Abatement strategies to reduce air pollution from transport in Germany

U. Kugler*, J. Theloke, B. Thiruchittampalam, T. Geftler, M. Uzbasich, R. Köble, R. Friedrich,
Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), Universität Stuttgart, Germany

P. Builtjes, H. Denier van der Gon
TNO Build Environment and Geosciences (TNO), Utrecht, Netherlands

R. Stern
Freie Universität Berlin –(FUB), Geowissenschaften, Institut für Meteorologie, AG Troposphärische Umweltforschung, Berlin, Germany

W. Jörß
Institut für Zukunftsstudien und Technologiebewertung (IZT), Berlin, Germany

U. Dämmgen
Johann Heinrich von Thünen-Institut, Institut für Agrarrelevante Klimaforschung, Braunschweig, Germany

J. Appelhans
Umweltbundesamt, FG II 4.1, „Grundsatzfragen der Luftreinhaltung", Dessau, Germany

Keywords: $PM_{10/2.5}$, Abatement strategies, road/offroad transport emissions, air pollution modelling

ABSTRACT: Large scale exceedances of PM_{10} and NO_2 ambient air limit values will continue in Germany despite the implementation of national and international policies. An integrated approach has therefore been developed to assess different cost-effective mitigation strategies for all source groups on a national level. On-road and off-road transport emission abatement strategies such as more stringent emission limit values, cost internalisation, speed limits and levelling of fuel taxes can contribute to the overarching goal of an improved air quality.

1 INTRODUCTION

According to projected and modelled ambient air concentrations, large scale exceedances of PM_{10} and NO_2 limit values in Germany will continue despite the implementation of current national and international legislation. On-road and off-road transport is one of the major sources of these exceedances, directly through NO_x and $PM_{10/2.5}$ exhaust and non-exhaust emissions and indirectly by emissions of aerosol precursors. To be able to comply with the existing European limit values for PM_{10} (and the expected ones for $PM_{2.5}$), it is therefore crucial to develop successful mitigation strategies that are not only considering all pollutants but also taking into account possible side effects on green house gases or noise.

In the PAREST research project (Particle Reduction Strategies) different cost-effective strategies on a national level are assessed to decrease air pollution caused by emissions of NO_x, SO_2, NH_3, NMVOC, PM_{10} and $PM_{2.5}$ and thus contribute to an improved air quality.

2 GENERAL METHODOLOGY

The methodology to assess abatement strategies for air pollution in Germany is as follows (Fig. 1).

* *Corresponding author:* Ulrike Kugler, Institut für Energiewirtschaft und Rationelle Energieanwendung (IER), Universität Stuttgart, Heßbrühlstr. 49a, 70565 Stuttgart, Germany. Email: ulrike.kugler@ier.uni-stuttgart.de

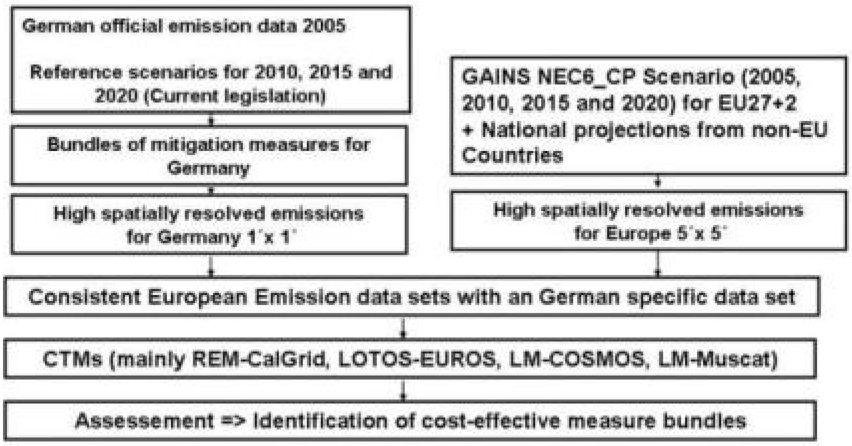

Figure 1. Methodology used for the assessment of abatement strategies for PM_{10} and $PM_{2.5}$ in Germany within the project PAREST

Emission inventory data for Germany in 2005 from the Umweltbundesamt, comprising all sectors, and reference scenario data for 2010, 2015 and 2020 comprising current legislation are used as a modelling basis. To the emissions of the reference scenario, different bundles of mitigation measures for sources such as on-road and off-road transport, electricity and heat production, other large and small combustion plants, agriculture and solvent use are applied to derive mitigation scenarios. All German emission scenarios are gridded to 1/60 x 1/60 (ca.1 min x 1 min) with the help of proxy data such as road, railway and river networks, coordinates of point sources (airports, power plants and industrial plants), population and land use data (Thiruchittampalam, 2008). A quality check of those gridded emission maps was undertaken by experts of the German environmental agency UBA, an example is given in Figure 2.

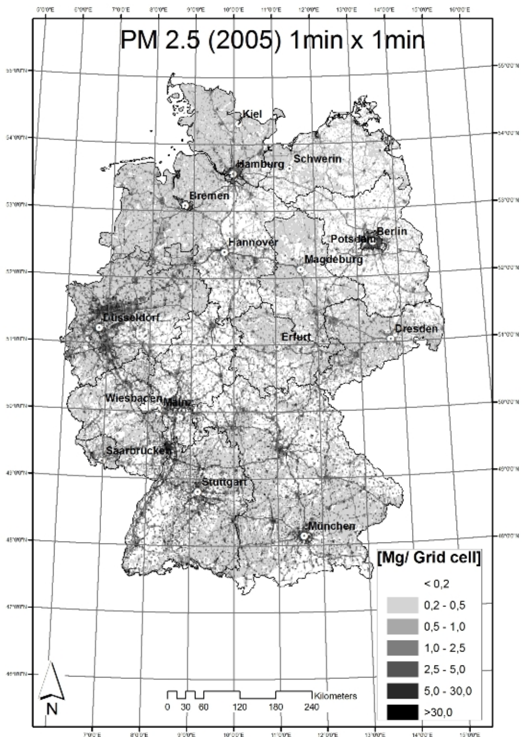

Figure 2. Highly resolved $PM_{2.5}$ emission map for Germany in 2005 (all sources, 1 min x 1 min)

For the European background, emission scenarios from GAINS from the NEC 6 scenario family (Amann et al. 2008) and national projections for non-EU countries are used. They are gridded on 5 min x 5 min (Denier van der Gon et al., 2009) and combined with the German emission data set to derive a consistent European emission data set (Fig. 3).

Figure 3. Highly resolved PM_{10} emission map for Europe in 2020 (NEC6_CP, all sources, 5 min x 5 min)

To model the effect of mitigation strategies on air quality with the focus on PM_{10} and $PM_{2,5}$, the chemical transport models (CTM) REM-CalGrid (major part of the modelling), LOTOS-EUROS, and COSMO-MUSCAT are used. A REM-CalGrid model result of PAREST is shown in Figure 4.

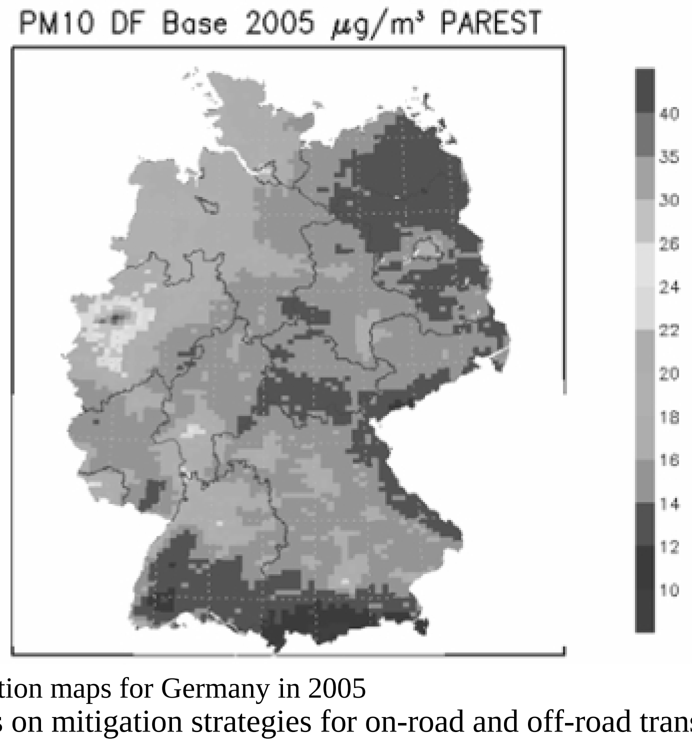

Figure 4. PM_{10} concentration maps for Germany in 2005

The paper will focus on mitigation strategies for on-road and off-road transport emissions.

3 ASSESSMENT OF ABATEMENT MEASURES FOR ON-ROAD AND OFF-ROAD TRANSPORT

3.1 *Off-road transport*

Off-road transport such as rail and air traffic, inland and coastal shipping and mobile machines has gained importance in recent years due to their relatively high emissions of $PM_{10/2.5}$ and NO_x. In view of that, more stringent emission limit values were set out which will lead to a distinct decrease. Figure 5 shows that in the reference scenario, emissions of PM_{10} in 2020 will be more then halved compared to 2005. The majority of off-road PM_{10} emissions are caused by mobile machines (agricultural machinery, industrial and building machinery as well as household and gardening machinery).

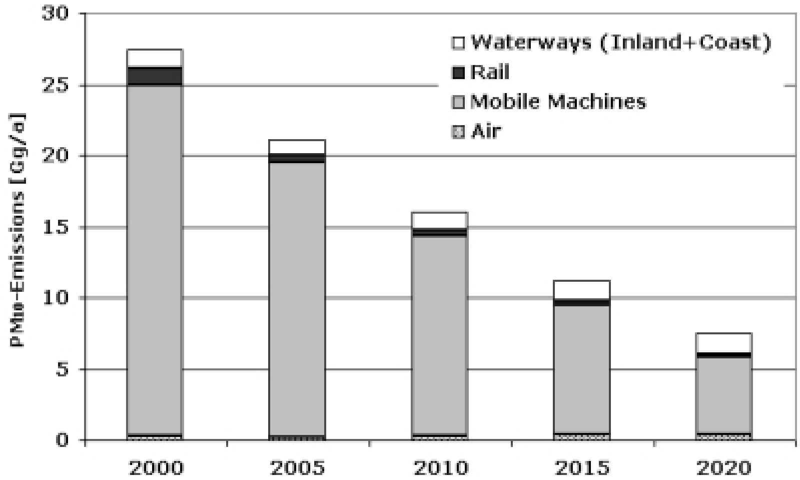

Figure 5. PM_{10} emissions in Germany from off-road sources in the reference scenario (2000-2020, UBA, 2009)

To assess further mitigation potentials for that sector, abatement measures were analysed for each subgroup. This was done on the basis of related research projects (Jörß et al., 2007; Theloke et al., 2007; Matthes et al., 2008), on literature reviews and on expert judgements. For each abatement measure, data sources, assumptions on reduction potentials, implementation degrees and mitigation costs as well as side effects on other environmental pollutants (e.g. CO_2) or stressors (e.g. noise) were documented and will be made available at the end of the project. The measures that were assessed for off-road sources in Germany are:

- More stringent emission limits (mobile machines, ships, trains)
- Limit values for evaporation emissions (gasoline machines)
- Ban on high emitting construction machines in cities (“Environmental Zone”)
- Differentiation of rail track prices: trains with older emission standards pay more
- Cost internalisation of emission impacts from air traffic (fuel tax, emission trading scheme)

When all of these measures are applied, a maximum mitigation potential of 5% in 2020 is feasible for PM_{10} emissions of off-road sources (compared to the reference situation in 2020).

3.2 *On-road transport*

On-road transport such as passenger cars, light and heavy duty vehicles, busses and two-wheelers causes exhaust and evaporation emissions, but also non-exhaust emissions from the wear of road surfaces, tires and brakes and the resuspension of road dust. So far, resuspension emissions are not part of the official German inventory and were thus calculated on the basis of (Schaap et al., 2008) as input to the CTMs in PAREST. The results show that while PM_{10} diesel exhaust emissions are going to decrease due to more stringent emission limits (Euro 5/V and 6/VI), non-exhaust emissions are going to increase due to an increase in vehicle mileage (Fig. 6). By 2010, non-exhaust emissions are the major emission source for PM_{10} emissions from on-road transport.

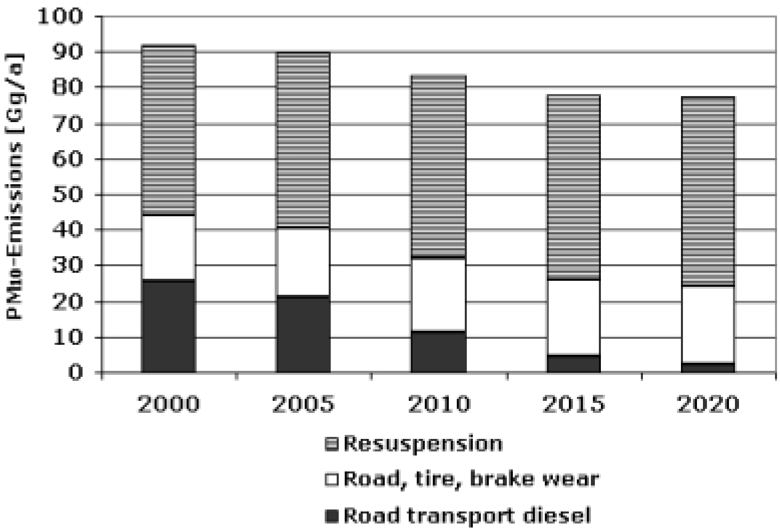

Figure 6. PM_{10} emissions in Germany from on-road sources in the reference scenario (2000-2020, UBA, 2009)

As for the other sectors, mitigation measures were assessed for on-road emission sources:

- Limit values for evaporation emissions from motorcycles
- Retrofit of diesel passenger cars with particulate filters
- Speed limit of 120 km/h for motorways
- Speed limit of 30 km/h in cities
- Levelling of fuel taxes for diesel and gasoline
- Enhancing the use of bicycles in cities
- Use of low viscosity oil
- Use of low rolling resistance tyres

When all of these measures are applied, a maximum mitigation potential of 4% in 2020 is feasible for PM_{10} emissions of on-road sources (compared to the reference situation in 2020).

4 CONCLUSION

An integrated approach on national level has been developed to assess reduction strategies for PM_{10}, $PM_{2.5}$ and NO_2 for Germany. It is thus possible to assess the impact of mitigation measure bundles on ambient air quality. For on-road and off-road sources, a decrease in emissions is projected. With mitigation measures such as more stringent emission limit values for off-road machinery, cost internalisation in air transport, speed limits for cars and levelling of fuel taxes, a further decrease of 5% PM_{10} emissions in 2020 compared to the reference situation is feasible. However, as the integrated approach comprises all emission source groups, most fitting cost-effective abatement strategies for air pollution can be designed.

5 ACKNOWLEDGEMENTS

This work is funded by Umweltbundesamt, Germany, in the frame of the research project PAREST (www.parest.de).

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ECATS - Mission of Association for an environmentally compatible air transport system

S. Matthes*, G. Erhardt, K. Gierens, A. Petzold,
Deutsches Zentrum für Luft- und Raumfahrt (DLR) – Institut für Physik der Atmosphäre Oberpfaffenhofen, Germany

P. Brok,
National Aerospace Laboratory (NLR), Netherlands

M. Hagström,
Swedish Defence Research Agency (FOI), Stockholm, Sweden

C. Helmis,
National Kapodistrian University of Athens, Greece

Ivar S. Isaksen,
University of Oslo, Norway

P. Laroche, X. Vancassel,
Office National d'Etudes et Recherches Aérospatiales (ONERA), France

D. Lee, D. Raper,
Manchester Metropolitan University, Manchester, United Kingdom

T. Panidis,
University of Patras, Greece

K. Mathioudakis, T. Tsalavoutas,
National Technical University of Athens, Greece

R. Kurtenbach, P. Wiesen,
Univ. Wuppertal, Germany

C. Wilson,
Univ. Sheffield, United Kingdom

P. Habisreuther, K. Schäfer, N. Zarzalis,
Karlsruhe Institute of Technolgy, KIT, Germany

Keywords: Aviation, emissions, environment, particulate matter, alternative fuels, climate impact, Association.

ABSTRACT: After 5 years of operation and collaboration the ECATS Network of Excellence (NoE) will now transform itself into a registered Association of European Research Establishments and Universities leading in the field of **aeronautics and the environment**. The transition from NoE to the Association will take place during 2010 and 2011. This future **ECATS Association** has the vision to support endeavours to make aviation more sustainable focussing on scientific expertise and exchange of information. ECATS' Virtual Fuel Centre focusses on alternative fuel characterisation allowing operating a premix burner, measuring flame velocities, expanding kinetic schemes and spray characterisation. ECATS' Airport Air Quality (AAQ) focus area povides an assessment of this highly interdisciplinary research field, and develops improved characterisation and approximation specifications for aviation particulate matter emissions. ECATS' third focus area is dealing with global impact of aviation and green flight. Close collaboration is exploited in order to provide updated estimates and synergies with other programmes established. The future ECATS Association provides an efficient framework for collaboration between universities and research establishments and helps making aviation more sustainable.

* *Corresponding author:* Sigrun Matthes, Deutsches Zentrum für Luft- und Raumfahrt (DLR) – Institut für Physik der Atmosphäre, Oberpfaffenhofen, D-82234 Wessling, Germany. Email: sigrun.matthes @dlr.de

1 INTRODUCTION

Reducing environmental impact of air transport with regard to emissions and noise is an important element in achieving the overall goals of Vision 2020 and the European Strategic Research Agenda (SRA). A coordinated collaborative effort is required, strengthened and guided by a single shared vision, through creation of a common network for research and technological development in order to overcome fragmentation. From this starting point the Network of Excellence (NoE) ECATS was brought to life in 2005, to harmonise and integrate European research aiming to help developing an environmentally compatible air transport system. Within the Network of Excellence ECATS a total of 12 partners – research establishments and universities - from 7 European Nations put their effort together to work jointly at an “Environmentally Compatible Air Transport System”. Partners within the Network of Excellence are Deutsches Zentrum für Luft- und Raumfahrt (DLR), National Aerospace Laboratory, Amsterdam (NLR), Office National d’Etudes et Recherches Aérospatiales (ONERA), Swedish Defence Research Agency (FOI), University of Sheffield (USFD), Manchester Metropolitan University (MMU), University of Norway (UiO), University of Wuppertal (BUW), National Technical University of Athens (NTUA), University of Patras (UP), the National Kapodistrian University of Athens (NKUA) and Karlsruhe Insitut of Technology (KIT).
After five years of successful network activities ECATS Association furthers integrative work that started in the Network of Excellence (FP6). This future Association aims making aviation more environmentally compatible. Main objectives in the field of **aviation and environment** are**:** (a) Organize knowledge transfer including education, (b) Technological and scientific leadership in Europe, and (c) Contribute to technical and political debate. Working groups are defining individual business plans within specific thematic areas. The scope of this paper is to present activities of the future ECATS Association which is scheduled to be established in 2010 focussing on above activities.

2 ECATS APPROACH

ECATS Association will continue activities of the ECATS Network of Excellence. Network activities, hence Association activities, are covering three different Thematic Areas (TA): (1) Engine technology, near field plume and alternative fuels, (2) Local and regional aspects of air quality – Airport Air Quality (AAQ), and (3) Global aviation impact and Green Flight operations. Within all three thematic areas the Association is aiming to achieve primary objectives spelled out. Close collaboration and exchange between those multi-disciplinary thematic activities allow exploiting synergies for visibility and training activities.
This future **ECATS Association** has the vision to help making aviation more sustainable. Specifically, it will serve the following stakeholder’s needs: **a.** Build up, maintain and extend scientific expertise and, moreover, to further link and integrate scientific expertise in the different thematic areas and exploit the multi-disciplinary platform available in ECATS; **b.** Organise exchange of information in particular about experience and development of related research, e.g., on basis of workshops, reports and publications, education and training, and web-based information; **c**. Provide liaison between customers and experts to provide integrated and professional support; **d.** Foster to the technical, strategic and political debate, e.g., to initiate research on those topics identified to be relevant; **e.** Perform research work where identified to be crucial, e.g., short studies. Primary objectives of ECATS Association are to help building up and maintain scientific expertise in the field of aviation and environment.
Visibility for ECATS Association will be provided by further exploring the existing common web-portal, but also preparation of relevant documentation. Functionalities are internal and public areas which is guaranteeing effective communication for internal and external dissemination.
ECATS as a Network of Excellence fully provides thematic nucleus for scientific expertise by establishing thematic workpackages and tasks. Until end of 2011 a specific workprogramme is identified and implemented jointly by ECATS Consortium. Association activities are in-line with network workprogramme. Main focus is given on addressing open questions while exploiting full synergies with other programmes. Such synergies can be exploited by complementing own funding with other project funding.

3 FOCUS AREA 1: VIRTUAL FUEL CENTRE

ECATS holds unique expertise and technology in Europe with respect to fuel charachterisation. Such characterisation is essential for exploring option on introducing alternative fuels into aviation. ECATS aim is to provide fuel characterization facilities for alternative fuels (XTL). The aviation fuel specification has developed over a number of years from the specification of kerosene for use in oil lamps. The specification has developed such that safety and supply of fuel are not compromised. However, the specification relies on properties of the fuel being within spec because other parameters are in spec and the fuel is generated in such a way that parameters are linked. By looking at alternative fuels it is important to identify which additional parameters need to be specified and how to check that the new fuels meet this specification.

Equipment to check a range of fuel functionalities needs to be assembled. Most of it is available but spread across Europe and not accessible to all partners. ECATS partners have evaluated which items are available and produced a virtual centre containing the equipment. The equipment contains all the standard specification equipment currently used and available within the major research establishments. ECATS has enhanced it by a range of additional facilities (some requiring modifications for application in the virtual fuel centre) such as: an engine simulator for the evaluation of fuel thermal stability at engine operating conditions, fuels injection facilities for the evaluation of spray composition, fuel auto ignition and flashback measurement facilities, combustion capabilities emissions reactivity measurement facilities, material compatibility facilities, alternative fuels modelling facility. During the early phase of the Network of Excellence ECATS capability has been enhanced and the ECATS Virtual Fuel Centre was established. Currently the ECATS Virtual Fuel Centre is commissioning a premixed burner and a rapid compression machine, it performs modifications to a bomb which is suited for measurements of flame velocities, and it develops kinetic schemes for improved representation of alternative fuels.

Specific work performed within ECATS’ Virtual Fuel Centre comprises commissioning a premixed burner in a manner that it can be transported and operated in various European laboratories. To ensure that the facility is operated correctly a number of modifications were performed. A high speed Flame Ionization Detector (FID) is purchased and utilised in the facility setup to ensure that the facility is setup at the correct operating condition. A controllable hot plate is required to vary the inlet temperature to the burner and a calibrated syringe driver is required to deliver the alternative fuels. A partner within ECATS Virtual Fuel Centre possesses a bomb which is suited for measurements of laminar flame velocities. The bomb also enables optical access which is necessary in order to measure the stretch effect on the flame velocity (Markstein Number). The described experimental facility is currently only used for gaseous fuels. So, there are only minor modifications required in order to enable investigation of liquid fuels within the existing facility. Further work is being performed in order to achieve conditions representative of today’s gas turbine engines. Additionally, modelling capabilities will continue to be developed. In particular, the historical way to represent kerosene combustion is to describe the fuel as a mixture of 70% n-dodecane and 30% aromatics. This needs to be developed to a more detailed description for alternative fuels. The fuels will include a narrow xTL cut, consisting mainly of relative low molecular weight n- and iso-paraffins, as a base case, and blends of the base case with appropriately selected single-ring aromatics, di-aromatics and naphthenes. A conventional wide kerosene cut, either neat or contaminated with a particular Fatty Acid Methyl Ester (FAME) mixture will also be considered. For each fuel a state-of-the-art detailed kinetic mechanism will be assembled and validated against laminar burning velocities, ignition time delays and stable species profiles from laminar premixed flames. Experimental data generated within the ECATS consortium or obtained from the open literature will be used for the validation procedure. ECATS Consortium has a significant and demonstrated capability in the development, assembly and validation of detailed kinetic mechanisms for hydrocarbon fuels. Additionally spray characteristics of alternative fuels will be assessed. Objective here is to enable the spray quality to be evaluated providing results on the fuels under consideration as well as a fuel spray testing protocol.

For above mentioned work close collaboration with fuel industry is exploited. Impact on the fuels’ behavior to each of these additives (assuring fuel compliance with specification) is jointly characterized within ECATS virtual fuel centre by experimental and theoretical studies.

4 FOCUS AREA 2: AIRPORT AIR QUALITY

ECATS holds unique expertise and technology with respect to airport air quality. Activities focus on preparation of an state-of-the-art assessment providing a comprehensive overview, and a documentation of recent ECATS advancements, approaches, methodologies applied and remaining issues. Reliable information on mechanisms, dominating factors, impact and mitigation strategies in local and regional air quality is required. Relevant stakeholders in this domain are airport operators, local authorities but also airlines and engine manufacturers which are linked via various research programmes (see figure 1). ECATS Consortium follows three major activities within network and Association activities: (1) Assessment of AAQ relevant issues, (2) particulate matter characterisation witin the frame of SAMPLE, and (3) improved First Order Approximation (FOA) for aviation particulate matter emissions.

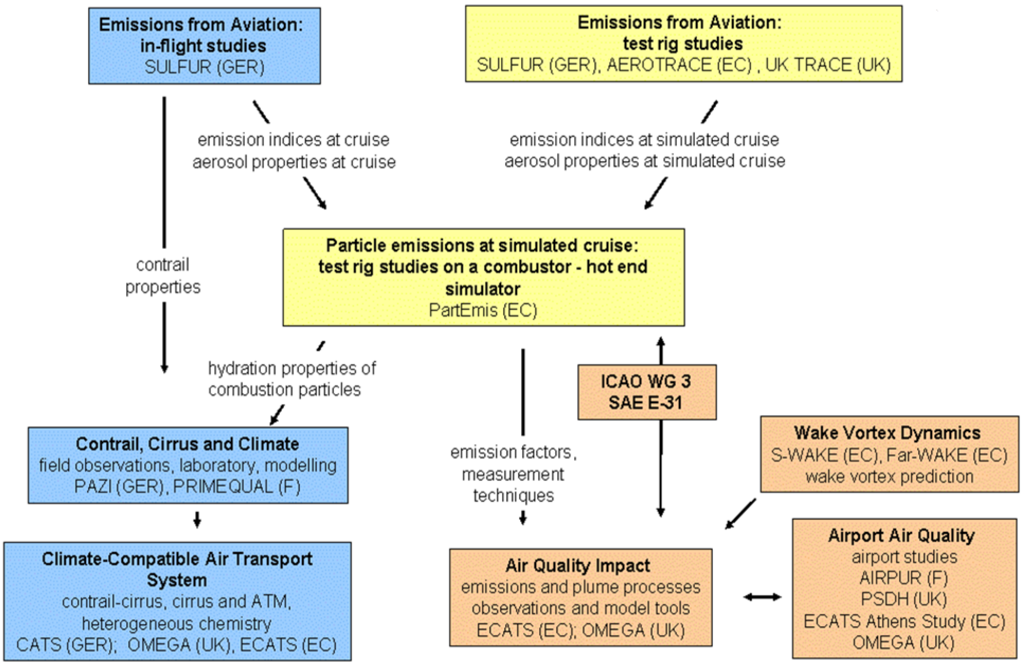

Fig 1: Activities on particulate matter emissions from aviation.

Regarding AAQ assessment, the main objectives are data interpretation of the ECATS airport campaigns and the further assessment of the impact of meteorology, source characteristics, atmospheric and emissions chemical properties on AAQ. In this framework, mitigation options in respect of AAQ will be studied with regards to technology, operational measures and economical measures, as well as source contributions and the evaluation and development of modelling tools. Regarding the SAMPLE II campaign, the role of the ECATS experts will be to further study the organic and inorganic matter emitted from aircraft engines. This work is expected to improve our understanding in this topic and to evaluate measurement methods in the framework of a new certification method based on the measurement of the mass and number of non-volatile particles. Furthermore, SAMPLE I and SAMPLE II results will build the basis for new Aerospace Recommended Practice (ARP) Guidelines for measuring particle emissions from aircraft engines. The new ARP which will be written in the next period will be sent in the ICAO CAEP/9 process to replace the outdated Smoke Number method by a modern methodology for engine certification issues. Regarding the First Order Approximation improvement for estimating particulate matter emission (PM) from aircraft, SAMPLE I and SAMPLE II results will be used together with literature data to improve the estimation of PM emissions from aircraft at the airport; the FOA will then become part of the ICAO Airport Air Quality Guidance Manual.

5 FOCUS AREA 3: GLOBAL AVIATION IMPACT AND GREEN FLIGHT

5.1 *Global Aviation Impact*

Despite the significant progress that has been made in reducing the specific emissions of aircraft, the absolute emissions have been increasing rapidly during the recent decades and are projected to continue to grow. Aviation CO_2 emissions in the EU nearly doubled over the period 1990 to 2005. Furthermore, aviation substantially impacts upon climate from non-CO_2 effects such as ozone formation and methane destruction from aviation's NO_x emissions, the formation of contrails and contrail cirrus, the emission of H_2O at high altitudes, emission of aerosols (e.g., soot) and aerosol precursors (e.g., SO_x), which are directly radiatively active and which modify cloudiness and cloud micro- physical and radiative properties.

The ultimate goal of ECATS is to contribute to solutions for a more environmentally sustainable aviation system. There are two principle pathways to that goal, namely (1) reducing the emissions and (2) reducing the climatic effects of the emissions. The first pathway proceeds mainly via novel technological solutions which are investigated in ECATS as one thematic area (TA1). The second pathway, reducing the climatic effects of emissions requires adapted flight operations that take into account the state of the atmosphere at the time and location of the specific emission.

ECATS thematic area Aviation climate impact and green flight (TA3) conducts research in order to increase the understanding of the effects of emissions in specific regions of the atmosphere. This research helps to reduce current uncertainties and helps to provide guidance to stakeholders and policy makers. In cases where uncertainties cannot be reduced substantially, for whatever reason, we explore the range of possibilities in order to allow robust decisions to be taken, i.e., decisions that work in almost all conceivable circumstances. ECATS work and achievements in TA3 help to develop operational mitigation strategies with respect to aviation's climate impact. One particular aspect is avoiding contrails that warm climate. Such contrails form in so-called ice supersaturated regions in the upper troposphere. Therefore we investigate properties of these regions and help aviation weather forecast to predict them in order to allow a flight routing that is able to take contrail effects into account. Another aspect is to investigate aviation global warming potential (GWP) due to NO_x emissions. Chemical impact of NO_x is highly non-linear. Short term warming effect due to ozone formation is compensated by a long-term indirect methane lifetime effect. The residium of both effects depends also on assumed time horizon for evaluating climate impact.

5.2 *Green flight*

With air traffic growth, aviation's contribution to climate change may well increase. Proper modelling tools, realistic scenarios and databases are needed to assess the impact. Inefficiencies in the air traffic management (ATM) system and flight operations lead to a considerable amount of unnecessary fuel burn and emissions; approx 10% for Europe! ECATS establishes central databases and investigates operational measures to reduce fuel burn and emissions and to avoid sensitive regions in the atmosphere.

Flight time, fuel consumption and emissions can be reduced due to various enhancements in the field of air traffic management (ATM) and supporting communication, navigation, surveillance (CNS) techniques. ECATS' broad expertise and capabilities in this field include ATM, airport and flight simulators, and tools to assess environmentally friendly flight operations. ECATS' partners contribute to ongoing European ATM programmes like SESAR. Close linkages exist with EUROCONTROL. Current flight routing under cruise conditions is optimized against criteria such as punctuality and costs. Environmental effects are often not taken into account. ECATS' idea is to expand today's flight planning so that it becomes environmental flight planning. As a pre-requisite current flight planning tools have to be extended in order to be able to assess the climate impact of aviation, e.g. on contrail formation. This needs the involvement and commitment of stakeholders. Assessment of aviation impact on the environment requires reliable estimates on emissions for current and future fleet scenarios. ECATS combines expertise on flight planning and routing with aircraft, engine, combustion and propulsion technology in order to generate, adopt or compare global emission inventories and scenarios. Such data was used in technological and environmental impact assessments within Europe, e.g. in the EC FP6 funded projects QUANTIFY and ATTICA.

6 CONCLUDING REMARKS

After having gained experience since the establishment of Network of Excellence ECATS in 2005 the ECATS Consortium now is stepping on to a future sustainable organisation structure, by establishing a registered Association. Founding members for this Association are the partners within the NoE ECATS. Other institutions are welcome to join this thematic Association which has spelled out scope to help making aviation more sustainable. Thematic focus areas of ECATS Association are alternative fuels, airport air quality and global aviation impact and green flight. ECATS will coordinate efforts for future research on aviation and environment within Europe.
In Spring 2010 ECATS Consortium has scheduled to apply for this registered Association ECATS. This future Association will provide an efficient framework for collaboration between universities and research establishment and help to make aviation more sustainable.

7 AKNOWLEDGMENT

ECATS is a Network of Excellence (FP6) funded by EU under Contract ANE4-CT-2005-012284.