses.

A policy aiming to prevent an increase in background concentration and ozone peaks is not easy: ozone is not a primary pollutant but is formed in situ from a complex mix of CO, VOC en NO_x precursors and under the influence of sun rays. Moreover, these precursors are transported across borders, as such an international approach is an absolute requirement.

Because of interlinkages, policy in the area of tropospheric ozone is:

- carried out at different levels:
    - International and European: UNECE (CLRTAP-Gothenburg Protocol); EU (CAFE, NEC Directive), ...;
    - Federal: the "Federal Plan against acidification and tropospheric ozone";
    - Regional: Walloon Region - "le Plan wallon de l'Air"; Brussels-Capital Region - "Plan voor structurele verbetering van de luchtkwaliteit en de strijd tegen de opwarming van het klimaat (2002-2010)" / "Plan pour l'amélioration structurelle de la qualité de l'air et la lutte contre le réchauffement climatique (2002-2010)"; Flemish Region - "Milieubeleidsplan 2003-2007 - Verontreiniging door fotochemische stoffen";

- carried out in the framework of a multi-effect approach, integrating acidification, eutrophication and tropospheric ozone;
- linked with climate policy as well, since ozone is also a greenhouse gas.

Because of (1) the non-linear influence of NO_x and VOC emissions on ozone production and destruction, (2) the impact of transport and dispersion processes on the atmospheric distribution and (3) the differences in lifetime of the chemical components, a scientific support to the development and implementation of reduction strategies is crucial.

A scientific basis is an absolute requirement to set the threshold values as correctly as possible, to quantify the emission reduction targets so that the threshold values are not exceeded, and to identify the most effective and cost-efficient package of measures. This scientific basis includes:

- Observations for trend analyses, insight into transport and dispersion, validation of predictive models, identifying emerging problems;
- Understanding the underlying chemical processes of ozone precursors;
- Scientific instruments to predict ozone concentrations and to evaluate the effectiveness of measures on concentrations (local, regional, global; share of different sectors); instruments to assess the socio-economic costs of tropospheric pollution as well as the socio-economic aspects of measures (costs, benefits, cost-efficiency, distribution, competitiveness, social acceptance, etc.) ...

In the last decade, the Belgian Science Policy has contributed to improve knowledge on this matter and the development of policy-supporting instruments by means of different research activities. Scientists linked to these research activities actively participated in workshops and/or negotiations in the framework of policy formulation at international and European level and within Belgium. A number of Belgian research findings were integrated in international assessment exercises and thus support international policy formulation/preparation, which in turn support national policy development. Embedding Belgian research findings in an international context offers information that is more relevant to policy than fragmentary results of individual projects.

In order to have the results of the research projects transferred in an efficient way to the users/decision-makers, a users committee is established for each project of SPSD II. The users committee is one of the mechanisms to improve the relationship between the researchers and the decision-makers. Each users committee is composed of, among others, federal and/or regional administrations potentially interested in the results of the project concerned. For instance, the users committee for the BELEUROS model included the members of the working group ATMOS of the Coordinating Committee for International Environmental Policy (CCIEP).

1.2. Research activities funded by the Belgian Science Policy

1.2.1. Research programmes

The Belgian Science Policy has been financing research projects in support of policy on tropospheric ozone (and acidification) since 1988, in the framework of the following research programmes:

- The "Global Change Impulse Programme" (1990-1996);
- The "Transport and Mobility Impulse Programme" (1991-1995);
- The first "Scientific support Plan for a Sustainable Development policy" (SPSD I) (1996-2001):
  - Global Change and Sustainable Development
  - Sustainable Mobility
  - Sustainable Management of the North Sea
  - Norms for Food Products
  - Levers for a Sustainable Development Policy
  - Supporting Actions of the Scientific Support Plan for a Sustainable Development Policy
  - Telsat 4
- The second "Scientific support Plan for a Sustainable Development policy" (SPSD II) (2000-2005):
  - Global Change, Ecosystems and Biodiversity
  - Sustainable Production and Consumption Patterns
  - Supporting Actions of the Scientific Support Plan for a Sustainable Development Policy
  - Mixed Actions
- "Impulse for research in the Belgian federal scientific institutes" (MO)

A detailed description of these research programmes can be found on:

- http://www.belspo.be/fedra

1.2.2. Federal scientific institutes

Both the Royal Meteorological Institute (IRM / KMI) and the Belgian Institute for Space Aeronomy (BIRA / IASB) possess expertise in the area of tropospheric ozone: in situ and satellite observations, analyses of the observations, research into the processes and modelling. Both institutes are taking part in the SPSD projects, space research and applications and international programmes such as the R&D programmes of the EC, EUROTRAC and ESA (DUP, PRODEX, etc).

Their work is presented on, respectively:

- http://www.meteo.be/ozon/
- http://www.oma.be/BIRA-IASB/Public/Research/Tropo/Tropo.en.html

1.3. International scientific cooperation

Participation in EUROTRAC (1988-1996) and EUROTRAC-2 (1996-2003)

Given that the ozone problem has to be tackled internationally, cross-border cooperation is an absolute necessity. The Belgian Science Policy has been participating in the EUREKA/EUROTRAC (Transport and chemical transformation of trace constituents in the troposphere over Europe) project since 1988, via the relevant programmes of the Belgian Science Policy but also via a financial contribution to the European project. Some EUROTRAC projects are specifically geared to the issue of tropospheric ozone. The aspects of this study that are relevant to policy have been bundled in: 'Photo-oxidants, Acidification and Tools: Policy Applications of EUROTRAC Results'. The recent publication of: 'Towards a cleaner air for Europe. Science, tools and applications' summarises the findings of EUROTRAC-2 for the benefit of policy actors. Chapter 3 on: 'Tropospheric Ozone and its control' is particularly relevant for the "Federal Plan against acidification and troposheric ozone".

Participation in the R&D programmes of the European Commission (DG RESEARCH)

Several relevant projects funded within the Framework Programmes for R&D involve Belgian research teams. These projects are meant for the scientific support of EU policy and its Member States.

Project descriptions and research findings can be found on:

- http://www.cordis.lu/Belgium

Participation in international space research and activities

The 'Space Research and Applications' department of the Belgian Science Policy supports the development of measuring instruments and algorithms and the missions (ENVISAT (SCIAMACHY, GOMOS, etc.)) as well as the analysis of measurements (DUP, PRODEX) in the framework of ESA and/or bilateral agreements. Belgium participates actively in the framework of GMES (Global Monitoring for Environment and Security) and GEO (Group on Earth Observations).

2. Projects funded by the Belgian Science Policy

This chapter presents a summary of the (expected) results of the research projects funded by the Belgian Science Policy. These projects are grouped according to the following topics:

A. Development of measuring techniques, instruments and algorithms; analysis and geophysical interpretation of the data

- Continuation of the experimental study on atmospheric changes;
- Development of instruments, spectroscopic methods and algorithms;
- Analysis of the evolution of background concentration of tropospheric ozone and the trends of ozone peaks.

B. Photochemical processes: understanding of ozone chemistry

- A better understanding of the processes that affect the balance of the active chemical elements in the troposphere;
- A better understanding of the role of biogenic and anthropogenic volatile organic compounds (VOC) and nitrogen compounds in the troposphere.

C. Simulations and expectations: development of numerical and statistical models

- Three-dimensional numerical models for the prediction of the composition of the atmosphere and the influence of anthropogenic activities (IMAGES, MOZART, GLOREAM);
- Three-dimensional numerical models for the assessment of specific measures in the framework of the control of acidification and tropospheric ozone;
- A policy-supporting model for the long-term prediction of ozone concentrations in the troposphere and for the assessment of emission reduction measures (per sector, per time unit, per pollutant, per area, a combination) in relation to their effectiveness in reducing ozone concentrations. This model was installed by CELINE / IRCEL at http://www.beleuros.be);
- Emission models for non-methane volatile organic compounds (NMVOC);
- An improved interpolation method for the automatic measuring system to support the SMOGSTOP model;
- Quantifying the emissions of ozone precursors via inverse modelling on the basis of satellite observations.

D. Scientific instruments and models in support of decision-making and assessment of policy measures

- Cross-sector technical/economic models;
- A theoretical framework for the allocation of emission reduction costs from simple technologies to several different pollutants. The design of a practical module for the calculation of marginal reduction costs;

– The identification of the pollutants and processes of which the emissions can be reduced simultaneously by applying specific environmental technologies, process modifications and fuel substitution.

Some studies are specifically related to the **transport sector** and its externalities:

– The assessment of the external costs of the transport sector;
– The development of transport emission models;
– The analysis of transport related measures to reduce tropospheric ozone;
– The comparative analysis of the environmental impact of vehicle technologies and transport modes; the user acceptance of more environmentally-friendly vehicles and modes;
– The development of a new diagnostic concept for lung disorders related to road traffic pollution.

Other research projects do not deal with the ozone issue directly but could be relevant in the framework of ozone reduction strategies. These projects (not presented here) are related to, among others:

– The development of renewable forms of energy and a more rational use of energy;
– The determinants of the demand for transport and the choice of transport mode;
– The product policy (e.g. lifecycle analysis).

How to read this document: The research results of topics A, B and C are presented in an integrated manner, but the nature of the projects presented in part D makes this approach more difficult. Therefore the corresponding results are presented 'project by project'.

A. Development of measuring techniques, instruments and algorithms; analysis and geophysical interpretation of the data

A.1. Introduction

The availability of high-quality data is essential to investigate the mechanisms of ozone formation, destruction, and transport in the troposphere. Such data are particularly useful for:

- determining the temporal evolution of ozone and its precursors and identifying trends in ozone peaks and precursor emissions in Belgium, in Europe, and on a global scale;
- improving our understanding of chemical and physical processes;
- studying the factors that determine the rate of ozone formation (sunlight intensity, temperature, availability of VOCs and NO_x);
- studying influx from the stratosphere, vertical exchange, intercontinental transport, the background ozone concentration, and the influence of VOCs and NO_x on this concentration;
- validating models with a view to predicting future developments;
- estimating effects on plants, animals, and humans;
- supporting the development of cost-effective measures;
- assessing the success of policy measures.

It is important not only to make observations on ozone and ozone precursors, but also to gain information on meteorological circumstances and circulation patterns in the atmosphere.

BIRA / IASB, ULG-GIRPAS, and ULB-SPECAT have been active for years in the development of high-performance instruments, measuring techniques, and algorithms for data analysis.

A.2. Synthesis of the research results

Developing of measuring techniques and instruments

In the framework of EUROTRAC (JETDLAG), a tunable diode laser was developed for measurement of atmospheric trace gases. This is an instrument for detecting atmospheric constituents, based on infrared detection.
BIRA / IASB develops sophisticated spectrometric instruments for automated (MAX)DOAS (Multi-AXIS Differential Optical Absorption Spectroscopy). It is likewise developing a system that will make FTIR (Fourier transform infrared) observations both autonomous and automated. In the future, the system will make it possible to conduct, in a less time- and cost-intensive manner, longer measuring campaigns at remote sites.

Developing spectroscopic methods

New measuring techniques require support from laboratory experiments and basic research. Measurements of concentrations of atmospheric constituents are based on measuring how solar, lunar, or stellar radiation is absorbed as it goes through the atmosphere. With knowledge of the absorption characteristics of the molecules present in the atmosphere, it is possible to derive from the observed absorption spectra concentrations of absorbing molecules. This technique thus requires good knowledge of spectroscopic absorption parameters. Such knowledge is acquired through lab work and is stored in spectroscopic databases. ULB-SPECAT and BIRA / IASB have contributed to the production of spectroscopic parameters for diverse molecules, notably NO_2.

Developing algorithms

In order to derive information on the composition of the atmosphere from spectral data, it is necessary to develop so-called inverse algorithms.

Depending on the observation geometry, it is possible to determine only the total amount of an absorbing molecule in the atmosphere or to derive a certain quantity of information about its vertical distribution in the atmosphere. Ground-based observations initially contain information about total column abundance. So-called 'vertical inversion algorithms' are developed to obtain height information from ground-based observations. Such an algorithm has been developed for Fourier transform infrared measurements (FTIR), such as those carried out at the Jungfraujoch since 1985. The inversion relies on the observation that the shape of absorption lines changes with height, as a result of their pressure and temperature dependence. Algorithms that allow this inversion are SFSP2, developed at BIRA / IASB, and SFIT2, widely used in the international community and recently characterised at BIRA / IASB for, among others, ozone and CO. In the near future it will be possible to re-analyse existing time series in order to study the behaviour, over the last decades, of different compounds at different heights, particularly in the troposphere.
In a very similar manner it is possible to obtain information about the vertical stratospheric distribution of atmospheric constituents such as NO_2 from UV-Vis DOAS measurements. In this case the inverse algorithm relies on the fact that the average height for light scattering depends on the height of the sun. BIRA / IASB has developed and validated such an inverse algorithm and has applied it to the measurement of stratospheric NO_2 in Harestua.

With the UV-visible light method it is also possible to obtain additional information on the troposphere and the boundary layer by measuring scattered sunlight simultaneously from different viewing angles with respect to the zenith, e.g. looking towards the zenith and almost horizontally. This is called Multi-AXIS DOAS (Differential Optical Absorption Spectroscopy) or the MAXDOAS method. New instruments have been built and made operational, and the first results on formaldehyde in the troposphere have been obtained at the Observatoire de Haute Provence.

An alternative method for characterising the boundary layer/lower troposphere relies on height-differentiated measurements. This method is based on measuring the total column of an atmospheric constituent simultaneously from two different heights. The difference between the two measurements yields the abundance of the constituent in the layer

between the two observation stations. Such a method was successfully applied during measuring campaigns in 1998 in the Jungfraujoch area and in 2002 on Reunion Island.

A new correction procedure for ozone-probe measurements has been developed. It corrects for various factors, and it implements a new correction profile for pump efficiency. The entire time series of ozone soundings in Uccle has been homogenised by means of this method.

The SMOGSTOP statistical model has been improved through development and integration of a computer module that computes the concentration of air pollution at all spatial points outside the reference points of the measurement grid, solely on the basis of values measured with meters or computed by a model at these reference points. With this so-called interpolation procedure it is possible to reproduce as correctly as possible a continuous reality.

Time series including trends in the concentrations of relevant chemical constituents

- In situ observations
  - These in situ observations of automatic measurement networks in Belgium fall under regional competence and are coordinated by CELINE / IRCEL.
  - Observations at stations of the NDSC (Network for the Detection of Stratospheric Changes)

    Research projects aim to carry out long-term observations of atmospheric gasses (notably O_3 and NO_2) by remote sensing at various European stations - Uccle, Jungfraujoch (Swiss Alps), Harestua (N), and the Observatoire de Haute Provence (F) - with the following instruments: Fourier transform spectrometers, Multi-AXisDOAS (MAXDOAS) instruments, UV-visible light radiometers (among which Dobson and Brewer instruments), and ozone probes. Existing time series of atmospheric data are completed in a consistent manner, and where necessary, the series are revised and homogenised. In the future, comparable measurements will be carried out on Reunion Island, in the subtropics; a first campaign took place in September-October 2002. Observations concern both the stratosphere and the troposphere. Relevant molecules are O_3, NO_x, formaldehyde, and C_2H_6.

    The time series for the Jungfraujoch go back to 1985, some to the mid-seventies, and a few even to 1950. They have proved extremely important for determining the variability of and changes in a large number of atmospheric constituents. The database that now extends over almost two decades has so far been used mainly to investigate long-term trends in total abundances of several atmospheric constituents such as O_3 and NO_2. Recently, attention has focused on how constituent concentrations are evolving in the troposphere, on the basis of the above-mentioned vertical inversion algorithms. This is happening on a European scale, within European collaborations (the EU project UFTIR led by BIRA / IASB). From the time series obtained with the (MAX)DOAS instruments – the longest ones go back to 1994 in Harestua – it is

possible to deduce total abundances of O_3, NO_2, OClO, and BrO in the atmosphere. The (MAX)DOAS technique is being adapted for determining the tropospheric contributions of O_3, NO_2, BrO, and H_2CO. New inversion methods make it possible to determine the vertical distribution of stratospheric NO_2 (and O_3).

Should the need arise, the above-mentioned instrumentation and related methods might possibly be implemented in Belgium.

Evolution of the ozone layer in Uccle: a time series of vertical ozone profiles (height range: 0 to 35 km), obtained by means of balloon soundings in Uccle, is available from 1969 to the present. This series is being re-evaluated so as to correct for instrument-linked effects and for changes made in the course of time. The analysis of this time series includes a climatological description of the vertical distribution of ozone over Belgium and a trend analysis of ozone concentration as a function of height. It shows the links that exist between the observed phenomena, local meteorological phenomena, and both seasonal and century-scale climate cycles in the troposphere.

- Satellite observations

  GOME and MOPITT are satellite-based instruments for studying the composition of the global troposphere. BIRA / IASB, ULG-GIRPAS, and the IRM / KMI have made a major contribution to validating satellite datasets (O_3, NO_2 and BrO) obtained with GOME on board ERS-2. This study is being pursued and extended (e.g. through validation of CO, N_2O, SO_2, and CH_4) to the instruments on board ENVISAT (GOMOS, MIPAS, SCIAMACHY), notably in the framework of the DUP project TEMIS.

  BIRA / IASB and ULG-GIRPAS have contributed to validating tropospheric CO measurements with MOPITT on board the Terra satellite; other comparisons of in-situ and FTIR observations of CO at the Jungfraujoch have been carried out, and the two datasets show good agreement.

Exploiting experimental data

Both raw observational data and geophysical results are collected in data archives and international databases (NILU's Atmospheric Database for Interactive Retrieval (NADIR), the NDSC database, the World Ozone and Ultraviolet Data Centre (WOUDC), the EUROTRAC TOR database) and thus made accessible to scientists and policy actors. The data are used to validate satellite observations, and as an input for modelling and assessment. They, moreover, support policy-making directly.

Analysis of the combined measurements obtained through ground-based observations, observation campaigns using planes and balloons, and worldwide satellite observations is bound to yield precious information on the local, regional, and global distribution, variability, and trends of ozone and ozone precursors. In North-western Europe, the background ozone concentration is increasing by 0.5 to 1% per year, whereas peak ozone concentrations are decreasing (by about 1.9 to 2.9 ppbv per year).

Since 1990, Belgium has been contributing to the worldwide effort to observe the state and evolution of the atmosphere in order to gain insight into the underlying processes and thus to support policy-making in the framework of the International Global Observing Strategy (IGOS) and through participation in diverse networks such as the Global Atmospheric Watch (GAW), the Network for the Detection of Stratospheric Changes (NDSC), EUROTRAC, and the International Global Atmospheric Chemistry (IGAC) project of the International Geosphere and Biosphere Programme (IGBP). Belgian researchers are likewise contributing to international assessments such as the IPCC assessments concerning tropospheric changes and climate.

Observations coupled with the development of numerical models of the atmosphere offer new insights into the chemical composition of the atmosphere, the underlying processes, and its future evolution.

A.3. Expected results and/or products of the ongoing projects

- A time series, extended by 4 years, of tropospheric chemical constituents at 4 NDSC stations;
- A revision of the evolution of atmospheric composition in the troposphere over the Jungfraujoch since 1985;
- Initiation of collaboration with Swiss research teams, the aims being to couple observations with regional models and to determine the influence of phenomena occurring in the boundary layer;
- New insights into the chemical composition of the atmosphere provided by data and their coupling with modelling studies;
- Improvement and development of observation techniques and data analysis methods.

A.4. List of projects

Projects funded by the Belgian Science Policy

- EUROTRAC - TOR (Tropospheric Ozone Research) - Determination of the total column density and vertical distribution of the atmospheric components, Delbouille L. (ULG), De Muer D. (IRM / KMI) (1988-1995)
- EUROTRAC - JETDLAG (Joint European Development of Tunable Diode Laser Absorption Spectroscopy for Measurement of Atmospheric Trace Gases): Gas spectroscopy with high solubility and dynamic aspects, Herman M. (ULB), (1988-1995)
- EUROTRAC - TOPAS (Tropospheric OPtical Absorption Spectroscopy), Colin R. (ULB), Simon P.C. (BIRA / IASB), Dufour P. (UMH) (1990-1994)
- Global change – SMAC (Spectroscopic Measurements of Atmospheric Changes), Simon P.C. (BIRA / IASB), Colin R. (ULB), Delbouille L. (ULG) (1990-1996)

- Global Change and Sustainable Development (SPSD I) - Experimental studies of atmospheric changes (ESAC), Simon P.C. and De Mazière M. (BIRA / IASB), De Muer D. (IRM / KMI), Colin R. (ULB), Zander R. (ULG) (1996-2000)
- Supporting Actions (SPSD I) - Development of a specific interpolation method for air pollutants measured in automatic networks (SMOGSTOP), Passelecq C., Hanton J. (FPMS) (1998-1999)
- Global Change, Ecosystems and Biodiversity (SPSD II) - Experimental studies of atmospheric changes II (ESAC II), De Mazière M. (BIRA / IASB), De Backer H. (IRM / KMI), Colin R. (ULB), Mahieu E.(ULG) (2001-2005)
- DUP - TEMIS (Tropospheric Monitoring Internet Service), Fonteyn D. (BIRA / IASB) (2001-2003)
- PRODEX - IASI retrieval of minor atmospheric compounds (including O_3, CO, e.a) from spectra taken by the IASI instrument on board of the METOP satellite series and use of these data along with chemistry transport models to study dynamical/chemical processes in the troposphere, De Mazière M. (BIRA / IASB), Gérard J-C., Zander R. (ULG-GIRPAS), Carleer M. (ULB) (1995-2005)
- PRODEX - Atmospheric chemistry of the Lower Atmosphere: validation of ENVISAT level-2 products related to lower atmosphere O_3 and NO_y chemistry by an FTIR Quasi-global network, Gérard J-C., Zander R. (ULG-GIRPAS) (2000-2004)
- PRODEX - Chemistry of the nitrogen and bromine families in the Earth atmosphere, De Mazière M. (BIRA / IASB) (2000-2004)
- PRODEX - Tropospheric UV, Ozone and precursors from ENVISAT: study the distribution and budget of Ozone and its main precursors in the troposphere, based on ENVISAT multi-year data and ground-based measurements, in order to constrain a global 3-dim. Chemistry transport model of the troposphere, Müller J-F. (BIRA / IASB) (2000-2004)
- MO - Study of troposheric ozone at Uccle, in relation with meteorological parameters, De Backer H. (IRM / KMI) (2001-2003)
- MO - New strategies for the development of a national high resolution forecasting model for Belgium, Quinet A. (IRM / KMI) (2000-2001)
- MO - Development of fast numerical integration algorithms for transport models used in chemical assimilation of the atmosphere, Fussen D. (BIRA / IASB) (2000-2003)
- MO - Global distribution and variability of tropospheric and stratospheric nitrogen dioxide: Enhancement and synergistic use of the multi-platform observing system, Van Roozendael M. (BIRA / IASB) (2001-2002)
- MO - Study of vertically resolved ground-based FTIR measurements at the Jungfraujoch for investigating dynamical and chemical processes at northern-mid-latitude, De Mazière M. (BIRA / IASB) (2001-2002)
- International cooperation - EO – Access to international infrastructures – Atmospheric spectrometry at Jungfraujoch and support to the Montréal and Kyoto Protocol, Gérard J-C. (ULG – GIRPAS) (2003- 2004, 2004-2006)

Participation of Belgian research teams in EUROTRAC-2

- EUROTRAC-2 – TROPOSAT: TROPOSAT: Use & usability of satellite data for tropospheric research (BIRA / IASB, ULg), 2000-2003
- EUROTRAC-2 – TOR-2 - Tropospheric ozone research, phase 2 (IRM / KMI)

Participation of Belgian research teams in the R&D programmes of the E.C.:

- Framework programme 4

- Regional differences In Tropospheric Ozone in Europe - an analysis of its controlling phenomena (IRM / KMI, Vito)

- Framework programme 5

- ASSimilation of Envisat daTa (ASSET) (BIRA / IASB)
- Global Monitoring for Environment and Security - Global ATmospheric Observations (GMES-GATO) (BIRA / IASB)
- Precursors of ozone and their effects in the troposphere (POET) (BIRA / IASB)
- Envisat for Environmental Regulation of Greenhouse Gases (Evergreen) (BIRA / IASB)
- Time series of Upper Free Troposphere observations from a European ground-based FTIR network (UFTIR) (BIRA / IASB, ULg)
- Global satellite observation of Greenhouse gas emissions (Evergreen) (BIRA / IASB, ULg)

- Framework programme 6

- Atmospheric composition change: an European Network (ACCENT) (BIRA / IASB)
- Stratosphere-Climate links with emphasis on the UTLS (SCOUT-O3) (BIRA / IASB)

B. Photochemical processes: understanding of ozone chemistry

B.1. Introduction

Ozone production is the result of hundreds of chemical reactions that should in principle be examined individually in laboratory experiments. On the basis of laboratory simulations and theoretical calculations it is possible to reduce drastically the number of reactions to be studied. The spatial and temporal distribution of ozone in the troposphere is determined by four important processes:

- photochemical production (oxidation of CO, VOCs, NO_x)
- photochemical destruction
- transport via atmospheric convection
- deposition at the earth's surface

The reaction mechanism that governs photochemical destruction and production of ozone remains quite complex. This complex, non-linear chemistry has major consequences for ozone management. The reduction of NO_x and VOC emissions on which future reductions in ozone concentration will depend requires good knowledge of the main emission sources: methane (CH_4), carbon monoxide (CO), and volatile organic compounds (VOCs) including biogenic and anthropogenic non-methane hydrocarbons. Biogenic emissions of isoprenes and terpenes released by vegetation are, on a global scale, ten times greater than emissions from anthropogenic VOC sources.

B.2. Synthesis of the research results

The Belgian Science Policy has funded a number of projects that unravel the degradation mechanisms of those terpenes, which appear most important in the light of their contribution to the worrisome rise of the background ozone concentration, and because of their role in aerosol formation.

On the laboratory scale it has been possible to identify carbon monoxide (CO), acetone (CH_3-CO-CH_3), and formaldehyde (CH_2O) and to determine the yields of reactions that produce them: oxidation of alpha- and beta-pinene, limonene, and carene (the main category of biogenic hydrocarbons). These compounds play a crucial role in the various mechanisms that explain the rising background concentrations of tropospheric ozone.

In addition, researchers have identified a number of previously unknown reaction products and proposed a reaction mechanism for their formation. This mainly refers to aldehydes and ketones responsible for aerosol formation. On the basis of these laboratory measurements, it was decided that the current chemical module 'Master Chemical Mechanism' (MCM) - used in the EMEP model on a European scale - is inadequate for explaining the observed product yields of these terpene oxidations. This model will thus have to be adapted.

Researchers are extending the collection, via laboratory techniques, of kinetic coefficients for alkyl radicals formed through reactions of OH with hydrocarbons, a first step in the mechanism of VOC oxidation. KULeuven-PAC has developed new general structure-activity relationships for crucial partial processes in the mechanisms of hydrocarbon oxidation. In collaboration with BIRA / IASB, KULeuven-PAC has introduced the new monoterpene oxidation mechanisms (partially derived on an excellent theoretical basis) into a numerical model. This is a first step towards implementation of this type of model in global model-based assessments of the impact of non-methane hydrocarbons on the tropospheric ozone balance, free radicals, and aerosol formation.

With the BOX model, a chemical model of interactions between O_3 and NO_x, it has been shown that, given the current level of NO_x emissions, their reduction, without simultaneous reduction of VOCs, causes a rise in the ozone concentration. This conclusion remains valid at least as long as NO_x reductions have not reached at least 50%. This result is illustrated clearly by the fact that ozone concentrations above cities, and largely also over the countryside in Belgium are higher over the weekend than during the week, despite a lower traffic density and thus lower NO_x emissions. This means that priority must be given to reducing VOCs in order to then reduce NO_x emissions.

B.3. Expected results and/or products of the ongoing projects

From the ongoing projects the following results are expected:

- new laboratory and theoretical techniques for studying the oxidation of biogenic hydrocarbons (monoterpenes);
- new mechanisms explaining the oxidation of various important biogenic hydrocarbons (monoterpenes), both in the laboratory and under atmospheric conditions;
- better understanding of the role of these hydrocarbons in global tropospheric chemistry, and particularly in the formation of aerosols.

B.4. List of projects

Projects funded by the Belgian Science Policy

- EUROTRAC - LACTOZ (Laboratory Studies of Chemistry Related to Tropospheric Ozone), (i) Kinetic Studies of Alkylperoxy and Haloalkylperoxy Radicals with NO; (ii) A Structure – Reactivity Relationship for Reactions of OH with Alkenes and Polyalkenes, Peeters J. (KULeuven-PAC) (1988-1995)
- EUROTRAC – HALIPP (Heterogeneous and Liquid Phase Processes), Heterogeneous Reactions of Air Pollutants on Various Solid Surfaces, Vinckier C. (KULeuven-PAC) (1988-1996)
- Global change - Role of alpha-pinene in the formation of greenhouse gases in the atmosphere, Vinckier C. (KULeuven-PAC) (1990-1995).

- Global Change and Sustainable Development (SPSD I) - Anthropogenic and biogenic influences on the oxidising capacity of the atmosphere, Müller J-F. (BIRA / IASB), Vinckier C. (KULeuven-PAC) (1996-2000)
- Global Change, Ecosystems and Biodiversity (SPSD II) - Anthropogenic and biogenic influences on the oxidising capacity of the atmosphere, Arijs E. and Müller J-F. (BIRA / IASB), Peeters J. and Vinckier C. (KULeuven-PAC) (2000-2005)

Participation of Belgian research teams in EUROTRAC-2

- EUROTRAC-2- Chemical Mechanism Development (CMD), Kinetic Study of the Degradation Mechanisms of Selected Terpenes with Hydroxyl Radicals, Vinckier C. (KULeuven-PAC)
- EUROTRAC-2- Chemical Mechanism Development (CMD), Experimental, Theoretical and Modelling Studies of the Oxidation of Volatile Organic Compounds, Peeters J. (KULeuven-PAC)

Participation of Belgian research teams in the R&D programmes of the E.C.:

- Framework programme 3

- Laboratory Studies on the Oxidation of Volatile Organic Compounds ('LABVOC') (Peeters J., KULeuven-PAC)

- Framework programme 4

- Structure-activity relationships for reactions in the degradation of biogenic volatile organic compounds ('SARBVOC') (Peeters J., KULeuven-PAC)

- Framework programme 5

- Upper Tropospheric Ozone: Processes Involving HO_x and NO_x ('UTOPIHAN') (Peeters J., KULeuven-PAC)

C. Simulations and expectations: development of numerical and statistical models

C.1. Introduction

The complexity of the processes involved in the production, destruction, and transport of tropospheric ozone makes the use of models indispensable. These models must make it possible to simulate the evolution of the concentration of ozone (and ozone precursors) over time at different locations and to assess the impact of emission reduction strategies on ozone concentrations.

C.2. Synthesis of the research results

SMOGSTOP

A first category of models are statistical models, based on the analysis of simulations of the past. An example is the 'Statistical Model Of Ground Short Term Ozone Pollution' (SMOGSTOP). SMOGSTOP was developed by the Vito and is operational at CELINE / IRCEL (Interregional Cell for the Environment). The project funded by the Belgian Science Policy has contributed to the improvement of the SMOGSTOP statistical model, through the development and integration of a computer module that calculates the concentration of air pollution at all spatial points outside the reference points of the measurement grid, on the sole basis of values measured by meters or calculated by a model at the reference points. With this so-called interpolation procedure (the values at all reference points are taken into account instead of being averaged by a smoothing technique) it is possible to reproduce as correctly as possible a continuous reality that is known only at certain points.

BELEUROS, IMAGES and MOZART

To establish a quantitative relationship between the respective increases in ozone precursor concentrations and tropospheric ozone concentrations, it is necessary to have recourse to deterministic numerical simulation models that take into account current knowledge of the physical, chemical, and dynamic mechanisms of the lower atmosphere. Such models can be used to simulate experimental measurements in the atmosphere or to predict the evolution of the composition of the troposphere under the influence of natural and anthropogenic disturbances.
In the framework of the relevant supported projects, the following models have been developed: BELEUROS (Vito-TAP), IMAGES, and MOZART (BIRA / IASB).

BELEUROS

In the framework of the BELEUROS project, a new version of EUROS (originally developed by RIVM-the Netherlands) was coupled with a 'state-of-the-art' user interface and installed

by CELINE / IRCEL as a policy-supporting instrument applicable to matters regarding tropospheric ozone.
This model is a numerical atmospheric model. It describes the various processes responsible for ozone formation and degradation (emissions of pollutants, atmospheric dispersion and transport, chemical transformations, and deposition) and simulates the long-term evolution of tropospheric ozone. It is an instrument that uses simulations to assess the impact of envisaged reductions of emissions on the ozone concentrations.
The new version contains a mixed-layer height that can be varied over a wide range and a multilayer description of horizontal transport. This provides a more realistic description of the atmospheric processes responsible for pollutant transport and dispersion. The model is now equipped with a three-dimensional grid structure that constitutes a first step towards a completely three-dimensional representation of transport and dispersion processes. The new version has been tested by comparing simulation results with measurements.

A user-friendly interface has been developed. This interface enables users to define the emissions scenario, to start the simulation from their own computer, and to display the results. The user has the option to alter the emission data for a given pollutant (NO_x or VOC), for a specific emission sector (traffic, building heating, refineries, solvents, combustion, industry) and for a specific geographic region. Monthly, daily, and hourly emission cycles can likewise be altered. The impact of the month of the year, the day of the week, and the time of day is taken into account through these cycles. As regards the output results, the user interface provides a simple display of the geographic distribution of pollutants over Europe. It is also possible to visualise long-term indicators such as AOTs (Accumulated Exposures over a Threshold). Above all, it is possible to display the time-dependent evolution of pollutant concentrations at a specific location.

The new version of the EUROS model, coupled with the user interface, has been installed by CELINE / IRCEL and can be used by policymakers and researchers to assess the impact of envisaged measures for reducing emissions. The output results of EUROS make it possible to calculate prevailing indicators so as to estimate the impact of ozone on public health and vegetation. Some of these indicators are also used in current European legislation pertaining to tropospheric ozone.

Within the framework of SPSD I a socio-economic module has been developed for the EUROS model. This model is described in § D.2.1.

IMAGES and MOZART

In collaboration with international research teams, the development and validation of two global (world-scale) chemistry and transport models have been completed (IMAGES and MOZART). Both models are precious instruments used by international teams to quantify processes that determine the composition of the troposphere, particularly as regards ozone and its precursors. The models compute the distribution of 60 chemical substances and take into account over 150 chemical reactions. They are used, for instance, to monitor the influence of diverse emission processes (biomass burning, lightening, aviation, etc.) on the distribution of trace chemicals. The ozone budget and the respective contributions of various chemical processes to ozone formation and 'ozone sinks' are quantified. The model can also simulate the rise in ozone concentrations over the next century. On the basis of a scenario that includes some reduction of precursors, the model predicts a rise in ozone

concentrations in Europe and North America, despite a major reduction of CO emissions. In other regions as well, particularly Southern Asia, the Middle East, and China, the model predicts high average monthly concentrations exceeding the European threshold values. New techniques have been introduced and applied in order to monitor how observations and trace gas measurements can be used to establish useful limiting conditions for ozone precursor emissions. In the future these developments will constitute the basis for exploiting satellite measurements of concentrations of tropospheric constituents. The models are also relevant to policy support in Belgium. They make it possible to evaluate the background ozone concentration and the room for manoeuvre of reduction policy.

IMAGES and MOZART have been used in particular for a quantitative assessment of the anthropogenic impact on the composition of the troposphere, for assessing the impact of subsonic airplane emissions on tropospheric ozone and the oxidising capacity (self cleaning) of the atmosphere. At our latitude over the summer, these emissions appear to cause a 6% rise in the ozone concentration. The impact of air traffic will increase, according to these models. These results have been included notably in the assessment reports of the Intergovernmental Panel on Climate Change (IPCC).

The future impact of industrialisation and of the rising world population and energy demand on the 'global' composition of the troposphere has been assessed on the basis of future scenarios for anthropogenic emissions of ozone precursors in the 21st century. The likely impact of climate changes on the chemistry of the troposphere is also estimated. The calculated rise in surface ozone concentrations appears very great in densely populated tropical regions.

These ozone levels will constitute a major threat to human health and agricultural activities and yields in these regions. It should be stressed, however, that predictions vary substantially according to the model used.

Recent satellite observations made with instruments such as UARS, ERS-2, and ENVISAT, in combination with models, make it possible to make a 'best estimate' of the composition of the atmosphere. So-called 'inverse modelling methods' are used to estimate emissions of tropospheric pollutants, including ozone precursors and greenhouse gasses. These estimates rely on optimal integration, within the IMAGES model, of ground-based observations, observation campaigns using airplanes or balloons, and worldwide satellite observations.

C.3. Expected results and/or products of the ongoing projects

- A better assessment of the role of hydrocarbons in the global troposphere, particularly as regards aerosol formation;
- A better understanding of the impact of anthropogenic pollutant emissions on the composition of the global troposphere;
- Quantification of anthropogenic and natural emissions of ozone precursors by inverse modelling.

C.4. List of projects

Projects funded by the Belgian Science Policy

- Supporting Actions (SPSD I) - Implementation and extension of the EUROS-model (EURopean Operational Smog) for policy support in Belgium, Mensink C. (Vito), Schayes G. (UCL-ASTR), Quinet A. (IRM / KMI), Passelecq C. (FPMS), Dumont G. and Demuth C. (CELINE / IRCEL) (1998-1999)
- Supporting Actions (SPSD I) - Development of a specific interpolation method for air pollutants measured in automatic networks (SMOGSTOP), Passelecq C., Hanton J. (FPMS) (1998-1999)
- Global Change and Sustainable Development (SPSD I) - Anthropogenic and biogenic influences on the oxidising capacity of the atmosphere, Müller J-F. (BIRA / IASB), Vinckier C. (KULeuven-PAC) (2000-2005)
- Global Change, Ecosystems and Biodiversity (SPSD II) - Anthropogenic and biogenic influences on the oxidising capacity of the atmosphere, Arijs E. en Müller J-F. (BIRA / IASB), Peeters J. and Vinckier C. (KULeuven-PAC) (2000-2005)
- MO - New strategies for the development of a national high resolution forecasting model for Belgium, Quinet A. (IRM / KMI) (2000-2001)
- PRODEX - Tropospheric UV, Ozone and precursors from ENVISAT: study the distribution and budget of Ozone and its main precursors in the troposphere, based on ENVISAT multi-year data and ground-based measurements, in order to constrain a global 3-dim. Chemistry transport model of the troposphere, Müller J-F. (BIRA / IASB) (2000-2004).

Participation of Belgian research teams in EUROTRAC-2

- EUROTRAC-2 - GLOREAM Global and regional atmospheric modelling (Vito-TAP)
- SATURN - Studying Atmospheric Pollution in Urban Areas (VUB, Vito-TAP)

D. Scientific instruments and models in support of decision-making and assessment of policy measures

D.1. Introduction

Whereas the projects described in parts A, B, and C focus on the development of new techniques for measuring atmospheric concentrations and on understanding and modelling chemical and climatic processes in the atmosphere, the projects presented below are based on a socio-economic approach. They thus deal with topics such as producer and consumer behaviours, the responsibility of different activity sectors, implemented technologies, (monetary) evaluations of negative externalities (deterioration of materials, diseases, decreased agricultural yields, etc.), the cost of implementing emission reduction policies, etc.

The projects fall into two groups:

- Development of technico-economic trans-sector models;
- Approaches specific to the transport sector.

The various projects retained come from the socio-economic part of the "Global Change and Sustainable Development" programme (SPSD I), the "Sustainable Mobility" programme (SPSD I), the SPSD I "Supporting Actions", and the "Sustainable Production and Consumption Patterns" programme (themes: Energy and Transport) of SPSD II.

The results related to topics A, B, and C are presented in an integrated manner, but the nature of the projects presented in part D makes this approach more difficult. Therefore the corresponding results are presented project by project.

THE LIST OF THE PROJECTS CONCERNED CAN BE FOUND ON PAGE 41, § D.3.

D.2. Synthesis of the research results

D.2.1. Technico-economical models for the assessment of policy measures

Such models contribute to assessing the impact of various policies on ozone precursor emissions. They take into account the various activity sectors and activity levels, the range of available technologies, and the corresponding emission levels (using a bottom-up approach). The damage caused by pollution (health effects, agricultural yields, deterioration of materials, etc.) is calculated and confronted with the cost of reducing emissions (activity level changes, fuel substitution, adoption of a higher-performance technology, ...). Different scenarios for distributing the effort to reduce emissions can thus be tested: costs for the individual polluter, at the level of a sector or region, ... These models have a horizon of one to several decades.

MARKAL, a model to support greenhouse gas reduction policies

MARKAL is not specifically aimed at the issue of ozone, because:
1) not all ozone precursors have been modelled up until now and
2) MARKAL is a long-term model that would only indicate long-term perspectives for the ozone precursors (and no short-term results).

The main objective of the MARKAL model is to assess alternative pathways for developing energy production and consumption, with a view to reaching objectives for reducing greenhouse gas emissions at minimal cost.

However, local environmental problems related to the deposition of acidifying emissions and ambient air quality linked to acidifying emissions and ozone concentration are taken into consideration. The model considers the energy-related emissions of NO_x, SO_2, VOC and particulates, which are the main source of air pollution.

The approach followed for the evaluation of the benefits from the reduction of local pollutants is based on the bottom up damage function approach as developed by the EU research project ExternE.

The MARKAL database has been extended into three directions:
- emissions coefficients for pollutants such as NO_x, SO_2, VOC and PM;
- transfer coefficients for those pollutants, i.e. coefficients for the translation of emissions into deposition and concentration, including the transportation mechanism;
- impact of deposition/concentration and their monetary valuation.

The last two parameters are derived from the ExternE study and are used to compute a damage value per unit of incremental emission in Belgium.

The MARKAL model was adapted to take into account (in the analysis of policy options) the benefits/costs coming from local pollutants, following two approaches:
- the environmental damage are computed ex-post, without feedback into the optimisation process;
- the environmental damages are part of the objective function and are therefore taken into account in the optimisation process.

MARKAL/TIMES, a model to support greenhouse gas reduction policies

MARKAL/TIMES is not specifically aimed at the issue of ozone. Nevertheless it could indicate long-term perspectives for some ozone precursors.

The objective of this project is to evaluate the support of the models MARKAL and TIMES and the role of the different sectors and technologies concerning greenhouse gas emissions. The method can also contribute to the evaluation of other policies: energy policy, rational use of energy, both on the demand and the supply side, or conventional air pollution policies within the energy system, ...

MARKAL/TIMES is a technico-economic model, which assembles in a simple but economic consistent way technological information (conversion-efficiency, investment and variable costs, emissions, etc.) for the entire energy system. It can represent all the energy demand and supply activities and technologies for a country over a horizon of 40/80 years, with their associated emissions (CO, CO_2, SO_2, NO_x, VOC and PM) and the damages generated by these emissions.

The further development of the model concerns two aspects: the integration of the international dimension regarding climate and energy policy in the Belgian model and the integration of a refinery module.

Economic Impact Modules for the EUROS-Model

EUROS is an atmospheric dispersion model developed by RIVM (Netherlands) and adapted for Belgium by Vito, calculating ozone concentrations as a function of NMVOC and NO_x emissions as well as meteorological and geographical data (this model has been tackled under part C.2). The aim of the project presented here is to build a module for evaluation of costs and benefits of emission reduction scenario's and hence of emission reduction policy measures.

An inventory of all available emission data was made up. Emission reduction technologies were inventoried as well.

The model allows to calculate - for a certain year in the future - the emissions in a business as usual scenario, the possible emission reduction for this year and the costs linked to this reduction. The model calculates also the mean and marginal costs for each combination. These data are used to calculate total costs and draw cost curves. 1997 served as the reference year. All the collected data are for this year. For the business as usual scenario 2010, the data from 1997 are projected with sector evolution factors, taking into account the current legislation and known end-of-life replacements till 2010.

Analysis of emission reduction options for greenhouse gases and tropospheric ozone precursors

This project was about both ozone precursors and greenhouse gas emissions. Its objective was twofold:

- to continue the development of the multi-pollutant model EPM (Emissions Projection Model) constructed by ECONOTEC in the framework of previous studies, in particular through an in-depth revision of the software organisation of the data;
- to apply the model for generating emission projection scenarios (reference scenarios and emission reduction scenarios).

The emphasis on ozone precursors took place in a first phase of the study, during the negotiation of the 'Gothenburg Protocol' (of the United Nations Convention on Long-range Transboundary Air Pollution), setting national emissions ceilings for SO_2, NO_x, VOCs, and NH_3 for 2010.

This work is described in a report presenting scenarios for NO_x and VOC emissions in Belgium in 2010, which has been used for preparing the negotiation of the protocol.

The second phase of the project has been devoted to greenhouse gases, mainly the development of a new Access version of the model for CO_2 emissions and the construction of related emission scenarios.

Multi Pollutant Emission Reduction Policies (MULTIPOL)

The MULTIPOL project aims at developing optimisation and simulation tools to support Belgian environmental authorities in developing policies and strategies to reduce air pollution from industrial sources. This project would like to demonstrate the benefits of a joint and collaborative approach in the field of air pollution reduction.

"Joint" refers to the different pollutants that have to be reduced. The project does not solely concentrate on one environmental problem or one particular type of related pollutants. In fact, Belgian environmental authorities have engaged in an international context to reduce GHG emissions (Kyoto protocol), but also emissions that contribute to acidification and ozone in the troposphere (European NEC (National Emission Ceilings) directive) and other pollutants will follow in the near future. The project aims at evaluating the mutual interference between different pollutants and to evaluate the benefits of a joint reduction approach.

"Collaborative" refers to the different political levels in this country. Here it could be demonstrated that the benefits of a collaborative approach are mutual. Flanders, Brussels and the Walloon region can only benefit from cooperation in this field.

In first instance, the model has been developed for Flanders. An historical emission database has been completed. It contains all relevant data from industrial emission sources (332 company sites, 1205 installations and many different pollutants). The database also contains technical and economical information on emission reduction options for the major part of industrial emissions sources.
An optimisation module serves to determine economically interesting combinations of emission reduction options as well as to derive emission reduction cost functions on sectoral or aggregated level.
The methodology includes different types of actions, based on reduction technologies or changes in energy consumption behaviour. This allows identifying the cheapest solution to reduce these emissions. The methodology also allows to estimate the benefits from a joint approach.

D.2.2. Synthesis of the projects dealing with the relationship between transport and tropospheric ozone

Several projects aim to assess the impact of one or more transport modes (at local, regional, national, ... level) by means of different model types. On the basis of field measurements and observations, it is possible to model traffic flows (composition, speed profile, timing, ...). Estimating the composition of the vehicle fleet and the emission rate of each different vehicle type, emissions/imissions due to traffic can be calculated. Some projects analyse the future introduction of new, more environmentally-friendly technologies, taking into account the consumer acceptance of these new vehicle technologies. Various measures are assessed and instruments (e.g. indicators) are developed for use by policymakers.
On the other hand, several methods can be used to estimate in monetary terms the external environmental costs (air pollution, noise, vibrations, ...).
Finally, the epidemiological analysis of the toxicity related to traffic pollution has resulted in the development of a new diagnostic concept for lung disorders.

An integrated instrument for the environmental evaluation of local traffic plans (MOBILEE)

The project MOBILEE develops and demonstrates an integrated methodology with which local administrations (town, commune and province) can assess the consequences of mobility plans for traffic amenity and environmental quality. Starting from the expected modelled traffic streams and thanks to an open toolbox, indicators on traffic amenity and environmental quality are devised. This analysis is made up of 4 sub-projects:

1. The study of emissions in the air and their impact, coordination and integration
2. The study of noise emissions and their impact
3. The modelling and analysis of traffic streams
4. The study of traffic amenity, crossing capacity and accidents

After the integration of the results for all indicators, the methodology allows for the comparison of several different mobility scenarios, to be tested for sustainability.

Specific research activities with regard to ozone

Sub-project 1 includes the analysis of the impact of air pollution. To do so a consistent set of indicators on air pollution is worked out.
A first section involves the working out of the emissions from road traffic. This is as detailed as possible, right up to street level. For this the calculations are made from the results from the simulated traffic streams. This way the effects of speed and the dynamics of traffic handling are computed as well. The module for the calculation of emissions takes account of the composition of the fleet of vehicles and is capable of assessing the effects of local measures, such as the incentive to use certain types of vehicles (e.g. buses on natural gas or with diesel filters).

The module for the calculation of emissions calculates emissions from the following precursors: NO_x, CO, Volatile Organic Compounds (VOCs), as well as other pollutants, such as particles, benzene-toluene-xylene, CO_2.

The second section focuses on the spread and transformation of the above-mentioned pollutants in the air. The model used calculates on the basis of background values and emissions per street segment, hourly concentration for a city as a whole, at district level and on individual streets.
With respect to ozone specifically, a module is used to gauge the local effects of local NO_x and VOC emissions on ozone at street level (among other things, for the simulation of the effect of NO-titration at street level), bearing in mind the appraised background values.

Transport sector measures for reducing CO_2 and tropospheric ozone

Twelve policy options, technological and non-technological, in the transport sector were investigated for their effectiveness to reduce CO_2 and tropospheric ozone, and for their techno-economic and social feasibility.
The evaluation of the policy options was performed by a multiple criteria analysis (MCA), in which several decision-makers were involved. Eight criteria were used for the evaluation of the policy options, of which two are indirectly related to tropospheric ozone: cumulative NO_x (nitrogen oxides) emission reduction and cumulative VOC (volatile organic compounds) emission reduction. By 'cumulative emission reduction' is meant the total emission reduction during the period 2001-2012, which is the time horizon of the study.
For the evaluation of the effect of policy options on ozone concentrations the Ozon94 model was extended and made operational for Belgium. This model can make assessments of the long-term effects of emission reductions on the ozone concentrations.
Furthermore, ozone working tables generally usable (also for the government) have been compiled for estimating the ozone effectiveness (AOT40, AOT60 en NET60) of measures and policy options.

Specific research activities with regard to ozone

For both ozone precursors, NO_x and VOC a strong decrease was found even under the Business-As-Usual (BAU) scenario. The emission trend set by the BAU scenario was only affected to a small extent by the policy scenarios.

To fulfil the Gothenburg Protocol for the transport sector, efforts will have to be mainly concentrated on NO_x-emissions. The NO_x levels for the different individual policy options are close to the emission ceiling. Taking into account the different uncertainties in the emission calculations and the fact that the ceiling will be amended in 2004, substantial efforts are required for reducing NO_x. This has been confirmed in recent European research, which indicates that NO_x emissions are an even bigger problem than initially reported. All of these new insights are currently under research within the SUSATRANS-project (SPSD II, project CP/43), which is the follow-up of this project.

At first view VOC emissions from transport do not seem to be a problem. However, the national VOC objective, taking into account all sectors, will be difficult to comply with, as well as the objectives for air quality in general. Additional measures within the transport sector would therefore be welcome.

Concerning the reduction of NO_x and VOC, the advanced introduction of environment-friendly vehicles and enhanced inspection and maintenance seem appropriate options. Also the advanced replacement of old vehicles could result in a significant decrease of VOC emissions, although the replacement of old cars was evaluated as a non economic and socially unfeasible option.

Sustainability assessment of technologies and modes for transport in Belgium (SUSATRANS)

The objective of this project is to carry out an integrated assessment of policy measures with a 2020 time horizon. The aim is a successful introduction of new technologies in the transport sector on the one hand and a shift between modes on the other, in order to promote sustainable mobility. Besides road traffic (including powered two-wheelers) also technological developments in railway traffic and inland navigation are studied extensively.

The specific goals are the following:

- Performing a technological, social, economical and environmental evaluation of technologies.
- Obtaining a better understanding of consumer behaviour with regard to new technologies.
- Updating and developing models to evaluate the impact of policy measures on mobility demand, emissions and external costs of transport.
- Delivering recommendations to national, regional and local policies related to mobility and environment.

Specific research activities with regard to ozone

The modelling of the precursor emissions NO_x and VOC followed the Copert/Meet approach. Recent European research has proven that real life NO_x emissions of new generations of diesel-fuelled passenger cars and heavy duty vehicles are higher than expected. Also the number of heavy trucks (32 to 40 tonne) has been underestimated by lack of good information in the official statistics. Vito managed to make an adjustment based on the results of its counting programme for trucks on all type of roads, making a distinction in the number of axles.
Meanwhile the related databases and models: TEMAT (Transport Emission Model to analyse (non-) technological measures), ExTC (model to calculate external costs from transport) have been updated by Vito.
The TREMOVE model which is used to assess activities for transport has also been updated, e.g. extension with small diesel cars and integration of a new vehicle choice model for passenger cars.

All these updated models will lead to the most up-to-date evaluation of transport policies in relation to emissions. Different possibilities to fulfil the NEC Ceilings are also studied.

As an intermediary conclusion, one can say that special attention has to be paid to the NO_x-emission reduction within the transport sector. Not only technological solutions, such as retrofit of diesel vehicles with a SCR (Catalytic Continuous Reduction) system are useful, but also the shift to other transport modes (rail and waterway).

The last two years a technological evolution within the non-road transport modes is starting to break through, which could affect the emissions from these modes in the medium long-term. Emission models are under development to quantify the effect of technological evolution within railway and waterway traffic.

External environmental costs of transport in Belgium

In this study, which was built on work co-financed by the JOULE III programme of the EC, the common European ExternE-methodology was applied to the Belgian context. The study aimed to generate accurate and specific external costs of transport for the first time. The study covers all major transportation modes, fuels and technologies for both passenger and goods transport. The main focus was on the analysis and comparison of the use phase for road transport, and on the life cycle analysis for other transportation modes. Therefore it was potentially useful for the drafting of policies at the national and regional levels.
The final report especially covers air pollution impacts on public health, crops, materials and global warming impacts. Ozone impacts were calculated for public health and agricultural crops.

Specific research activities with regard to ozone[1]

The EMEP Lagrangian model has been used to calculate the effect of reducing precursor emissions in each European country. A country-to-grid matrix was constructed and used to estimate the effect of changes in emissions at one location on the ozone statistics (AOT60 and AOT40) in all gridcells. Belgium was among the regions where additional emissions of NO_x led to a depression of ozone formation. This effect was thought to be stronger than the effects of the associated VOC emissions and the increase in ozone elsewhere in Europe. Meanwhile the modelling of ozone in the BELEUROS project has been significantly improved.

Based on epidemiological evidence ExternE selected key pollutants adversely related to health. Particles and ozone were considered to be the main drivers of the pollution mixture. A comprehensive set of E-R (exposure-response) functions for particles and for ozone was constructed. There is strong evidence linking (daily) ozone and (acute) mortality. The most delicate point of discussion has always been the presumed existence of a threshold for

[1] In hindsight it can be said that the emissions of modern trucks have been underestimated for two reasons: (1) the correction for loading was only fully implemented after the end of the project and (2) real life NO_x emissions of Euro2 & Euro3 trucks have recently proven to be much higher than expected.
Meanwhile the related databases and models (Mimosa, eXtc, Ecosense and TEMAT) have been updated.

acute effects. It now seems that the assumption of no threshold continues to be the approach best supported by current epidemiology.

A wide range of studies confirm that ozone can damage many plants at concentrations over 40 ppb. For several crop species, the E-R functions derived in the ExternE project have been used. Meanwhile these functions have been updated from recent literature within the European ExternE-POL project.

The methodology used to estimate ozone impacts on crops was state-of-the-art until 2003. In view of the changing methodology (flux based) it is necessary to develop a new approach when the ExternE-methodology is updated in the future.

In the comparison of different transportation modes most attention was given to externalities of PM and CO_2 and ozone impacts were only taken into account as a sensitivity measure. For passenger transport it was concluded that of all vehicles studied motorcycles and mopeds had the most detrimental effect on ozone formation due to high emissions of VOC. Precursor emissions of other road vehicles were reduced significantly during the previous decade. Similar European standards for motorcycles were drafted well after the end of this project. Some diesel trains were found to have high externalities whereas electric trains, advanced cars and coaches with a high occupancy scored best.
For freight transport even the most advanced diesel trucks were found to have higher external costs than any of the other modes. Diesel trains have higher use-phase externalities from air pollution, but lower Life Cycle costs. Inland ships have the lowest use-phase costs. Their Life Cycle costs are lower than for trucks, but higher than for trains. All things combined this leads to the conclusion that (large) inland ships and electric trains are the best option for freight transport especially when population densities are higher than in our reference case. Although no attempt has been made to estimate noise externalities, it needs to be stressed that these are not negligible for trucks and trains, but close to zero for ships. Taking this into consideration, inland ships seem a good alternative to road or rail transport from an environmental point of view.
These conclusions have meanwhile been confirmed in more detail and in a more reliable way in more recent Vito projects. Important, and related to the question of ozone, it was found that the fleet averaged NO_x-emissions of inland ships are still thought to be lower than for trucks, despite the rapid evolution of emission standards for trucks. In addition the first emission standards for ozone precursors from inland ships have recently come into effect and will become more stringent in the future.

Evaluation of the risks of toxicity from the road traffic pollution: a molecular epidemiology approach

There is ample epidemiological evidence that ambient air pollutants can produce a variety of short- and long-term adverse health effects, including decrement of lung function, exacerbation of asthma, increased risk of respiratory infection and, even in the most sensitive groups, premature mortality from cardio-pulmonary diseases. The research project was part of a broader research programme whose main objective was to improve the assessment of the short- and long-term health risks of air pollutants by developing new non-invasive tests of lung toxicity and to apply them in children and other vulnerable

populations exposed to ambient air pollutants. This research programme was largely developed from the observations made with a new protein - Clara cell protein - suggesting that serum contains lung-specific proteins that can be used to non-invasively assess integrity of the lung epithelium, which is the primary target of most air pollutants.

Specific research activities with regard to ozone

In the framework of this project, a new diagnostic concept for lung disorders that was called "pneumoproteimia", i.e. assay in serum of lung-specific proteins reflecting the cellular integrity or the permeability of the lung epithelial barrier was developed. The development of immunoassays for measuring surfactant-associated proteins A and B allowed extending this concept to proteins secreted by the alveoli and not only by the small conducting airways (Clara cell protein). In collaboration with the Unit of Chemical Biology of the University of Mons-Hainaut, by proteome analysis of broncholaveolar lavage fluid several lung-secretory proteins were identified, which potentially could serve as markers of lung toxicity or disease. During this project, the first studies were carried out on subjects acutely or chronically exposed to air pollutants, including ozone. A cross-sectional survey was conducted among Brussels policemen, comparing their lung function tests and serum pneumoprotein levels with that of foresters living in the Ardenne. This study confirmed the potential of biomarkers to assess the exposure to urban air pollutants and to detect their possible impact on the respiratory epithelium of populations particularly at risk. The most interesting observations were however made when applying pneumoproteins to subjects with short-term exposure to ozone in ambient air. In particular, a study on cyclists exposed to episodes of ozone peaks during summertime showed that ozone causes a dose-dependent disruption of the lung epithelium barrier from exposure levels close to current air standards. This unique sensitivity of serum Clara cell protein to ambient ozone was confirmed by a series of experimental studies in rats or mice using an original assay for rodent Clara cell protein developed by UCL.

These studies were then pursued with the support of the FP4 and FP5 Research programmes of the European Union (PNEUMO-NEPHROTOX and HELIOS projects coordinated by UCL) and of the Brussels-Capital Region. Among other achievements, these projects further validated the assay of serum Clara cell protein as the first non invasive test to detect ozone-induced lung epithelium damage (this test is now commercially available) while an immunoassay for a new lung-specific protein is currently under investigation in patients with various lung diseases. A series of experiments to study the earliest inflammatory changes produced by ozone in children was conducted in Belgium, Italy and Sweden and it could be estimated that these effects are likely to occur from threshold level of about 135μg/m^3 (one-hour maximal concentration). But by far the most important finding was made when applying the pneumoprotein concept to assess the chronic effects of air pollutants in children. These studies led to the discovery of a so far unsuspected air pollutant, closely related to our Western lifestyle, which is a major determinant of the lung epithelium integrity of children. This pollutant is trichloramine, an irritant gas building up in the air of indoor chlorinated pools. Although this gas can reach concentrations that are way above those of classic air pollutants (with mean levels of around 500 μg/m^3 in Belgian pools), its health impact has remained almost totally unevaluated over the past decades. These challenging observations, now confirmed by a recent study, have paved the way to the chlorine hypothesis, postulating that the increasing exposure to chlorination products in

indoor pools be at the origin of childhood asthma epidemic observed in industrialised countries.

Sustainable mobility in the Brussels region

In this project, the assessment of the external costs of road traffic was taken into account by looking in particular at the external environmental costs (atmospheric and noise pollution) and focussing on their assessment in urban areas, where the problems caused by road traffic are more acute, and where the effects on the environment are more pronounced.

The approach, based on the European ExternE project, was adapted to the situation in the Brussels-Capital Region through the development of a four stages analysis:

- the assessment of pollutant emissions caused by road traffic (with the 'AMORTEC' model);
- the determination of the resulting concentrations of pollutants in the atmosphere; an econometric model (Bruxelles - Air model) based on a non-linear multiple regression analysis has been used;
- the calculation of the physical damage;
- its expression in monetary terms (cost of illness, replacement cost, contingent valuation methods).

Local particularities such as the population characteristics, the stock-at-risk exposed to air pollution in the Brussels-Capital Region were also taken into consideration in this process.

Taking 1998 as a reference year and for main air pollutants (CO, PM, NO_x, SO_2, VOCs ...), this analysis enabled the estimated cost of damage to health and buildings to be placed within the interval [220 - 3,526 M€], with a median value of 882 M€ and a degree of probability of 67%.
From results of the FUND 2.0 model for greenhouse gases-linked externalities, the external costs associated with global warming caused by road traffic were evaluated at 1.7 M€ for 1998.
As far as the costs deriving from the noise caused by road traffic are concerned, the average external cost comes out at 34€ per person per year.

Damage associated with photochemical pollution

The METPHOMOD model has been used; it falls back on a determinist approach to model weather conditions and the chemical processes leading to the formation of ozone. The use of this eulerian model required the establishment of a register for Belgium covering hourly emissions for a series of 36 pollutants such as CH_4, CO, NO, NO_2 and SO_2 as well as 31 types of NMVOCs. In terms of damage from ozone, the approach was limited to short-term effects (episodes) for which exposure-response functions were available. The methodology enabled the damage associated with it to be calculated over a 120 sq. km. zone centred on Brussels. Taking an episode in 1998, the assessment produced external costs of 2.2 M€, 80% of which were associated with acute mortality.

Three scenarios involving the reduction of ozone-forming gas emissions (NO_x and VOCs) were also analysed: reducing the total NO_x emissions in the Brussels-Capital Region by 50%, the VOCs emissions alone by 50%, and NO_x and VOCs emissions together by 50%.

Electric and hybrid vehicles: a measure for the control of tropospheric ozone?

The main objective of the project was to clarify the definition of controlling strategies of photochemical pollution, by specifically analysing a technological-type measure, consisting of the introduction of electric or hybrid vehicles into the Brussels-Capital Region.
A more general objective of the undertaken study relates to the development of a tool in support of decision-making in term of control of photochemical pollution. Particular attention was thus paid to the methodological developments necessary to approach these problems seriously. For this purpose a cost-benefit analysis was carried out.

The overall methodology employed is based on an assessment of the damage costs. Also known as the 'impact pathway' approach, the European 'ExternE' methodology was used.
For the modelling of the 'emission-immissions' relationship during periods of photochemical pollution, the eulerian METPHOMOD model was used. This model requires the establishment of a register for Belgium covering hourly emissions for 36 pollutants such as CH_4, CO, NO, NO_2 and SO_2 as well as 31 types of NMVOCs. 237 chemical reactions are treated with the RACM module.
In terms of health damage, the approach is limited to short-term effects (episodes) for which exposure-response functions were available. They cover the harmful effects on public health, acute mortality and hospital admissions as the result of respiratory problems during periods of photochemical pollution. Damage to buildings and vegetation and the reduction of agricultural yield as well as for global change are accounted as ancillary effects.
As far as the cost assessment is concerned, functions were built from conventional European methodologies. Sensitivity analyses were performed in order to estimate the impact of relevant parameters (fuel and electricity prices, discount rates, etc.).

Environmental and economic effects in the Brussels-Capital Region

A first series of scenarios was built from an introduction of 10% of electric vehicles and hybrid vehicles respectively into the road traffic in the Brussels-Capital Region. The second type of scenarios considered that the 'share of market' of the electric vehicles is 50% in the centre town, 20% in an intermediate zone and 5% in the surrounding area.

With regard to the effects of this last type of scenarios specifically on the situation in the Brussels-Capital Region, simulations made it possible to show significant reductions in the maximum ozone concentration during the episode and in the maximum 8 hours average concentration. These evolutions lead to damage associated with photochemical pollution estimated at 0.33M€, which represents a decrease of almost 4% in the external costs in comparison with the reference case.

The economic analysis of scenarios showed that the purchase of electric vehicles is the highest financial burden, at least as far as scenarios such as a hiring network of electric vehicles or a goods distribution network are concerned.

To conclude, the reduction of the damage related to photochemical pollution, due to the introduction of electric vehicles in the Brussels-Capital Region, does not compensate for the costs of implementation of a 'voluntarist' policy. Meanwhile, the ancillary benefits, such as the effects on health at the local level, could justify such an investment.

D.3. List of projects

D.3.1. Technico-economical models for the assessment of policy measures

Global Change and Sustainable Development (SPSD I), MARKAL, a model in support of greenhouse gas reduction policy, Proost S. (KULeuven), Wouters G. (Vito) (1996-2001)

Sustainable Production and Consumption Patterns (SPSD II), MARKAL/TIMES, a model to support greenhouse gas reduction policies, Proost S. (KULeuven), Duerinck J. (Vito) (2001-2005)

Global Change and Sustainable Development (SPSD I), Economic impact modules for the EUROS-model, Wouters G. (Vito), Constant P. (ECONOTEC) (1998-2001)

Supporting Actions (SPSD I), Analysis of emission reduction options for greenhouse gases and tropospheric ozone precursors, Constant P. (ECONOTEC) (1998-2001)

Sustainable Production and Consumption Patterns (SPSD II), Multi Pollutant emission reduction policies (Multipol), Duerinck J. (Vito), Nemry F. (ICEDD), D'Hondt P. (VMM), Hannequart J-P. (IBGE-BIM) (2001-2005)

D.3.2. Projects dealing with the relationship between transport and tropospheric ozone

Sustainable Production and Consumption Patterns (SPSD II), An integrated instrument for the testing of local mobility plans for traffic amenity and environmental quality (MOBILEE), De Nocker L. (Vito), Asperges T. (Langzaam Verkeer), Botteldooren D. (UG), Immers B. (KULeuven) (2001-2005)

Sustainable Production and Consumption Patterns (SPSD II), Sustainability assessment of technologies and modes in the transport sector in Belgium (SUSATRANS), De Vlieger I. (Vito), Proost S. (KULeuven) (2001-2004)

Sustainable Mobility (SPSD I), Measures in transport to reduce CO_2 and tropospheric ozone, De Vlieger I. (Vito), et al. (1997-2000)

Sustainable Mobility (SPSD I), External costs of transport in Belgium, Proost S. (KULeuven), De Borger B. (UFSIA), Wouters G. (Vito) (1996-2000)

Sustainable Mobility (SPSD I), Evaluation of the risks of toxicity from the road traffic pollution: a molecular epidemiology approach, Bernard A. (UCL), Falmagne P. (UMH) (1996-2000)

Sustainable Mobility (SPSD I), Sustainable mobility in the Brussels region – Part II, Hecq W. (ULB) (1996-2000)

Global Change and Sustainable Development (SPSD I), Electric and hybrid vehicles: a measure for the control of tropospheric ozone?, Hecq W. (ULB) (1998-2001)

Sustainable Mobility (SPSD I), Modular simulation of environmental, energy and mobility aspects of traffic policies, Maggetto G. (VUB) (1997-2000)

3. Scientific perspectives

Even though a lot of research has been conducted on the problem of tropospheric ozone, certain issues remain to be explored. Hereafter, some examples of unsolved scientific problems are enumerated with regard to the monitoring networks and policy-supporting measures.

As far as atmospheric ozone process is concerned:

- Is there a good enough understanding of the connection between ozone and the emission of its precursors so that one can easily predict ozone concentrations?
- Do current strategies lead to the changes foreseen in the concentration of ozone precursors and the expected reduction of ozone concentration (peaks and background)?
- What is the impact of natural versus anthropogenic (industry, traffic, agriculture) emissions on ozone concentrations in Europe?
- How can ozone concentration in Europe be affected by the influx of ozone and its precursors from other continents and from the stratosphere and what is the impact of European ozone concentration on global background ozone concentration and climate?

As far as the monitoring networks are concerned:

- Is the existing monitoring network capable of successfully observing the results of policy measures?
- Are the geographic spread and the density appropriate?
- Are the selected set of parameters and chemical components appropriate?
- Are the resolution and the quality of the measurements appropriate?

As far as the policy-supporting measures are concerned:

- What are the major uncertainties in the models and how they should be improved in these models in terms of meteorology, chemistry (heterogeneous processes on aerosols and in clouds), preconditions and nesting (zooming-in on smaller areas?).
- In the area of socio-economic measures: study of the interaction between measures geared towards different policy objectives (ozone, CO_2, etc.).
- Integrating new knowledge regarding the impact (on the environment, on health, etc.) of pollutants into the instruments/models aimed at the assessment of social costs and benefits of this impact and of policy measures.
- ...

The Belgian Science Policy will take some of these issues into consideration while preparing a new research programme ('Science for a Sustainable Development', 2005-2010).

4. Publications and websites

4.1. Publications

4.1.1. Synthesis documents

- Ozon op leefniveau en ozonprecursoren: wetenschappelijke instrumenten en beleid, proceedings van de studiedag, Brussel, 10 juni 2004, L'ozone dans l'air ambiant et les précurseurs d'ozone: les instruments scientifiques et la politique, actes de la journée d'étude, Bruxelles, 10 juin 2004, Politique scientifique fédérale / Federaal Wetenschapsbeleid, 2004
- Ozon in de troposfeer: onderzoek en beleid, proceedings van de studiedag, Brussel, 26 juni 1998, Ozone dans la troposphère: la recherche et la politique, actes du colloque, Bruxelles, 26 juin 1998, SSTC / DWTC, 1999 (SP0594)
- Changes in the chemical composition of the atmosphere. Belgian Impulse Programme Global change (1996-1999), Adams F., Colin R., De Muer D., et al., Brussels, OSTC, 1997 (SP0454): chap. 4, pp. 31 – 37
- Global Change and Sustainable Development (SPSD I) - Part 1: reducing uncertainties: synthesis of the Integrated Scientific reports, Brussels, OSTC, 2000 (SP0614/1-3)
- Global Change and Sustainable Development (SPSD I) - Final reports - summaries, Brussels, 2002
- Sustainable Mobility (SPSD I) - Final reports - summaries, Brussels, 2004
- Global Change and Sustainable Development (SPSD I) - Volume I: Atmospheric processes; Volume II: The climate system, Brussels, 2004
- Belgian global change research 1990-2002: Assessment and integration report (funded by the Belgian Science Policy), Chap. 2 (in particular § 2.2, 2.4, 2.5), Brussels, 2004
- Belgian global change research 1990-2002: Synthesis of the assessment and integration report, Brussels, 2004
- The Earth Observing System: Synergy between Ground-based and Satellite Observations and Model Experiments', De Mazière M., Colin R., De Muer D., Zander R. in Space Scientific Research in Belgium, Ed. by the Prime Minister's Services - Federal Office for Scientific, Technical and Cultural Affairs, Volume 3: Earth Sciences, Part III, 1994-2000, pp. 9-32, 2002
- Transport and mobility: 10 years of research, Beuthe M. and Meersman H., Brussels, 2001

4.1.2. Documents for the broad public

- Cyberspace: brochure éditée à l'occasion de l'exposition 'Vivre ou survivre' – Cyberspace: brochure samengesteld ter gelegenheid van de tentoonstelling 'Leven of overleven', SSTC / DWTC et al., Brussel, SSTC / DWTC, 2001 (SP0703)

- Experimentele studies van veranderingen in de atmosfeer (ESAC) - Etudes expérimentales des changements atmosphériques (ESAC) http://www.belspo.be/belspo/home/publ/cyber_nl.stm
- Ozon - eerst denken, dan doen, Leuvense Economische Standpunten, Proost S., Vinckier C., Mayeres I., Nemery B., Leuven, 1995
- Gas-Phase (Photo-)Chemical Processes in the Troposphere, Peeters J. and Fantechi G., UNESCO Encyclopedia on Life Support Systems (EOLSS), 15 October 2003 - http://www.eolss.net/E6-13-toc.aspx

4.1.3. Final reports of the projects related to themes A, B and C

SPSD I and II

- Syntheses SPSD I: http://www.belspo.be/belspo/home/publ/viewrap_nl.stm general list: http://www.belspo.be/belspo/home/publ/pubgen.Asp?l=nl
- Experimental studies of Atmospheric changes (ESAC): Final Report, De Mazière M., Colin R., De Muer D., et al., Brussels, OSTC, 2001 (SP0921)
- Anthropogenic and biogenic influences on the oxidizing capacity of the atmosphere: Final Report, Müller J-F., Vinckier C., Wallens S., et al., Brussels, OSTC, 2001 (SP0918)
- Modelling the climate and its evolution at the global and regional scales (CLIMOD): Final Report, Fichefet Th., Huybrechts Ph., Van Ypersele J-P., et al., Brussels, OSTC, 2001
- Biogeochemical cycles of Belgian forest ecosystems related to global change and sustainable development: Final Report, Lemeur R., Lust N., Ceulemans R., et al., Brussels, OSTC, 2001 (SP0923)
- Species diversity: importance for the sustainability of ecosystems and impact of climate change: Final Report, Reheul D., Nijs I., Verelst I., et al., Brussels, OSTC, 2001 (SP0922)
- Parameterisation and inventarisation of gaseous nitrogen compounds from agricultural sources: Final Report, Goossens A., De Wever H., De Visscher A., et al., Brussels, OSTC, 2001 (SP0924)
- The global carbon cycle and the future level of atmospheric CO_2: Final Report, Gérard J-C., Veroustraete F., Wollast M., et al., Brussels, OSTC, 2001 (SP0927)
- Recent ENSO and PALEO ENSO of the last 1000 years in lake Tanganyika: Final Report, Klerkx J., Lambin E., Seret G., et al., Brussels, OSTC, 2001 (SP0920)
- Understanding the decadal-century-to millennia climate variability by simulating extreme paleoclimatic situations: Final Report, Loutre M.F., Berger A., Crucifix M., et al., Brussels, OSTC, 2001 (SP0919)

Relevant EUROTRAC- 2 reports

- Towards Cleaner Air for Europe - Science, Tools and Applications, Part 1. Results from the EUROTRAC-2 Synthesis and Integration Project: Midgley P.M., Builtjes P.J.H., Fowler D., Harrison R.M., Hewitt C.N., Moussiopoulos N., Noone K., Tørseth K., Volz-Thomas A., Margraf Verlag, Weikersheim 2003, ISBN 3-8236-1390-1

- Towards Cleaner Air for Europe - Science, Tools and Applications - Part 2. Overviews from the Final Reports of the EUROTRAC-2 Subprojects, Margraf Verlag, Weikersheim 2003 (Editors: Midgley P.M. and Reuther M.), ISBN 3-8236-1391-X
- Transport and Chemical Transformation of Pollutants in the Troposphere, An overview of the work of EUROTRAC (Editors: Borrell P., Borrell P.M.), June 2000

The Final Reports of the following relevant EUROTRAC-2 subprojects have been published by the EUROTRAC-2 ISS, EXPORT-E2 and TOR-2. In general each Final Report can be downloaded from the Subproject's own web site.

- EXPORT 2 - European Export of Particulates and Ozone by Long- Range Transport: A Study in EUROTRAC-2 (Editors: Stuart A., Penkett K., Law S., Platt U., Volz-Thomas A.), 2003
- GENEMIS - Generation and evaluation of emission data, Springer Verlag, 2003
- SATURN - Studying Atmospheric Pollution in Urban Areas (Editor: Moussiopoulos N.), Springer Verlag, 2003
- TROPOSAT - Use & usability of satellite data for tropospheric research (Borrell P., Borrell P.M., Burrows J.P., Platt U.), Springer Verlag, 2003
- CMD - Chemical Mechanism Development (Editors: Schurath U., Naumann K-H.), 2003
- LOOP - Limitation of oxidant production (Editors: Neftel A., Spirig Ch.), 2003
- TOR-2 - Tropospheric ozone research, phase 2 (Editor: Lindskog A., Swedish Environmental Research Institute, IVL), 2003
- GLOREAM - Global and regional atmospheric modelling (Editor: Builtjes P.), 2003

Relevant EUROTRAC reports

- Photo-oxidants, Acidification and Tools: Policy Applications of EUROTRAC Results, (Editors: Borrell P., Hov Ø., Grennfelt P., Builtjes P.), December 1996
- Tropospheric Modelling and Emission Estimation: Chemical transport and emission modelling on regional, global and urban scales (Editors: Ebel A., Friedrich R., Rodhe H.), October 1997
- Tropospheric Ozone Research: Tropospheric ozone in the regional and sub-regional context (Editor: Hov Ø.), December 1997
- Chemical Processes in Atmospheric Oxidation: Laboratory studies of chemistry related to tropospheric ozone (Editor: Le Bras G.), December 1996
- Biosphere-Atmosphere Exchange of Pollutants and Trace Substances, Experimental and theoretical studies of biogenic emission and of pollutant deposition (Editor: Slanina S.), December 1996

4.1.4. Final reports of the projects related to theme D

- MARKAL, a model to support greenhouse gas reduction policies: Final Report, Proost S. (KULeuven), Brussels, OSTC, 2001 (SP0730)
- Modèle EPM: Analyse prévisionnelle des émissions de gaz à effet de serre en Belgique en 2010: Rapport Final, Constant Ph. (ECONOTEC), Bruxelles, SSTC, 2002 (SP1091) - EPM model: Emission projection of greenhouse gases in Belgium in 2010: Summary (SP1093)
- Maatregelen in de transportsector voor de vermindering van CO_2 en troposferische ozon: Eindrapport, De Vlieger I. (Vito), et al., Brussel, DWTC, 2001 (SP0882) - Transport sector measures for reducing CO_2 and tropospheric ozone: Summary (SP0884)
- The external costs of transportation: Final Report, Proost S. (KULeuven), et al., Brussels, OSTC, 2001 (SP0850)
- Mobilité durable en région bruxelloise - Partie II: Rapport Final, Hecq W. (ULB), Brussels, SSTC, 2001 (SP0853) - Sustainable mobility in the Brussels region - Part II: Summary (SP0855)
- Véhicules éléctriques et hybrides: une mesure pour réduire l'ozone troposphérique?: Rapport Final, Favrel V. (ULB), et al., Bruxelles, SSTC, 2001 (SP0735) - Electric and hybrid vehicles: a measure to reduce trophospheric ozone?: Summary (SP0742)
- Assessment of the risks of toxicity from the road traffic pollution: a molecular epidemiology approach: Final Report, Bernard A. (UCL), Falmagne P. (UMH), Brussels, OSTC, 2002
- Modular simulation of environmental, energy and mobility aspects of traffic policies: Final Report, Maggetto G., Deloof W., Van Crombruggen E. (VUB), Brussels, OSTC, 2001
- Economische impactmodules voor het EUROS-model: Eindrapport, Altdorfer F. (ECONOTEC), Duerinck J., Marien K., Torfs R. (Vito), Brussel, DWTC, 2001 (SP0732) - Economic impact modules for the EUROS-model: Summary (SP0744)

4.2. Websites

- Belgian Science Policy

  http://www.belspo.be/fedra (Federal Research Actions Database)
- Ozone research group at the Royal Meteorological Institute of Belgium

  http://www.meteo.be/ozon/
- Experimental Studies of Atmospheric Changes II

  http://www.oma.be/ESACII/Home.html

- The BIRA-IASB BrO Product

  http://www.oma.be/bira-iasb/Molecules/BrO/
- Global Ozone Monitoring Experiment (GOME)

  http://www.oma.be/GOME/
- BELEUROS

  http://www.beleuros.be
- Institute of Chemistry and Dynamics of the Geosphere (ICG) (Germany)

  http://www.fz-juelich.de/icg/icg-ii/homepage
- Tropospheric Emission Monitoring Internet Service (the Netherlands)

  http://temis.nl
- EnVisat for Environmental Regulation of GREENhouse gases (EC, Framework Programme 5)

  http://www.knmi.nl/evergreen/
- ASSimilation of Envisat daTa

  http://nadir.nilu.no/asset/
- Precursors of Ozone and their Effects in the Troposphere

  http://nadir.nilu.no/poet/

Chemical formulas

BrO	bromine oxide
C_2H_6	ethane
CH_3	methyl
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
H_2CO	formaldehyde
HO_x	hydrogen oxides
N_2O	nitrous oxide
NH_3	ammonia
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
O_3	ozone
OClO	chlorine dioxide
OH	hydroxyl radical
SO_2	sulphur dioxide

Acronyms

ACCENT	Atmospheric Composition Change
AMORTEC model	Aggregate Model for Road Traffic Emissions Calculation
AOT	Accumulated Exposure over a Threshold
ASSET	ASSimilation of Envisat daTa
ATMOS	CCIEP Working Group on the Atmosphere
BAU	Business As Usual
BELEUROS	EURopean Operational Smog Model adapted to Belgium
BIRA / IASB	Belgisch Instituut voor Ruimte Aëronomie (BIRA) / Institut d'Aéronomie Spatiale Belge (IASB) / "Belgian Institute for Space Aeronomy"
CAFE	Clean Air For Europe
CCIEP	Coördinatiecomité Internationaal Milieubeleid (CCIM) / Comité de Coordination de la Politique Environnementale Internationale (CCPIE) / "Coordination Committee for International Environmental Policy"
CLIMOD	CLImate MODelling (research project funded by the Belgian Science Policy)
CLRTAP	Convention on Long-range Transboundary Air Pollution
CMD	Chemical Mechanism Development
DOAS	Differential Optical Absorption Spectroscopy
DUP	Data User Programme
DWTC	Federale Diensten voor Wetenschappelijke, Technische en Culturele Aangelegenheden (now Belgian Science Policy)
EC	European Commission
ECONOTEC	Consultancy that performs techno-economic evaluation and provides decision support in the field of energy and the environment
EMEP-model	Co-operative Programme for Monitoring and Evaluation of the Long-range Transmission of Air pollutants in Europe
ENVISAT	Environmental Satellite
EPM	Emissions Projection Model
ERS-2	European Remote Sensing Satellite-2
ESA	European Space Agency
ESAC	Experimental Studies of Atmospheric Changes (research project funded by the Belgian Science Policy)
EU	European Union
EUREKA	A Network for Market Oriented R&D
EUROS	EURopean Operational Smog Model
EUROTRAC-2	The EUREKA project on the transport and chemical transformation of trace constituents in the troposphere over Europe; second phase
Evergreen	Envisat for Environmental Regulation of Greenhouse Gases
ExTC	Model to calculate external costs from transport
FEDRA	Database of research actions funded by the Belgian Science Policy
FP 4 / FP 5 / FP 6	Framework Programme 4 / 5 / 6 (European Commission)
FPMS	Faculté Polytechnique de Mons
FTIR	Fourier Transform InfraRed

FUND 2.0 model	Model for greenhouse-effect linked externalities
GAW	Global Atmosphere Watch
GENEMIS	Generation and Evaluation of Emission Data
GEO	Group on Earth Observations
GHG	Greenhouse Gases
GLOREAM	Global and Regional Atmospheric Modelling
GMES-GATO	Global Monitoring for Environment and Security - Global ATmospheric Observations
GOME	Global Ozone Monitoring Experiment
GOMOS	Global Ozone Monitoring by Occultation of Stars
HALIPP	Heterogeneous and Liquid Phase Processes
HELIOS	Biomarkers for the non-invasive assessment of acute and chronic effects of air pollutants of the respiratory epithelium. Development and application to adults and children along a north-south gradient (project funded by FP 5)
IASI	Infrared Atmospheric Sounding Interferometer
ICEDD	Institut de Conseil et d'Etudes en Développement Durable / "Institute for advice and studies in sustainable development"
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere and Biosphere Programme
IGOS	Integrated Global Observing Strategy
IMAGES	Intermediate Model for the Annual and Global Evolution of Species
IPCC	Intergovernmental Panel on Climate Change
IRCEL / CELINE	Intergewestelijke Cel voor het Leefmilieu (IRCEL) / Cellule Interrégionale de l'Environnement (CELINE) / "Belgian Interregional Cell for the Environment"
JETDLAG	Joint European development of tunable laser absorption spectroscopy for measurement of atmospheric trace gases
JOULE	Research programme of the European Commission regarding non-nuclear energy
KMI / IRM	Koninklijk Meteorologisch Instituut van België (KMI) / Institut Royal Météorologique de Belgique (IRM) / "Royal Meteorological Institute of Belgium"
KULeuven-PAC	Katholieke Universiteit Leuven - Division for Physical and Analytical Chemistry
LABVOC	Laboratory studies on the Oxidation of Volatile Organic Compounds
LACTCZ	Laboratory studies of Chemistry related to Tropospheric Ozone
MARKAL	Model to support greenhouse gas reduction policies
MARKAL/TIMES	Model to support greenhouse gas reduction policies (successor)
MAXDOAS	Multi-AXIS Differential Optical Absorption Spectroscopy
MCA	Multiple Criteria Analysis
MCM	Master Chemical Mechanisms
METOP	Satellite aiming to provide global weather trend coverage
METPHOMOD	Model to evaluate the ozone concentrations in the atmosphere
MIPAS	Michelson Interferometer for Passive Atmospheric Sounding
MO	Impulse for research in the Belgian federal scientific institutes (research actions funded by the Belgian Science Policy)
MOBILEE	An integrated instrument for the environmental evaluation of local traffic plans (research project funded by the Belgian Science Policy)

MOPITT	Monitoring of Pollution In The Troposphere
MOZART	Model of OZone And Related Trace species
MULTIPOL	Multi-pollutant emission reduction policies (research project funded by the Belgian Science Policy)
NADIR	NILU's Atmospheric Database for Interactive Retrieval
NDSC	Network for the Detection of Stratospheric Changes
NEC	National Emissions Ceilings
NILU	Norwegian Institute for Air Research
NMVOC	Non-methane Volatile Organic Compound
OSTC	Federal Office for Scientific, Technical and Cultural Affairs (now Belgian Science Policy)
PM	Particle Matters
PNEUMO-NEPHROTOX	Peripheral markers for risk assessment of pneumotoxic and nephrotoxic pollutants (project funded by FP 4)
POET	Precursors of Ozone and their Effects in the Troposphere
ppbv	part per billion (volume)
PRODEX	PROgramme de Développement d'Expériences
R&D	(R&D – O&O) Research and Development
RACM	Regional Atmospheric Chemistry Model
RIVM	Rijksinstituut voor Volksgezondheid en Milieu / "National Institute for Public Health and the Environment"
SARBVOC	Structure-Activity Relationships for reactions in the degradation of Biogenic Volatile Organic Compounds
SATURN	Studying Atmospheric Pollution in Urban Areas
SCIAMACHY	SCanning Imaging Absorption SpectroMeter for Atmospheric CHartographY
SCOUT	Stratosphere Climate links with emphasis on the UTLS
SCR	Catalytic Continuous Reduction
SFIT2	Algorithm allowing the retrieval of information on the distribution of some target gases versus altitude (standard code)
SFSP2	Algorithm allowing the retrieval of information on the distribution of some target gases versus altitude (BIRA-IASB home-made code)
SMAC	Spectroscopic Measurements of Atmospheric Changes
SMOGSTOP	Statistical Model Of Ground Short Term Ozone Pollution
SPARC	Stratospheric Processes and their Role in Climate
SPSD	Scientific Support Plan for a Sustainable Development Policy (research programme funded by the Belgian Science Policy)
SSTC	Services Fédéraux des affaires Scientifiques, Techniques et Culturelles (now Belgian Science Policy)
SUSATRANS	Sustainability assessment of technologies and modes for transport in Belgium (research project funded by the Belgian Science Policy)
TEMAT	Transport Emission Model to Analyse (non-) Technological measures
TEMIS	Tropospheric Emission Monitoring Internet Service
TERRA	Earth Observing System (EOS) flagship satellite
TOPAS	Tropospheric Optical Absorption Spectroscopy
TOR	Tropospheric Ozone Research
TREMOVE	a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector
UARS	Upper Atmosphere Research Satellite

UCL-ASTR	Université Catholique de Louvain / "Catholic University of Louvain - Institute of Astronomy and Geophysics Georges Lemaître"
UFTIR	Upper Free Troposphere observations from a European ground-based FTIR network
ULB-SPECAT	Université Libre de Bruxelles - Unité de spectroscopie de l'atmosphère / "Free University of Brussels - Unit of Spectroscopy and Atmosphere"
ULG-GIRPAS	Université de Liège - Groupe InfraRouge de Physique Atmosphérique et Solaire / "University of Liège - InfraRed Group of Atmospheric and Solar Physics"
UMH	Université de Mons-Hainaut / "University of Mons-Hainaut"
UNECE	United Nations Economic Commission for Europe
UNESCO	United Nations Educational, Scientific and Cultural Organisation
UTLS	Upper Troposphere and Lowermost Stratosphere
UTOPIHAN	Upper Troposheric Ozone: Processes Involving HO_x and NO_x
UV	Ultra-Violet
UV-vis	UV visible
Vito-TAP	Vlaamse Instelling voor Technologisch Onderzoek / "Flemish Institute for Technological Research - Remote Sensing and Atmospheric Processes"
VMM	Vlaamse Milieumaatschappij / "Flemish Environment Agency"
VOC	Volatile Organic Compound
WOUDC	World Ozone and Ultraviolet Radiation Data Centre