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SCENARIOS FOR GLOBAL EMISSIONS FROM AIR TRAFFIC.

The development of regional and gridded (5°x5°) emissions scenarios for aircraft and for surface sources, based on CPB scenarios and existing emission inventories for aircraft and surface sources.

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PREFACE

This report describes the part of the global environmental assessments of air traffic performed by RIVM for the Advisory Group **'LuLu'**, that is related to global emissions. This work has been carried out within the framework of the Dutch research in support of the preparation of the Memorandum to the Parliament on 'Air traffic and Air pollution', which has the Dutch acronym **'LuLu'** (of '**Lu**chtvaart en **Lu**chtverontreiniging').

In the study current trends of global emissions of greenhouse gases from air traffic were analysed and related to other anthropogenic emissions. To this end economic assumptions of three reference scenarios were used, as described by the Dutch Central Planning Bureau, since they are well known in the Netherlands and often used in Dutch economic and environmental scenario studies. In addition, to allow for a comprehensive and consistent assessment by atmospheric models, three dimensional distributions of emissions from aircraft and from other sources were generated for present and future emissions related to the baseline scenarios. More details about this topic can be found in Veenstra *et al.* (1995).

This study is unique in that it combines the results of an air traffic projection model with a gridded air traffic emissions database to generate for future years three dimensional spatial distributions of aircraft emissions using well recognized and documented reference scenarios, thus allowing a comprehensive assessment of the atmospheric impact of aircraft emissions relative to other sources.

The assistance and co-operation of the following persons and organizations is greatfully acknowledged: dr. C.T. Walker of the (former) Warren Spring Laboratory (WSL) for the use of the WSL air traffic database and making the necessary modifications, dr. P.J. Newton of the Aerospace Division of the British Department of Trade and Industry (DTI) for performing computer runs with the DTI civil air traffic demand projection model, dr. R.M. Gardner of the British Department of Transport (DOT) for his advice on the use of gridded aircraft emissions inventories, drs. J. Veldhuis of the Dutch Ministry of Transport, Directorate-General of Civil Aviation (RLD) for his advice and providing economic information related to the CPB scenarios, ir. J.A. Peper formerly at the National Aerospace Laboratory (NLR) for his advice on technological air traffic scenario variables and for providing emission factors for carbon monoxide to the WSL database, dr. A.K. Mortlock (McDonnell-Douglas) for providing information on the seasonal variation of air traffic, dr J.-F. Müller of the Belgian Institute for Space Aeronomy (OMA) for assistance and providing the gridded inventory of surface source emissions, and dr D.A. Wuebbles of LLNL and Mrs K. Sage of NASA for providing the military air traffic emissions inventory part of the NASA inventory. Drs R. Baart of PSB developed the EDGAR software to handle the emission inventories on 5°x 5° resolution.

To improve to readability of this report for readers of different backgrounds a list of abbreviations has been added to the report.

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ABBREVIATIONS AND UNITS

AL	Activity Level
ANCAT	Abatement of Nuisances Caused by Air Transport (environmental committee of ECAC)
BG	Balanced Growth (CPB scenario)
BG0	Balanced Growth (CPB scenario), with DTI assumptions on air fares
CBP	Central Planning Bureau
CH_4	Methane
CHI	China (CPB region)
CIS	Commonwealth of Independent States (i.e. former USSR)
CO	Carbon monoxide
CO_2	Carbon dioxide
CPE	Centrally Planned Europe (i.e. Eastern Europe and the former USSR)
DAE	Dynamic Asian Economies (CPB region)
DC	Developed Countries (OECD countries) (CPB region)
DTI	Department of Trade and Industry (UK Ministry)
ECAC	European Civil Aviation Conference
EDGAR	Emission Database for Global Atmospheric Research (RIVM)
EF	Emission Factor (Emission Index)
EFTA	European Free Trade Association
EIA	Energy Information Administration (of US-DOE)
EM	Emission
ER	European Renaissance (CPB scenario)
ER0	European Renaissance (CPB scenario), with DTI assumptions on air fares
EU	European Union
FTP	File Transfer Protocol
FC	Fuel Consumption
GATT	Global Agreement on Trade and Tariffs
GNP	Gross National Product
GS	Global Shift (CPB scenario)
GS0	Global Shift (CPB scenario), with DTI assumptions on air fares
HSCT	High Speed Civil Transport
HSRP	High-Speed Research Programma
H_2O	Water (vapour)
IATA	International Air Transport Organization
IEA	International Energy Agency
IIASA	International Institute for Applied Systems Analysis
IPCC	Intergovernmental Panel on Climate Change
IS92	IPCC Scenario constructed in 1992
KNMI	Royal Netherlands Meteorological Institute
LDC	Less Developed Countries (IPCC/CPB region)
LDC+	Less Developed Countries plus Australia and New Zealand (LULU region)
LF	Load Factor (fraction of seats occupied)
LH	Long Haul
LI	Link (i.e. all flights from one world region to another region)
LLO	Laboratory for Air Research (RIVM)
LTO	Landing and Take-Off

LuLu, LULU	Luchtvaart en Luchtverontreiniging (Dutch acronym for 'Air traffic and Air pollution')
N	Nitrogen (element basis)
NA	North America; Not Available; Not Applicable
NASA	National Aeronautics and Space Administration
NLR	National Aerospace Laboratory
NME	New Market Economies (CPB region)
NO_x	Nitrogen oxide (NO and NO_2)
N_2O	Nitrous oxide
OAG	Official Airline Guide
OECD	Organisation for Economic Cooperation and Development
PMMS	Project Mainport and Environment Schiphol
rLDC	Rest of Less Developed Countries (CPB region)
S	Sulphur (element basis)
SFC	Specific Fuel Consumption (kg fuel per P-km or per S-km)
SH	Short Haul
SO_2	Sulphur dioxide
SST	Super Sonic Transport
TC	Traffic Conference (IATA area)
TPES	Total Primary Energy Supply (IEA definition)
TNO	Netherlands Organization for Applied Scientific Research
VAT	Value Added Tax
VOC	Volatile Organic Compounds (here assumed to be equal to 'unburned hydrocarbons')
WE	Western Europe (OECD Europe)
WSL	Former Warren Spring Laboratory
UN	United Nations
UNEP	United Nations Environment Programme
3D	Three-dimensional

Units

Btu	British Thermal Unit (1005.04 Joule)
EJ	Exa Joule (10^{18} Joule)
kton	kiloton (1 000 metic tonne)
Mton	Megaton (1 000 000 metric tonne)
Pg	Peta gramme (10^{15} gramme)
P-km	Passenger-kilometre
S-km	Seat kilometre (irrespective whether of not it is occupied)
SKO	Seat Kilometres Offered
Tg	Tera gramme (10^{12} gramme)
t-km	tonne-kilometre

ABSTRACT

An estimate was made of present global emissions from air traffic using statistical information on fuel consumption, aircraft types and applying emission factors for various compounds. To generate scenarios for future emissions from air traffic, assumptions were used regarding the development of the volume of air traffic, of specific fuel consumption and of the emission factors. In addition, some policy alternatives were calculated in which a number of measures were implemented to reduce aircraft emissions. In co-operation with the UK Department of Trade and Industry (DTI) scenarios of the development of the volume of global air traffic have been constructed, using economic growth figures from three scenarios defined by the Dutch Central Planning Bureau (CPB), labelled 'European Renaissance' (ER), 'Global Shift' (GS) and 'Balanced Growth' (BG). Combined with assumptions on the development of specific fuel consumption and on the emission factors global emission scenarios for air traffic were constructed for the years 2003 en 2015.

Current trends of global emissions of greenhouse gases from air traffic show for the period 1990-2015 a substantial autonomous growth of about 140-190% for NO_x and between 180-250% for other compounds. Global totals appear to be rather insensible with regard to the economic scenarios used for the projections. Related to other energy-related emissions, the growth will be larger since air traffic is expected to grow faster than other energy consumption.

Furthermore, indications are given of the maximum potential of policy measures to reduce aircraft emissions globally. Depending on the compound, emissions could be reduced substantially in 2015 (typically 25% compared with the reference scenarios), if strong technological measures would be implemented to a high degree (without retrofits of the current fleet). The cumulative effect of integrated (technical, operational or economic) control policies can be substantial, in particular with regard to NO_x emissions. The results indicate that a substantial limitation - in some cases even a reduction in absolute figures - of the uncontrolled growth of emissions may be achieved, provided that the assumed strong technological development would indeed occur and were implemented to a high degree, and were combined with other (operational and economic) policy measures.

The calculated future global emissions were spatially distributed in three dimensions using the 3D air traffic database of Warren Spring Laboratory (WSL) (now: AEA, Harwell) and emission factors defined by WSL and the Dutch National Aerospace Laboratory (NLR). The data from this database were aggregated and included as Version 1 of the Emissions Database for Global Atmospheric Research (EDGAR) of RIVM/TNO. Subsequently, the EDGAR functionality was used to generate 3-dimensional distributions of emissions for the years 2003 and 2015. Combined with time profiles, which were compiled from data provided by McDonnell-Douglas, these 3D emissions scenarios were used for atmospheric-chemical research. The cruising altitude per aircraft type and the seasonal variation were assumed to stay constant in time.

This study combines the results of an air traffic projection model with a gridded air traffic emissions database to generate for future years three-dimensional spatial distributions of aircraft emissions using well recognized and documented reference scenarios, thus allowing a comprehensive assessment of the atmospheric impact of aircraft emissions relative to other sources. This complements the aggregated comparison of global emissions from aircraft and other sources, such as presented in this report, and provides pivotal information for environmental assessments of the impact of the emissions by atmospheric models.

EXECUTIVE SUMMARY

This report describes the part of the global environmental assessments of air traffic performed by RIVM for the Advisory Group **'LuLu'**, that is related to global emissions of greenhouse gases. This work has been carried out within the framework of the Dutch research in support of the preparation of the Memorandum to the Parliament on 'Air traffic and Air pollution', which has the Dutch acronym **'LuLu'** (of '**Lu**chtvaart en **Lu**chtverontreiniging'). In this study current trends of global emissions of greenhouse gases from air traffic were analysed and related to other energy-related emissions. To this end the regional GNP assumptions of three reference scenarios were used, as described by the Dutch Central Planning Bureau (CPB). Furthermore, indications are given of the potential of policy measures to reduce aircraft emissions globally.

In addition, to allow for a comprehensive and consistent assessment of these scenarios by atmospheric models, three-dimensional distributions of emissions of nitrogen oxides (NO_x), methane (CH_4) and carbon monoxide (CO) from aircraft and from other sources were generated for present and future emissions related to the baseline scenarios, based on available emission inventories at 5°x5°x 1 km. To relate regional air traffic demand projections with the spatial emission inventory, regions and aircraft types were aggregated to a common level in order to match the results of the projection model with the groupings identified in the gridded inventory. A similar type of aggregation was done for the surface sources.

The objectives of this study were: (1) to estimate and analyse current trends of global and regional emissions of greenhouse gases from air traffic and to relate these to other anthropogenic emissions, (2) to show the possible impact of policy measures to reduce aircraft emissions globally, and (3) to estimate the associated three dimensional distribution of emissions from aircraft and from other sources. The latter part required the availability of gridded inventories of present emissions of air traffic and other sources and scenarios describing trends for source categories, that could be related to the gridded emissions inventories.

For the aggregate calculations the following compounds were considered: the direct greenhouse gases CO_2, CH_4 and N_2O, and the indirect greenhouse gases NO_x, SO_2 (also acidifying gases), CO and VOC (also gases contributing to the formation of photochemical smog). Since NO_x, CH_4 and CO are all precursors of tropospheric ozone, which is both a toxic compound and enhances radiative forcing (greenhouse effect), these are considered the most important gases for the atmospheric models used in the **LULU** programme. According to recent assessments by the Intergovernmental Panel on Climate Change (IPCC) NO_x emissions from aircraft are most important for the formation of tropospheric ozone, whereas the gases CO_2 and NO_x appear to be compounds of air traffic emissions which contribute most to the enhanced greenhouse effect.

Present emissions

Present emissions of various compounds from global total air traffic were calculated using global jet fuel consumption data for 1990 (Table 2.1) and aggregate, fleet average emission factors for NO_x from the air traffic database of Warren Spring Laboratory (WSL) and for other compounds from other sources (Table 2.2). When resulting global air traffic emissions are compared with other energy-related emissions, CO_2, NO_x en VOC appear to contribute about 2% to total emissions from fossil fuel combustion (Table 2.3). Emissions of CH_4, CO and SO_2 contribute about 0.1% or less, whereas the share in the emission of N_2O is rather uncertain with a range of 1 to 13%.

Reference scenarios

Using GNP assumptions of three CPB scenarios "European Renaissance" (ER), "Global Shift" (GS) and "Balanced Growth" (BG) of the CPB (Table 4.1), together with specific assumptions regarding air traffic (load factor, ticket prices) and with the assistance of the UK Department of Trade and Industry (DTI), which was willing to perform a number of scenario runs with their civil air traffic projection model, it was possible to generate three reference aircraft emissions scenarios. By incorporating assumptions about global average load factors, specific fuel consumption and emission factors (Table 4.2), the projected Seat-Km-Offered were converted into emissions for the years 2003 and 2015. Emissions from air traffic were compared with other energy-related emissions using IPCC estimates for both current and future emissions. By relating one of the IPCC IS92 scenarios to one CPB scenario, estimates of future global aircraft emissions were compared with global surface source emissions (Table 6.2).

From the scenario studies it is tentatively concluded that there will likely be a substantial growth of global aircraft emissions in the base case of autonomous development, also including the substantial effects of the assumed autonomous improvement of the fleet average Specific Fuel Consumption (-12.5%) and load factor (+4%) in 2015 (Table 6.3): the *autonomous growth* by 2015 of global air traffic emissions is somewhere between 140-190% for NO_x and between 180-250% for other compounds. The results of the three reference scenarios in terms of global total emissions show only minor differences, in particular when compared to the overall growth rates. The contribution of North America to total aircraft emissions will remain high, but by 2015 the share of the Far East has increased almost to a similar level (Figure I.1).

The very low emissions of methane, sulphur dioxide and carbon monoxide can be neglected (Table 6.2). Although nitrous oxide emission levels are rather uncertain, they are negligible when compared to the total of all anthropogenic sources (Tables 6.2 and 4.6).

Policy alternatives

Per compound (except for nitrous oxide) the effect on emissions of one technical policy measure was added to illustrate the impact of additional policy on aircraft emissions. If strong technological measures are implemented to a high degree in new aircraft (Table 5.1), this could reduce emissions in 2015 substantially (typically 25%, with a range of 10-40% without retrofits). Reduction of sulphur dioxide emissions requires a change in the fuel quality, whereas other emissions are reduced by technical improvement of the engines (or indirectly by reducing the aerodynamic drag of the aircraft, or by operational measures such as an increase of the load factor). Assuming no additional policies for other energy-related emissions, the share in 2015 in energy-related emissions could be effected by individual measures as follows (Table 6.3):

* NO_x and SO_2: controlled emissions share may be stabilized (GS), or reduced up to 40% (ER);
* CO and VOC: controlled emissions share may be stabilized (ER), or growth limited up to 40% (GS);
* CO_2, CH_4 and N_2O: controlled growth of the share limited to 40% (ER) to 90% (GS), except for N_2O in GS (130%).

These percentages are only meant to give an indication of what could be achieved 'at maximum' by individual technical control options; the practical potential is a fraction of this. Thus, NO_x and SO_2 emissions from aircraft may be technically controlled most effectively, whereas CO_2 emissions appear to be most difficult to control.

Integrated policies

Subsequently, it was illustrated for CO_2 and NO_x that the cumulative effect of integrated control policies by applying different control options - either being technical, or operational or economic - can be substantial, in particular with regard to NO_x emissions (Table 7.7; Figure 7.2). With respect to CO_2 emissions the selected examples show that the effect of each type of control option can be of a similar size (Table 7.6; Figure 7.1) and that the combined effect on CO_2 and NO_x emissions may result in a substantial limitation, or for NO_x even a reduction in absolute figures, of the uncontrolled growth of emissions - if the assumed strong technological development is indeed taking place and is implemented to a high degree.

Spatial emission scenarios; seasonal variation

With the available gridded emission inventories at 5°x5°x 1 km resolution for air traffic, provided by Warren Spring Laboratory (WSL) and for surface sources (including the monthly variation), provided by J.-F. Müller, we generated 3D emission fields related to the regional emission scenarios as input for atmospheric modellers. To this end the WSL base year emissions data for NO_x and, with support of NLR, of CO, calculated and aggregated to LULU regions/aircraft and to the 5°x5°x0.5 km LULU grid, were extracted from the WSL database and included as Version 1 of RIVM's global emissions database EDGAR. Information on the monthly variation of air traffic provided by Mortlock completed the air traffic data required by atmospheric models of KNMI and LLO. Using the EDGAR functionality, 3D emissions for NO_x and CO (and 3D fuel consumption) were calculated for the years 2003 and 2015 for the reference scenarios using different growth rates per region/aircraft type and a globally uniform development of emission factors, specific fuel consumption and load factors. Subsequently, the results were extracted from the database and supplied to modellers at KNMI and RIVM-LLO, together with temporal information (monthly variation).

Regarding the temporal distribution of air traffic, it was shown that in particular flights between North America and (Western) Europe show a very strong seasonality effect, as is the case for flights within Europe. This is an important factor to take into account since the height of the tropopause also varies substantially per season.

For the surface source emissions a similar procedure was followed. The data provided by Müller were first converted to the required 5°x5° LULU grid and then included as Version 1 of the Emission Database for Global Atmospheric Research (EDGAR) of RIVM/TNO. From the emissions of IPCC source categories indices for the development of global emissions were derived for the sources distinguished by Muller. Using the EDGAR functionality, emissions of NO_x, CH_4 and CO were calculated for the three scenarios using different, though globally uniform, growth rates per Müller category. Subsequently, as done for aircraft emissions, the results were extracted from the database and supplied to KNMI and RIVM-LLO.

Conclusions

Current trends of global emissions of greenhouse gases from air traffic show for the period 1990-2015 a substantial autonomous growth of about 140-190% for NO_x and between 180-250% for other compounds. Global totals appear to be rather insensible with regard to the quite different economic scenarios used for the projections. Related to other energy-related emissions, the growth will be larger since air traffic is expected to grow faster than other energy consumption.

Furthermore, indications are given of the maximum potential of policy measures to reduce aircraft emissions globally. Depending on the compound, emissions could be reduced substantially (typically 25% compared to the base line scenarios), if strong technological measures would be implemented to a high degree (without retrofits of the current fleet). The cumulative effect of integrated (technical, or operational or economic) control policies can be substantial, in particular with regard to NO_x emissions. The results indicate that a considerable limitation - or in some cases even a reduction in absolute figures - of the uncontrolled growth of emissions may be achieved, provided that the assumed strong technological development would indeed occur and were implemented to a high degree, and were combined with other (operational and economic) policy measures.

This study combines the results of an air traffic projection model with a gridded air traffic emissions database to generate for future years three-dimensional spatial distributions of aircraft emissions using well recognized and documented reference scenarios, thus allowing a comprehensive assessment of the atmospheric impact of aircraft emissions relative to other sources. An important result is the creation of a comprehensive and consistent set of spatial and temporal emissions data for both aircraft and other sources for both CPB and IPCC scenarios, especially dedicated to spatial developments in aircraft activities, which has been achieved by a unique combination of spatial data from the air traffic database ofWSL, detailed projections by the DTI scenario model, information of the monthly variation of air traffic by Mortlock, and spatial and temporal data from the surface source database of Müller, and integrated by trend calculations of EDGAR. This complements the aggregated comparison of global emissions from aircraft and other sources, such as presented in this report, and provides pivotal information for environmental assessments of the impact of the emissions by atmospheric models.

SAMENVATTING

Een schatting is gemaakt van de huidige mondiale emissies van vliegverkeer met behulp van statistische informatie over brandstofverbruik, vliegtuigtypen en de toepassing van emissiefactoren voor verschillende stoffen. Voor scenario's van toekomstige emissies van vliegverkeer zijn aannames gebruikt over de volume-ontwikkeling van vliegverkeer, de ontwikkeling van het specifiek energieverbruik en voor de emissiefactoren. Tevens zijn enkele varianten opgesteld van scenario's waarin extra emissiereducerende maatregelen verondersteld zijn. In samenwerking met het Britse Department of Trade and Industry (DTI) zijn met het DTI-luchtvaartmodel scenario's voor de volume-ontwikkeling van de mondiale luchtvaart opgesteld waarbij de economische groeicijfers zijn gebruikt van drie door het Centraal Plan Bureau gedefinieerde scenario's genaamd 'European Renaissance' (ER), 'Global Shift' (GS) en 'Balanced Growth' (BG). Samen met veronderstellingen voor de ontwikkeling van specifiek brandstofverbruik en emissiefactoren zijn hiermee mondiale emissiescenario's voor luchtvaart opgesteld voor 2003 en 2015.

De huidige trend van broeikasgasemissies door vliegverkeer vertoont in de periode 1990-2015 een aanzienlijke autonome groei van 140 tot 190% voor NO_x en tussen 180 en 250% voor andere stoffen. De ontwikkeling van de wereldwijde emissies van broeikasgassen door vliegverkeer is tamelijk ongevoelig voor de verschillen tussen de economische scenario's die gebruikt zijn. Ten opzichte van andere energie-gerelateerde emissies is de groei van luchtvaartemissies groter, omdat luchtverkeer naar verwachting sneller zal groeien dan het overige energiegebruik.

Er is ook een schatting gemaakt van het maximale mondiale effect van beleidsmaatregelen gericht op de reductie van luchtvaartemissies. Afhankelijk van de stof zouden de emissies in 2015 aanmerkelijk gereduceerd kunnen worden ten opzichte van de referentiescenario's (gemiddeld zo'n 25%), indien een zwaar pakket van maatregelen volledig geïmplementeerd zou worden (zonder zgn. retrofits bij de bestaande luchtvloot). Het cumulatieve effect van een geïntegreerd (technisch, operationeel en economisch) pakket van reductiemaatregelen kan aanzienlijk zijn, in het bijzonder bij de emissies van NO_x. De resultaten laten zien dat een aanzienlijke beperking - en in sommige gevallen zelfs een reductie in absolute zin - van de autonome groei van de emissies zou kunnen worden bereikt, mits de veronderstelde sterke technologische ontwikkeling inderdaad plaats vindt en deze nieuwe technologie ook volledig wordt toegepast, en wordt gecombineerd met andere, stringente (operationele en economische) beleidsmaatregelen.

De berekende toekomstige mondiale emissies zijn drie-dimensional verdeeld met behulp van de 3D-luchtvaartdatabase van Warren Spring Laboratory (WSL) (nu: AEA, Harwell) en emissiefactoren opgesteld door WSL en het Nationaal Lucht- en Ruimtevaart Laboratorium (NLR). De gegevens van deze database zijn opgenomen in Versie 1 van de Emissions Database for Global Atmospheric Research (EDGAR) van het RIVM, en vervolgens bewerkt tot drie-dimensionale emissieverdelingen voor de jaren 2003 en 2015. Vlieghoogte per vliegtuigtype en tijdverdeling (over maanden) zijn daarbij constant verondersteld. Samen met tijdprofielen, die ontwikkeld zijn door bewerking van

gegevens van McDonnell-Douglas, zijn deze emissiescenario's gebruikt worden voor atmosferisch-chemisch onderzoek.

Door de combinatie van resultaten van een luchtvaart-scenariomodel met een luchtvaart-emissiedatabase op grid zijn voor toekomstige jaren 3-dimensionale ruimtelijke verdelingen van luchtvaartemissies verkregen, die gebaseerd zijn op bekende en goed gedocumenteerde basisscenarios. Dit maakt het mogelijk om een geïntegreerde analyse te maken van de atmosferische effecten van de emissies van luchtverkeer tegen de achtergrond van andere emissiebronnen.. Deze resultaten zijn een 'ruimtelijke aanvulling' van de geaggregeerde vergelijking tussen de totale luchtvaart en wereldwijde grondemissies zoals hierboven beschreven en verschaffen informatie voor analyse van de milieu-effecten van de emissies door atmosferisch-chemische modellen.

1. INTRODUCTION

The objectives of this study were: (1) to estimate and analyse current trends of global and regional emissions of greenhouse gases from air traffic and relate these to other anthropogenic emissions, (2) to show the possible impact of policy measures to reduce aircraft emissions globally, and (3) to estimate the associated three dimensional distribution of emissions from aircraft and from other sources. The latter part was required to provide atmospheric modellers with a consistent set of emissions data related to the scenarios used in this study, thus resulting in a comprehensive and consistent analysis of the present and future environmental impact of air traffic. It also required the availability of gridded inventories of present emissions of air traffic and other sources and scenarios describing trends for source categories, that could be related to the gridded emissions inventories.

Being part of the overall **LULU** project, we used reference scenarios comparable with those used for assessment of future air traffic in the Netherlands, more specific air traffic to and from Schiphol Airport (CPB scenarios applied by the air traffic projection model of the RLD for the Project Mainport and Environment Schiphol [PMMS]).

In the next chapters we present the main results of the study: an analysis of present emissions, both from aircraft and from surface sources (Chapter 2), an outline of the different steps in scenario definition and calculation (Chapter 3), definition of the reference scenarios, including specific assumptions regarding air traffic required by the air traffic projection model and assumptions to convert global or regional emissions scenarios into gridded emissions (Chapter 4), a discussion on some key policy alternatives to show the potential when policies measures were implemented globally (Chapter 5). Next, we discuss the main results, including a comparison of emissions of air traffic and surface sources on a global basis and the effects of individual policy measures (Chapter 6), followed by a discussion of the potential of integrated policy measures on the emissions of CO_2 and NO_x (Chapter 7). Finally, we recall the main conclusions we can draw from this work (Chapter 8). We focused our analysis on global aircraft emissions, but attention was also given to surface sources and we related regional to gridded emissions. More details are provided in the appendices.

The route to arrive at global and gridded emissions scenarios consisted of the following key elements, as will be discussed in Section 3.4:

1. Definition of the reference scenarios
2. Selection of the air traffic projection model
3. Air traffic model runs (regional)
4. Selection of gridded air traffic emissions inventories; data processing and extraction for 1990
5. Calculation of reference emissions scenarios for air traffic, including key policy alternatives
6. Ibidem for surface sources
7. Spatial (3D) emission calculations for reference scenarios for air traffic; data extraction
8. Selection of gridded inventory of surface sources; data processing and extraction for 1990

9. Spatial calculation for reference scenarios of surface sources; data extraction.

To relate air traffic demand projections (by region and by aircraft type) with the spatial emission inventory it was necessary to aggregate both to a common level, in order to match the results of the projection model with the groupings identified in the gridded inventory. The same aggregation step was necessary for the surface sources. As mentioned above, the elaboration and relations to the requirements posed by **'LULU'**, including the practical limitations posed by the time schedule and availability of models and inventories, are discussed in more detail in Chapter 3.

Table 2.2: *Fleet average emission factors (in g/kg) for 1990: WSL, NASA, LULU.*

Compound	WSL (1)	NASA (11)	LULU grid calc.	LULU global calc.	Reference
CO2	-	-	3188 (3)	3188	(4)
CH4	-	-	0.3 (2)	0.3	(5)
N2O	-	-	0.15 (3)	0.15	(6)
SO2	-	-	1(3)	1	(7)
NOx	11.4	10.94	11.4	11.4	(8)
CO	4.3 (9)	8.45	4.3 (1)	4.3	(9)
VOC	-	2.64	-	2.6	(10)

Notes/references: (1) Fleet averaged WSL database (McInnes and Walker, 1992).
(2) Emissions on grid can be derived from the 0-1 km altitude map for fuel consumption.
(3) Emissions on grid can be derived from the altitude maps for fuel consumption.
(4) IPCC, 1994.
(5) Calculated as 10% of the VOC emission factor for the LTO cycle (Olivier, 1991) based on the VOC emission factor of 3 g/kg for 0-1 km of NASA, 1993.
(6) Wiesen et al., 1994.
(7) Olivier, 1991.
(8) WSL database (McInnes and Walker, 1992).
(9) Average factor based on WSL database average of emission factors specified by NLR for the WSL aircraft types/flights modes (Peper, 1994).
(10) Fleet averaged emission factor of NASA, 1993.
(11) Fleet averaged emission factors (NASA, 1993).

For NO_x, until a few years ago no measurement data for emissions during cruise were available (Arnold *et al.*, 1992). The fleet average emission factors for NO_x and carbon monoxide (CO) were calculated using the aircraft/flight mode specific factors in the WSL database. The NO_x factors in the WSL database were calculated for the LTO modes from statistics of the ICAO exhaust emissions database, and for the climb, cruise and descend mode from relationships derived by Rolls Royce (McInnes and Walker, 1992). For CO the factors for the WSL aircraft types and flight modes were estimated by NLR (Peper, 1993b, pers. comm.) (see Appendix D).

Recently, some measurements were reported of aircraft emissions of direct greenhouse gases methane (CH_4) and nitrous oxide (N_2O) (Wiesen *et al.*, 1994). The emissions of CH_4 are negligible in most flight conditions, except for the Landing and Take-Off (LTO) cycle, where according to Olivier (1991) the emission of methane is about 10% of the total VOC emissions. To estimate CH_4 emissions from air traffic we used 1/10 of the fleet average emission factor of 3 g VOC per kg fuel during the LTO cycle, multiplied by the fuel used during the LTO cycles. This was calculated from the fraction of fuel used in the 0-1 km altitude band of the NASA/HSRP aircraft inventory (NASA, 1993) (see Appendix C). The first measurements of N_2O indicated an emission factor of about 0.15 g N_2O/kg fuel. A range of 0.05-0.5 g/kg is used in this study as uncertainty estimate of the fleet average factor.

In this study the emission factor for Volatile Organic Compounds (VOC) is assumed to be equal to the factor for unburned hydrocarbons, in aircraft literature often referred to as C_xH_y. The fleet

2. PRESENT EMISSIONS

First we discuss in this chapter current emissions, global totals and global distributions over regions or links, over the hemispheres and over altitude bands, and the seasonality of air traffic. Furthermore two inventories of WSL and NASA are discussed as well as the activities required to create emissions files for the atmospheric models, based upon the WSL inventory and time profiles which describe the seasonality of air traffic. Subsequently, global estimates of present emissions of surface sources are discussed, both totals and sectoral contributions.

2.1 Present emissions of air traffic

2.1.1 Global total emissions

For the aggregate calculations the following compounds were considered: the direct greenhouse gases CO_2, CH_4 and N_2O, and the indirect greenhouse gases NO_x, SO_2 (also acidifying gases), CO and VOC (also gases contributing to the formation of photochemical smog). In particular NO_x, CH_4 and CO are precursors of tropospheric ozone, which is both a toxic compound and enhances radiative forcing (greenhouse effect). For atmospheric models used in the **'LULU'** programme the most important gases are NO_x, CO and CH_4.

Present emissions by global total air traffic were calculated using global jet fuel consumption data for 1990 from UN statistics (UN, 1992) (Table 2.1) and fleet average emission factors (Table 2.2). The emission factor for nitrogen oxides (NO_x) was taken from the WSL database (WSL, 1993). Emission factors for carbon dioxide (CO_2) and sulphur dioxide (SO_2) do not depend on the aircraft but only on the fuel composition (quality) and were taken from (IPCC, 1995) and (Olivier, 1991), respectively.

Table 2.1: *Fuel combustion in the WSL database: original data and scaled to 1990.*

Code	Region	in WSL-database (kton): region	link	1989 total	scaled WSL (1990 total) (kton)	%	IEA (1990 total) (kton)	%
R1	North America (o)	34,660	4,946	39,606	73,648	47	74,920	44
R2	W. Europe (o)	11,450	4,991	16,441	30,572	20	28,905	17
R3	Far East (o)	12,760	NA	12,760	23,728	15	20,430	12
R4	LDC+ (o)	13,590	NA	13,590	25,271	16	23,950	14
R5	Former CPE (u)	1,639	NA	1,639	3,048	2	22,520	13
Sum	Total	74,099	9,937	84,036	156,267	100	170,725	100

Source: EDGAR, 1994; based on data extracted from WSL database (Walker, 1993).
EDGAR, 1995; based on IEA country statistics (IEA, 1994).

Notes: Flights are allocated according to the region of departure.
Acc. to UN in 1990: 156.2 Mton (UN, 1992)
Scale factor WSL to 1990: 156.2/84 = 1.860
(o) = Overestimated, due to incomplete coverage of air traffic of CIS and scaling to global total fuel consumption.
(u) = Underestimated, due to incompete coverage of regional air traffic.
NA = Not Applicable

Regions:
North America: USA and Canada
W. Europe: OECD Europe
Far East: Asia, including Japan
LDC+: Less Developed Countries (+): Latin America, Africa, Middle East, Oceania + Australia & New Zealar
Former CPE: Former Centrally Planned Europe: Eastern (= non-OECD) Europe and former USSR

average value has been taken from the NASA/HSRP inventory for 1990 (NASA, 1993) (see Appendix C).

Table 2.3 shows the global total emissions as calculated from these emission factors and the total jet fuel consumption in 1990 as specified in the energy statistics of the UN (UN, 1992).

Table 2.3: *Global emissions in 1990 from air traffic and from anthropogenic sources.*

Compound	Unit	Air traffic **	Energy	% aircraft of energy	All anthr. sources	Uncertainty ind.
CO2	Mton	498	22,000	2.26	27,000	10%
CH4	kton	5	91,000	0.01	351,000	30%
N2O	kton	23 (8-78) *	600	4 (1-13)	7,000	50-75%
NOx	kton	1,786	82,000	2.18	112,000	20-50%
SO2	kton	156	130,000	0.12	150,000	10%
CO	kton	679	303,000	0.22	996,000	50%
VOC	kton	406	27,000	1.50	103,000	50%

Source: UN, 1992 (jet fuel consumption); Pepper et al., 1992 (energy and all anthropogenic emissions).
Uncertainty indication of total anthropogenic emissions are based on: Houghton et al., 1992; Ahuja, 1992; own estimates.

Notes: * Aircraft emissions of N2O are very uncertain; range and middle value is indicated here.
** Calculations based on global jet fuel consumption in 1990 of 156.3 Mton and fleet average emission factors of Table 2.1; numbers shown do not indicate the accuracy but re merely the result of the calculation

2.1.2 Spatial distribution of emissions: existing inventories

At the time of the study there were only two inventories available showing the global 3 dimensional distribution of aircraft emissions: the Warren Spring Laboratory (WSL) database for 1989, covering about 50% of total jet fuel consumption and including data on fuel consumption and NO_x (McInnes and Walker, 1992), and the comprehensive NASA inventory for 1990, covering about 85% of jet fuel consumption of civil airlines, general aviation and military aircraft and including fuel consumption, and emissions of NO_x, CO and VOC (Wuebbles *et al.*, 1992). The NASA inventory has been adopted by the *Global Emission Inventory Activity* (GEIA), a core project of the *International Global Atmospheric Chemistry* (IGAC) programme, as first version of an emissions inventory for air traffic in a collection of 1°x1° grid emissions inventories that is being compiled or constructed by GEIA for use by the international modelling community. The NASA inventory is only available as is, together with a number of scenarios designed for the purpose of NASA's *High Speed Research Programme* (HSRP). No regional details nor information on aircraft types is made available, so the applicability of the NASA inventory for the construction of new scenarios is in practice limited to globally uniform scaling of the emissions. Nevertheless, it provided useful information for this study (e.g. for methane and VOC emissions) and could be used to check the global distribution of the WSL inventory. A third detailed and comprehensive inventory was being constructed by the ECAC/ANCAT emissions inventory database group in support of the AERONOX research project of the European Union (ECAC/ANCAT, 1994). Unfortunately, this database was not available within the time schedule of this project.

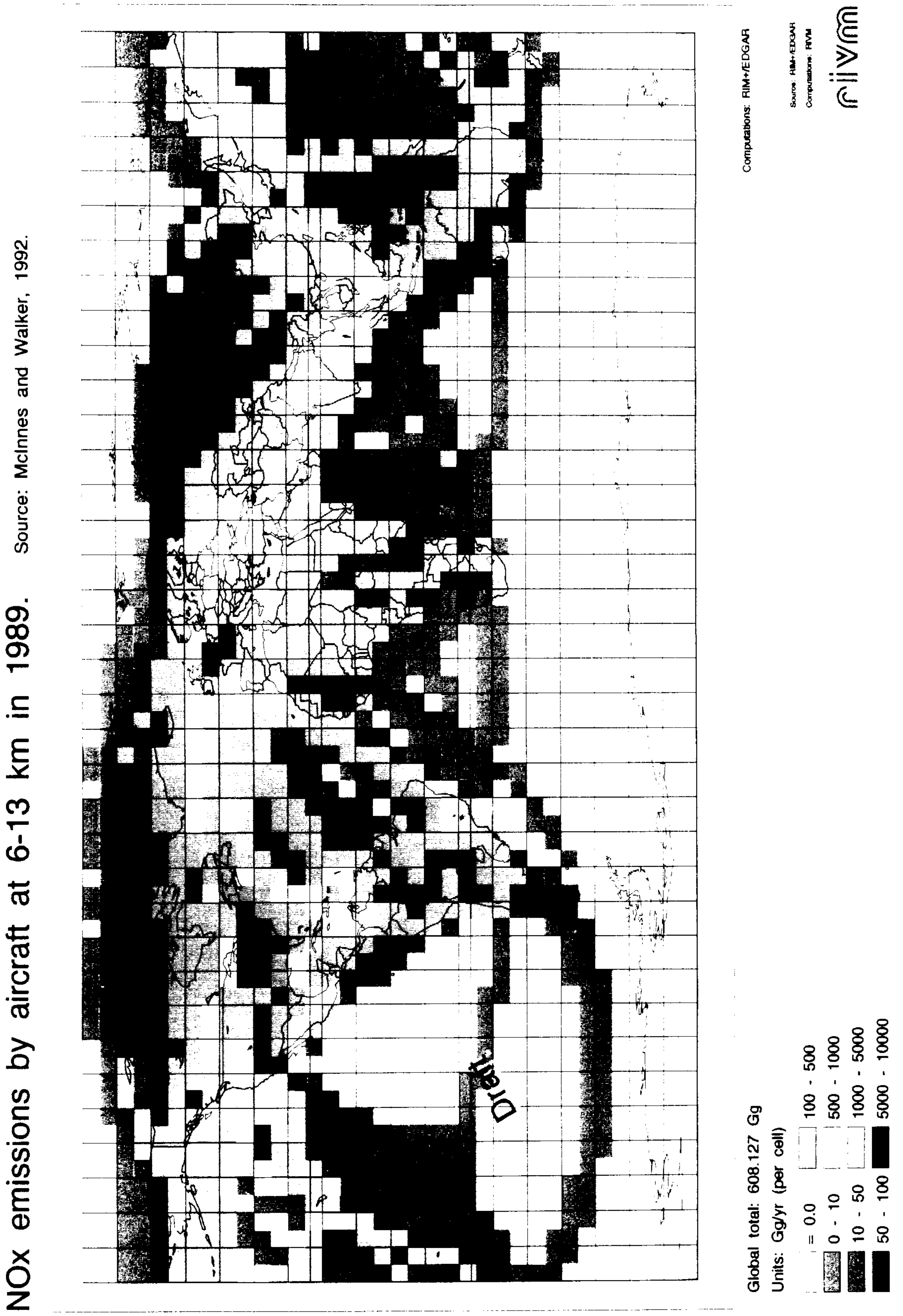
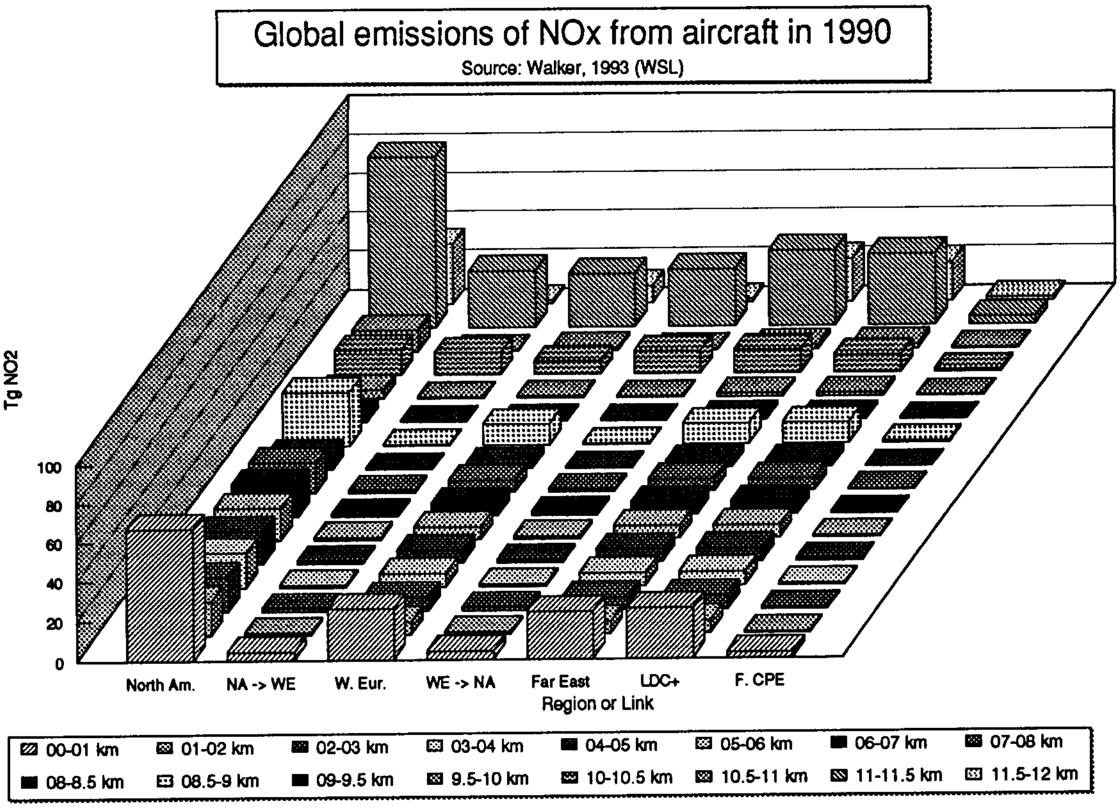


Figure 2.1: *Spatial distribution of* NO_x *emission at 6-13 km in 1989 in the WSL database on a 5°x5° grid.*



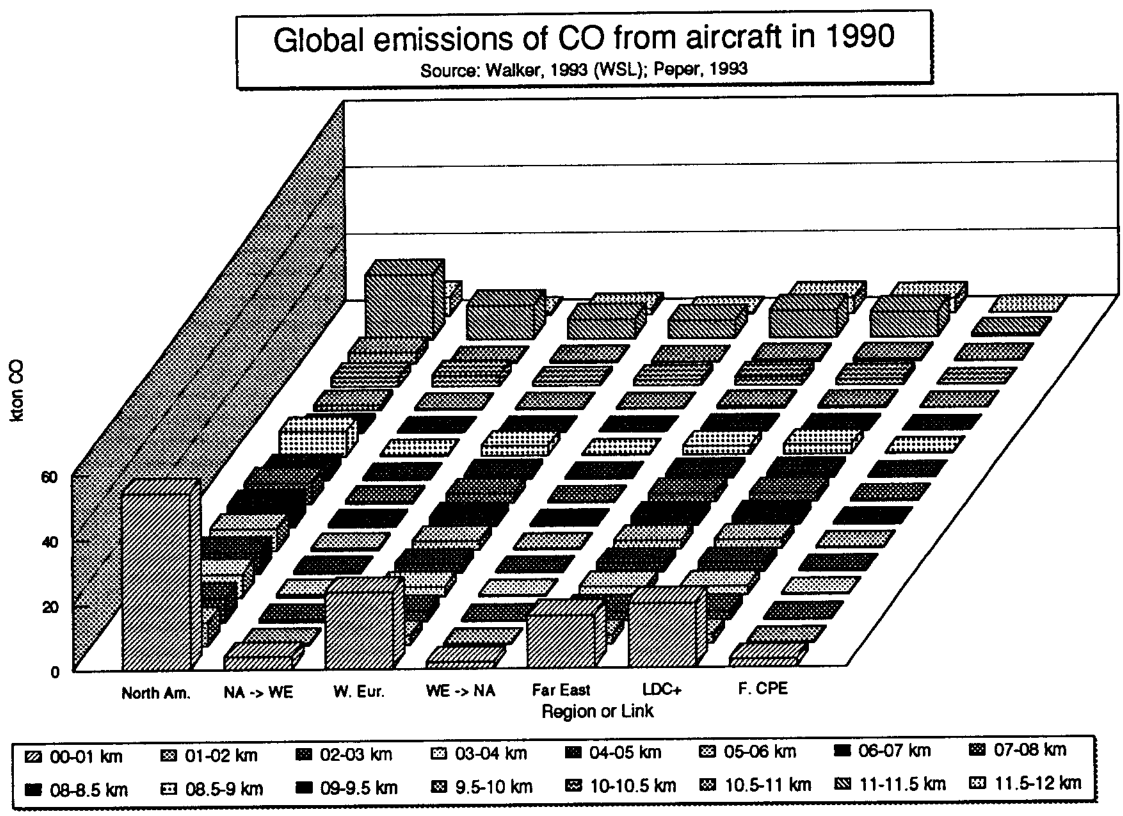


Figure 2.2: *Altitude distribution of NO_x and CO emissions per region/link.*

For scenario applications it was decided to use the WSL database, since it could be made available with regional and aircraft cross sections that allowed us to construct gridded aircraft emission scenarios using differentiated growth rates by region and by aircraft/range types, thereby simulating structural changes in the 3D flight distribution caused by this differentiation. Although it has not such an extensive coverage of global air traffic as the NASA/HSRP or the ECAC/ANCAT database, the WSL database is based on ABC time table data of scheduled flight statistics for a representative week in September 1989 and scaled up to one year. It does not include military aviation, non-scheduled flights, charter and general aviation (also not included in the original scaling up). Also, most of the domestic flights in the former USSR and of China are not included in the database. Charter flights occur predominantly in Western Europe and in North America. The overall coverage is about 50% in terms of fuel consumption; the other 50% being the sum of underestimated civil transport (in particular in the former USSR and in China), of military air traffic and of charter traffic (in particular in Western Europe). The ANCAT database has 1992 as its base year. As shown in Table M.3 of Appendix M, the differences in base years of the three inventories can not explain the differences in their estimate of global total fuel consumption by air traffic (and thus of emissions). However, comparison of the regional fuel consumption in the WSL database with IEA data in Table 2.1 - although both are defined somewhat differently - reveals that in particular the former USSR is heavily undervalued in the WSL inventory. This table also shows that global total estimates of jet fuel consumption in 1990 by UN and IEA differ about 9%, indicating the apparent difficulty in estimating this figure, in particular in an area in which military activities play a substantial role. As mentioned in Section 2.1.1, NO_x emissions are provided with the WSL database; CO emissions were added using differentiated emission factors from NLR (see Appendix D).

Within these limitations we can draw some conclusions from the cross sections made of the WSL database. Table 2.1 indicates that at present air traffic is dominated by North America, in particular the USA. Furthermore, it shows that traffic in the North Trans-Atlantic flight corridor between North America and Europe (column marked 'link') is of the same magnitude as traffic starting from other regions: Western Europe, the Far East (predominantly Japan), and the Less Developed Countries plus Australia and New Zealand. In Figure 2.1 the global distribution of NO_x emissions in the WSL database is presented in the 5^ox5^o LULU grid. Figure 2.2 clearly shows that NO_x is emitted mainly during cruise (at about 11 km altitude) and during the LTO cycle (below 1 km). Also note the dominant position of North America and the occurrence of cruise levels of minor importance at about 9 and 10 km. The distribution of NO_x emissions closely follows the distribution of fuel consumption shown in Figure 2.3. In contrast, CO are emitted mostly below 1 km, because of the rather high degree of incomplete combustion during the LTO cycle, notably in the idle and taxi modes.

2.1.3 Comparison of WSL and NASA inventories

When we compare the WSL emissions map on 5^ox5^o of Figure 2.1 with the NASA map of fuel

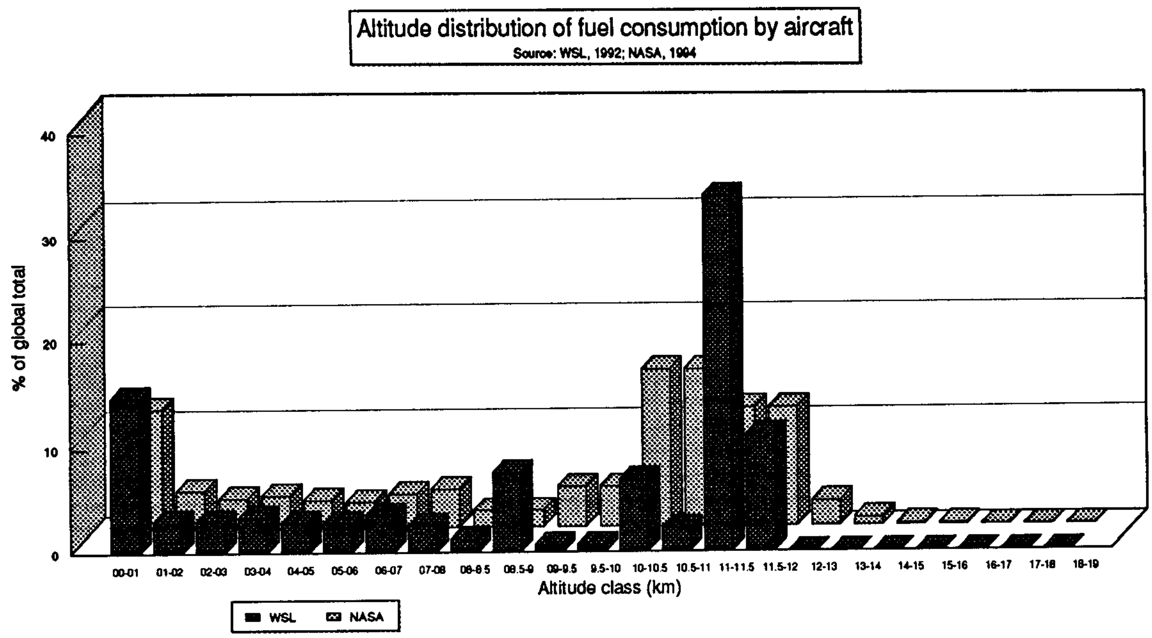


Figure 2.3: *Altitude distribution of fuel consumption according to the WSL and NASA air traffic database.*

use on a 1°x1° grid (Figure 2.4) the resemblance of the general horizontal pattern and of the most intensively flown areas is quite good. If we compare the altitude distribution of the two inventories, they also look rather similar (Figure 2.3). This confirms the choice of using the WSL data for gridded scenario construction. The main difference is that NASA inventory assumes a different mix of cruise levels and is dispersed to higher altitudes, because of the inclusion of flight profiles for some military aircraft, flying at altitudes between 13 and 16 km, and for the concorde, which cruises at an altitude between 16 and 19 km, whereas the majority of civil aircraft cruise at levels between 10 and 12 km. A comparison of the LTO emission/fuel consumption maps (see Figures 2.5 and 2.6) - i.e. near airports up to 1 km altitude - shows that air traffic in the former USSR and, to a lesser extent, China is not fully represented in the WSL database. In Appendix C the NASA/HSRP inventory of aircraft activities is summarized by a number of overview tables, showing the averages, totals and altitude distributions of fuel consumption, emissions and emission factors. In Figure 2.7 the distribution of fuel consumption over the two hemispheres is shown. About 94% of all aircraft emissions occur in the Northern Hemisphere, which is a consequence of the very high share in global air traffic of OECD countries, most of them being located at the Northern Hemisphere. In this inventory military aircraft contribute to about 19% of global fuel consumption but to about 13% of NO_x emissions by aircraft. Military aircraft appear to have fleet average emission factors for NO_x which are 30% below the global average, but factors for CO and VOC which are more than double the world average; also their flight levels are more dispersed to higher altitudes: LTO and cruise bands include the zones between 1 and 2 km and between 13 and 16 km, respectively (NASA/HSRP inventory of military air traffic as provided by Sage (1994, pers. comm.).

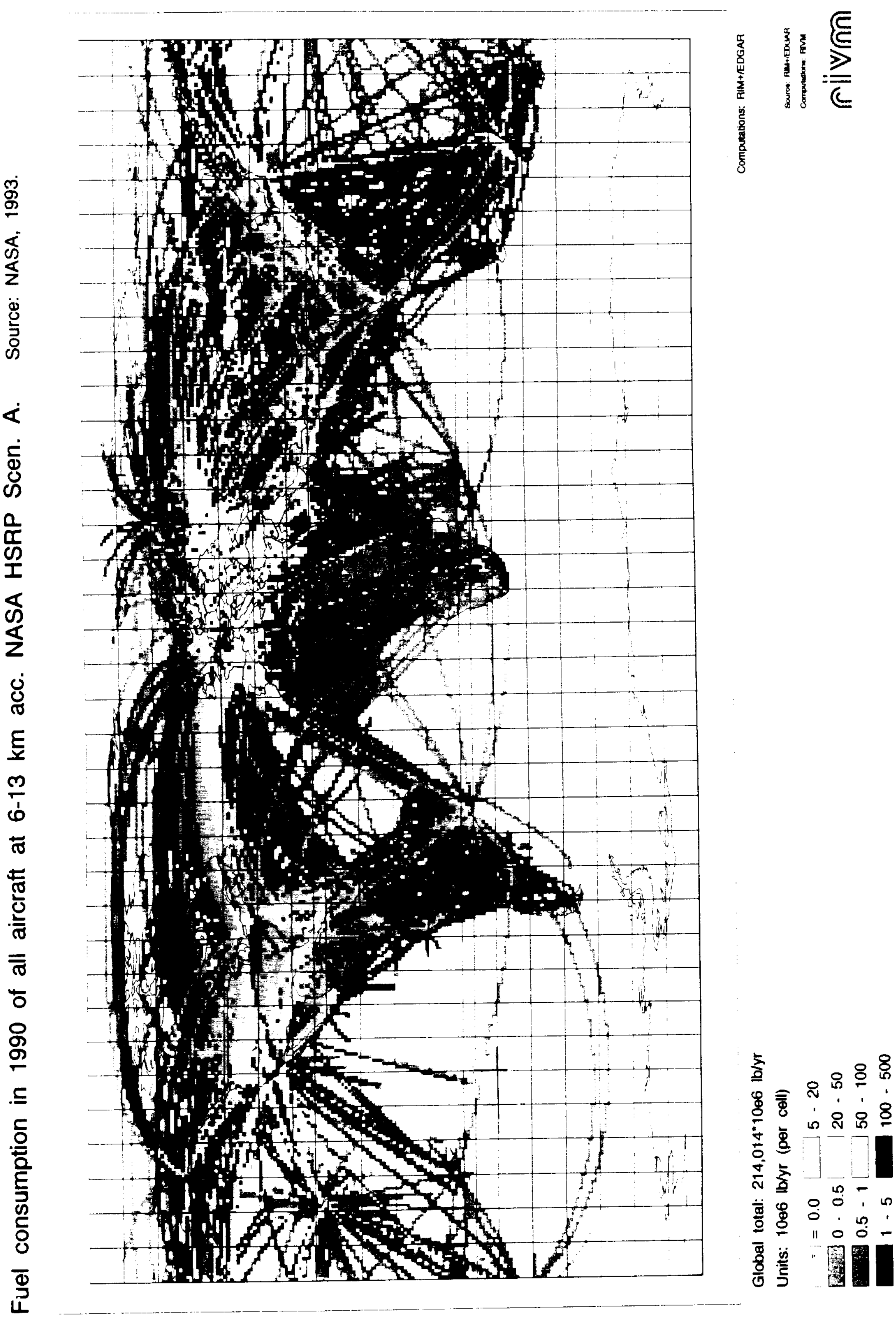


Figure 2.4: *Spatial distribution of fuel consumption in the NASA database on 1°x1° grid (1990).*

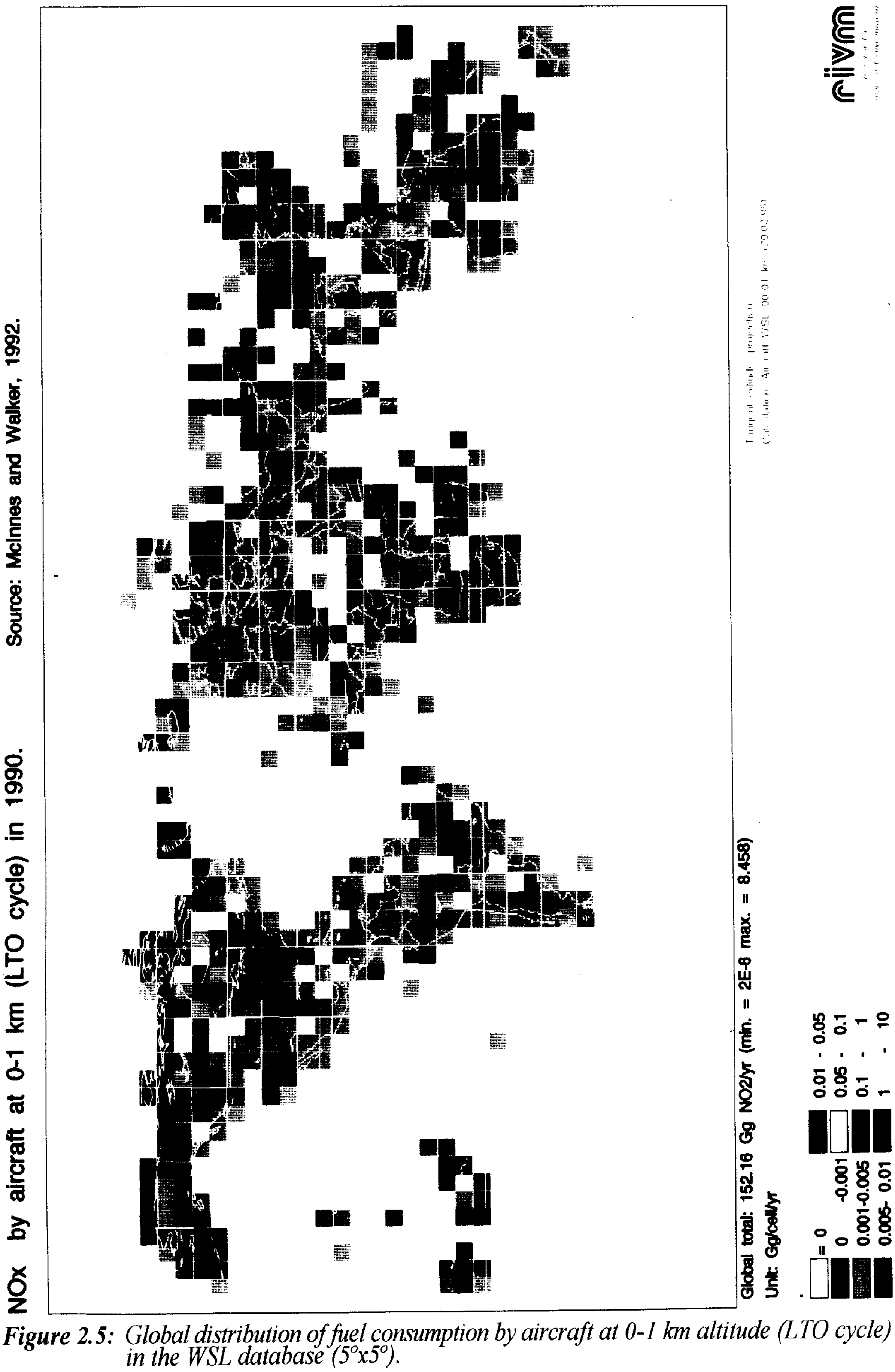


Figure 2.5: *Global distribution of fuel consumption by aircraft at 0-1 km altitude (LTO cycle) in the WSL database (5°x5°).*

Fuel consumption by aircraft at 0-1 km (LTO cycle) acc. NASA HSRP Scen. A. Source: NASA, 1993.

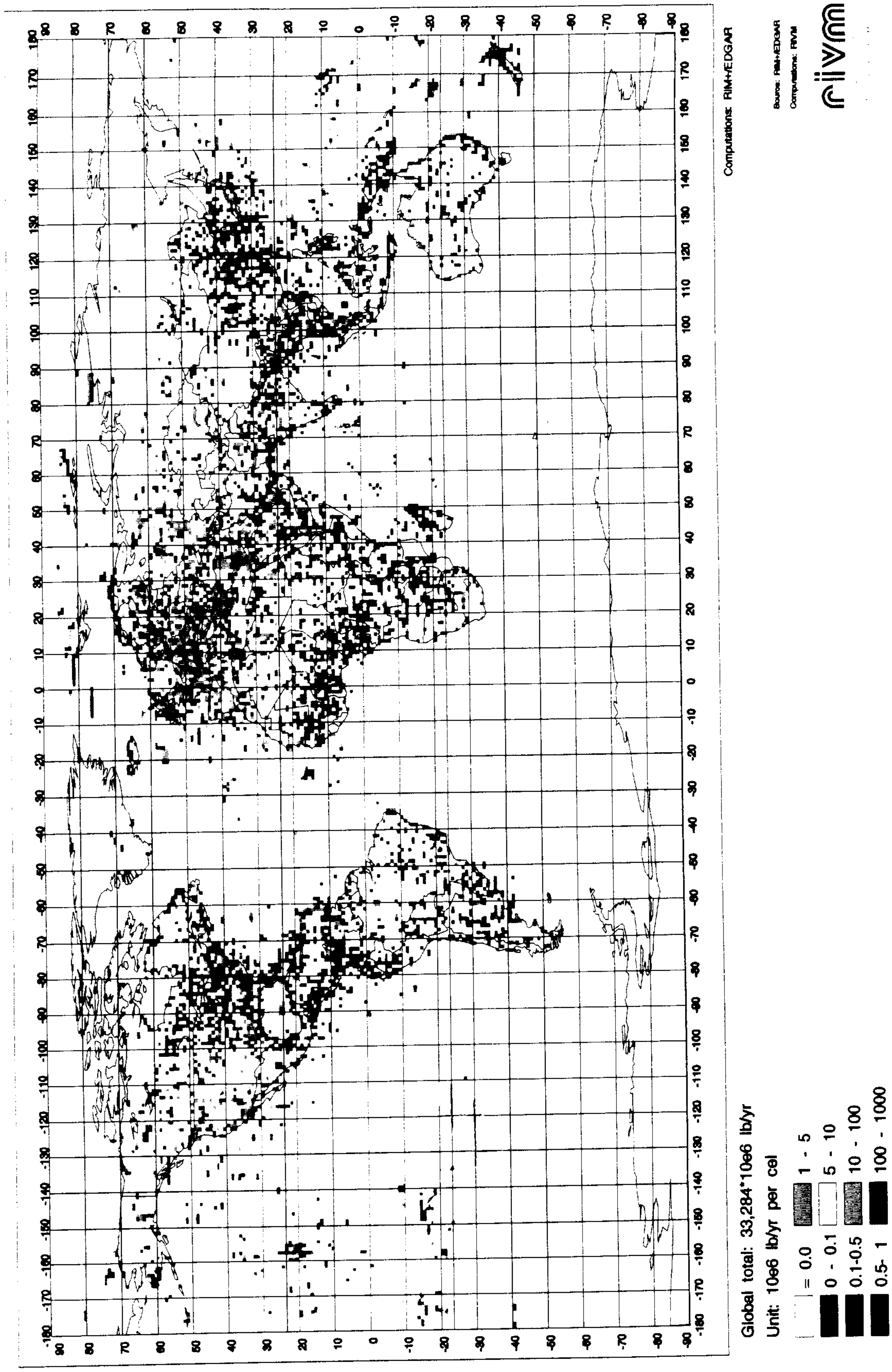


Figure 2.6: *Global distribution of fuel consumption by aircraft at 0-1 km altitude (LTO cycle) in the NASA database (1°x1°).*

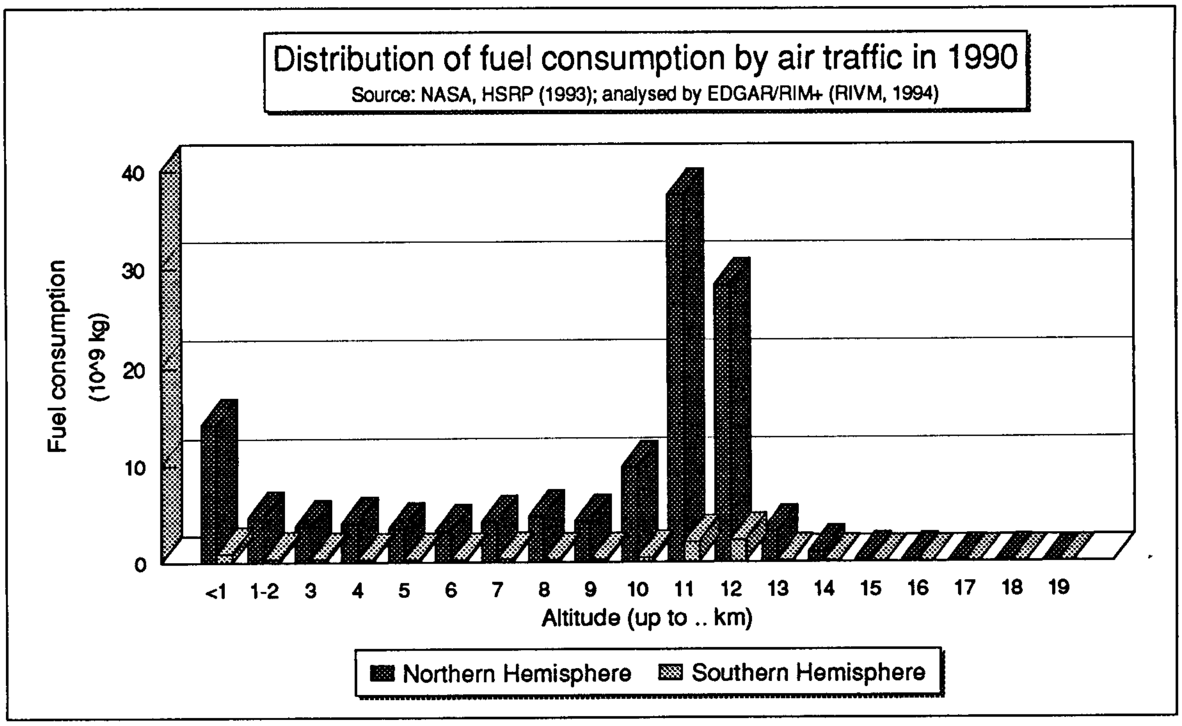
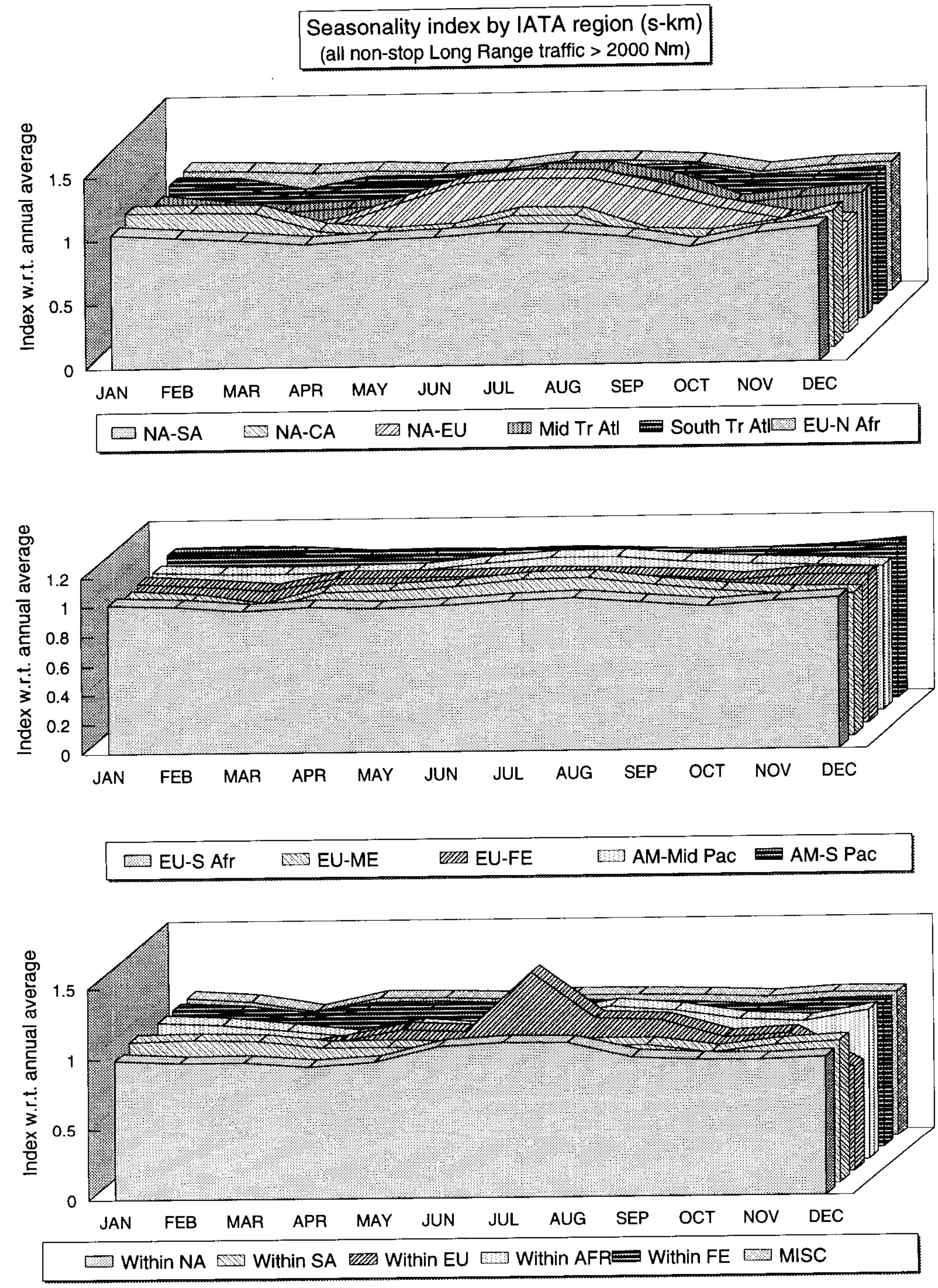


Figure 2.7: *Altitude distribution of fuel consumption of air traffic per hemisphere in 1990.*

2.1.4 Temporal distribution of emissions

Finally, we estimated the temporal distribution of air traffic. Both WSL and NASA inventories only show annual total distributions, whereas atmospheric models need emissions data on a monthly basis. The importance of this dimension is easily recognized when we recall, that the altitude of the tropopause, which separates the troposphere from the stratosphere, varies not only according to the latitude but also according to the season (Olivier, 1991). Mortlock of McDonnell-Douglas kindly provided us with the results of his analysis for the HSRP of seasonality of air traffic, which was done for all non-stop long range passenger traffic greater than 2000 miles in 19 IATA regions/links, and was based on monthly Official Airline Guide (OAG) traffic data from 1976 through 1991 (Mortlock, 1994, pers. comm.). Details for the 19 IATA regions can be found in Appendix G.

From his analysis it was concluded that the strongest seasonal effects, with monthly deviations from the average of more than 20%, are found for North Trans Atlantic flights and for flights within Europe (see Figure 2.8). The former shows a strong but smoothly seasonal variation, whereas in Europe there is a high peak in July (presumably holiday traffic) and a deep dip in December (presumably much less business travel). Based on these results we have split global air traffic in three seasonality sections, with time profiles as shown in Figure 2.9: the links North America-Western



N.B. Scheduled OAG passenger air traffic data from 1976 through 1991.

Source: Mortlock, 1994.

Note:

NA = North America
CA = Central America
SA = South America
AM = Americas

EU = Europe, incl. former USSR (West of Urals)
ME = Middle East
FE = Far East, incl. former USSR (East of Urals)
MISC = Miscellaneous

Figure 2.8: *Seasonal variation of civil air traffic by IATA region/flow (seat-km, based on OAG passenger air traffic data from 1976 through 1991).*

Europe and *vice versa*, short and medium range flights within Western Europe, both with a distinct seasonality, and the rest of the world, for which a uniform distribution was assumed.

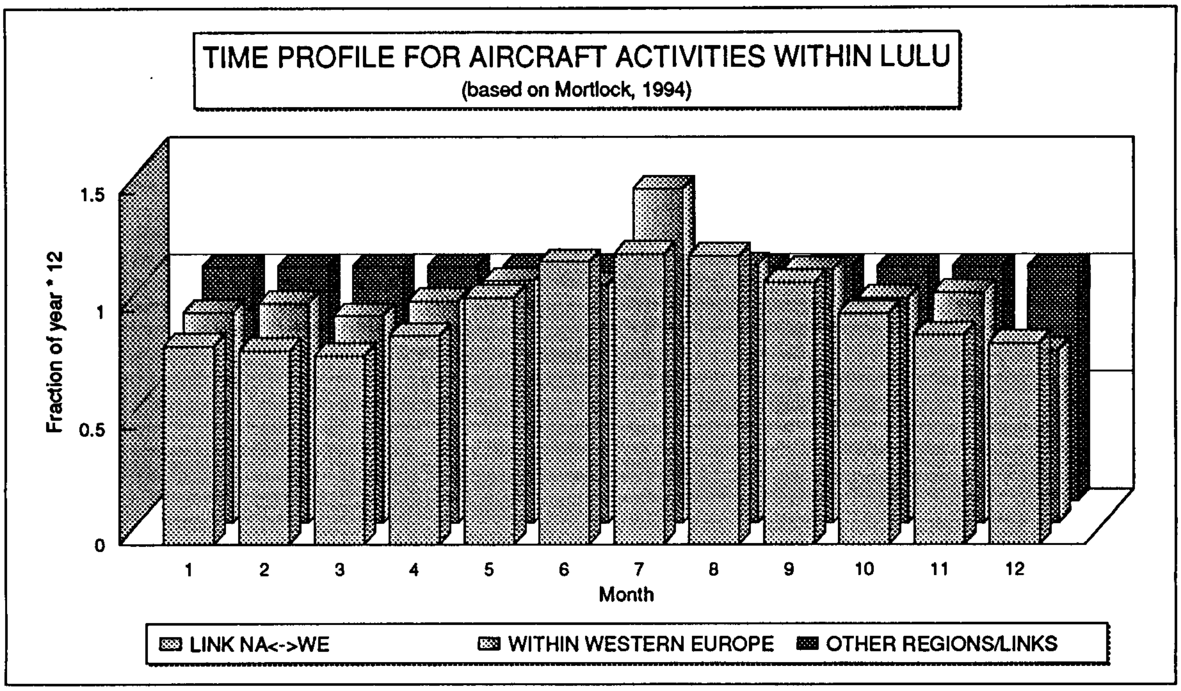


Figure 2.9: *Time profile for aircraft activities within LULU (based on Mortlock, 1994).*

2.1.5 <u>Data preparation for atmospheric models</u>

The atmospheric models of LLO and KNMI require emissions of NO_x, CH_4 and CO on a monthly basis to evaluate the impact of aircraft emission on tropospheric ozone (Beck *et al.*, 1992). To this end the WSL base year emissions data for NO_x and of CO were calculated and included in Version 1 of RIVM's global emission database EDGAR (Emission database for Global Atmospheric Research) (Olivier *et al.*, 1994b). The NO_x and CO emissions were exported from the EDGAR database for the three different seasonality sections discussed above. For methane no aircraft emissions files were prepared, since only aircraft activities below 1 km emit this compound (see Section 2.1.2), and this contribution is negligible compared to other surface sources. Information on the monthly variation of air traffic provided by Mortlock completed the air traffic data required by atmospheric models of KNMI and LLO.

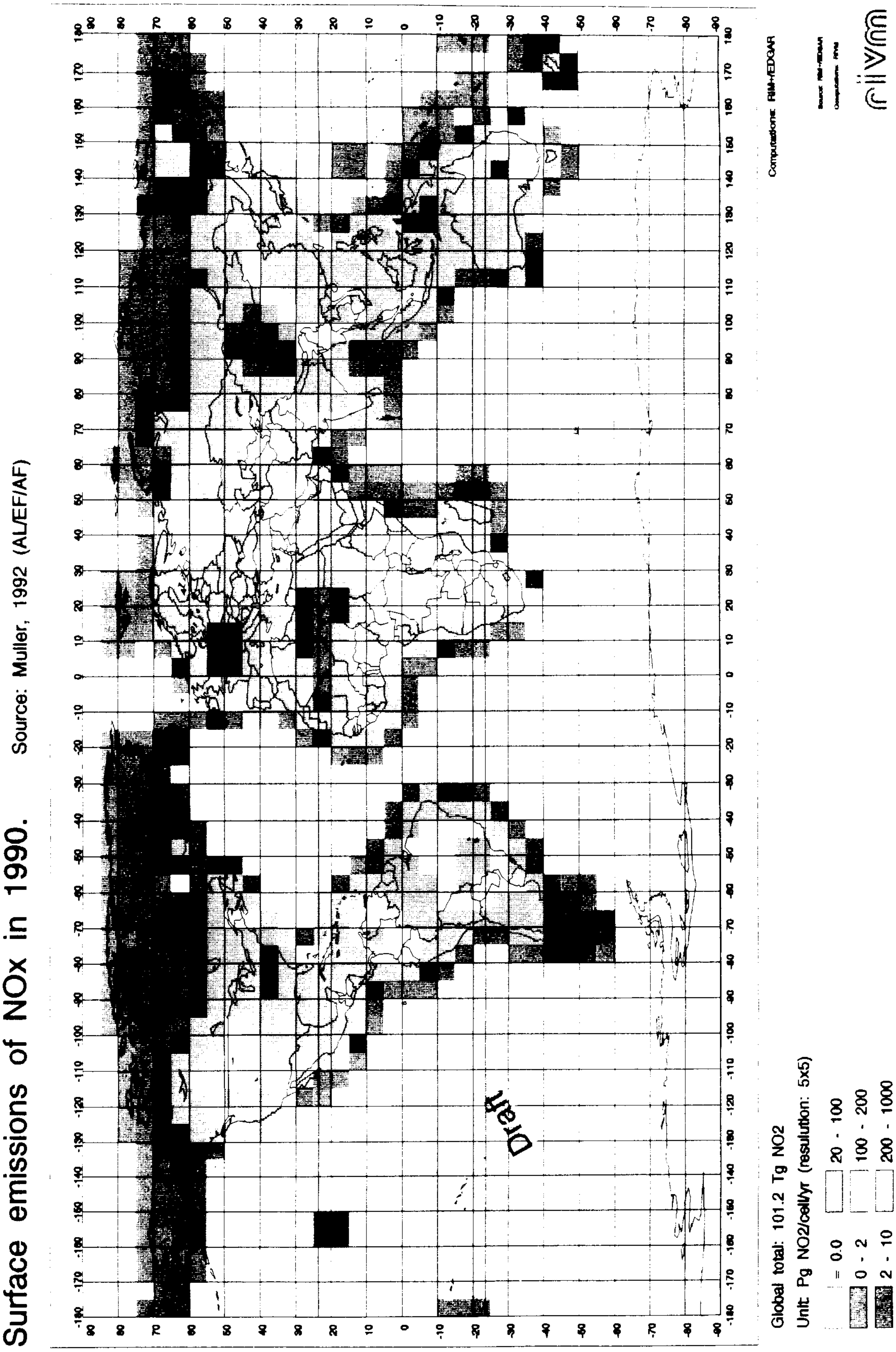


Figure 2.10: *Spatial distribution of NO_x emissions from surface sources in the Müller database on 5°x5° grid (1990).*

2.2 Surface source emissions

2.2.1 Global total emissions

To compare present as well as future emissions from air traffic with other anthropogenic emissions - e.g. energy-related emissions - we need emissions from surface sources as well.. Because the uncertainty is quite high in some cases, we decided to use the consensus view of the IPCC estimate of current emissions as presented in Table 2.3 (Pepper *et al.*, 1992). This table also shows an indication of the uncertainty in the estimate of global anthropogenic emissions based on Houghton *et al.* (1992), Ahuja (1992) and own estimates. More details on the contribution from individual sources can be found in Table 4.6.

Global aircraft emissions expressed as fraction of energy-related emissions appear to play a limited role (~2%) (CO_2, NO_x, and VOC, possibly N_2O) or are almost negligible (~0.1%) (CH_4, SO_2, CO). From this comparison, however, one may *not* conclude that aircraft emissions only play a minor role in the environmental impact of these emissions, since the *effect* of their discharge at higher altitudes - in contrast with all other sources - may be quite different compared to emissions at ground level (WMO, 1994).

2.2.2 Spatial distribution of emissions: Müller inventory

To generate the spatial and temporal distribution of the background emissions, the inventory of NO_x, CO and CH_4 emissions constructed and provided Müller was selected, as the more advanced EDGAR database was not yet available for this study (Müller, 1992). This gridded inventory of the surface sources has been used for LULU calculations on grid, as it was the only inventory of this type available and since it has the required spatial and temporal resolution. Two aspects should be mentioned in using this inventory for generating background emissions for this study: (1) the original 5°x5° grid had to be moved to the requested grid definition by LLO, and (2) the calculated annual sectoral and global total emissions are somewhat different from the IPCC 'best estimate' figures for 1990 used in the IPCC emission scenarios. The latter data are used in this study for comparison of global total aircraft emissions and energy related emissions. The spatial distribution of NO_x emissions for surface sources is shown in Figure 2.10.

2.2.3 Comparison of global emissions estimates of IPCC and Müller

Comparison between the two global total figures of the source strength for 1990 shows that the Müller data differ at most plus and minus 30% from the IPCC 'best estimate', but are within the uncertainty ranges estimated by IPCC (see Table 2.4). Regarding specific source strengths used by atmospheric modellers, the Müller figures are also within the uncertainty range of IPCC, except

Table 2.4: *Comparison of global emissions of NO_x, CO and CH_4 in 1990 per category as estimated by Müller and by IPCC.*

Compound	Category	Muller	IPCC total	Difference	IPCC'92 Sup	IPCC (Pepper et al., 1992)			Ref.
		Tg NO2		(%)	(range)	Tg NOx-N			
NOx	Anthropog.	72	82	-12	82	25			
	Bio Bur (*)	15	30	-49	10-43	9			
	Soil	22	39	-44	16-66	12			
	TOTAL:	**109**	**151**	**-28**	**108-191**	**46**			
		Tg CO			Tg CO	Tg CO-C			
CO	Anthropog.	383	303	26	400-1000	130			
	Biogenic	784	693	13	400-1400	297			
	Soil	166	131	27	50-200	43	13		(1)
	Sea	162	40	308	20-80	17			
	TOTAL:	**1495**	**1167**	**28**	**870-2680**	**500**			
		Tg CH4			Tg CH4	Tg CH4			
CH4	Anthropog.	131	154	-15	90-190	91	38	25	(2)
	Bio	100	183	-45	126-380	28	155		(3)
	Cattle	80	110	-27	85-130	84	26		(4)
	Rice	90	60	50	20-150	60			
	TOTAL:	**401**	**507**	**-21**	**320-850**	**507**			

Sources: Pepper et al., 1992; Houghton et al., 1992; Muller, 1992.
Muller data received by FTP and analyzed with EDGAR.

Notes:
(*) Biogenic and Biomass burning
(1) Emissions of plants and wildfires, respectively.
(2) Emissions of energy, landfills, and domestic sewage, respectively.
(3) Emissions of biomass burning and natural sources, respectively.
(4) Emissions of enteric fermentation (ruminants) and animal wastes, resp

for carbon monoxide from oceans:

* NO_x: the Müller data are at the lower end of the uncertainty range (differ about 30% from the IPCC best estimate). The anthropogenic NO_x emissions are 12% below the IPCC estimate, but this is within the expected uncertainty of this category. Biomass burning and soil emissions appear to be at the lower end of the range;

* CH_4: the Müller data are well within the uncertainty range (differ about 20% below the IPCC best estimate). Biological sources appear to be quite low;

* CO: the Müller data are well within the uncertainty range (differ about 30% above the IPCC best estimate). However, emissions from oceans appear to be very high compared to the uncertainty range.

The result of using these 'spatially shifted' emissions inventories is, that the emissions pattern is a somewhat dispersed to neighbouring grid cells, and the assessment of the impact of air traffic emissions by LLO and KNMI is using a somewhat different total source strength for the *background* sources than used in this report for the comparison of global total aircraft emissions and energy related emissions. However, these effects can be neglected (i) in comparison with the uncertainty in total aircraft emissions and in the spatial distribution, and (ii) as the Müller inventory is not of primary interest for this study, which are the emissions at altitude, but serves to provide a background for atmospheric models. Thus, it can be concluded that this data set was a good choice for the needs of this study.

3. METHODOLOGY FOR SCENARIO CONSTRUCTION

3.1 Objective

The aim of this study was to assess and to compare *global emissions* from aircraft and from other anthropogenic sources, both for *present* emissions and for possible *future* emission levels. Furthermore, the second aim was to generate also an estimate of the related *spatial and temporal distribution* of emissions, to allow for consistent assessment of environmental impacts by atmospheric models. To this end we needed for air traffic and other sources: (a) emissions estimates for the present; (b) either readily available emissions scenarios or a projection model capable of running chosen reference and policy scenarios; and (c) gridded emission inventories. In addition, because of the exploratory character of the study, the selected policy alternatives should cover a broad scope of options available on the global level.

To consistently compare global emissions scenarios for aircraft and for surface sources, common assumptions with respect to economic growth etc. are required for the reference scenarios and for the policy alternatives. To achieve this goal also for atmospheric model studies, the source categories used in the datasets of both the global emission aggregates and of the spatial and temporal distributed emission inventories must be related to each other. Figure 3.1 shows the role of emission scenarios within the context of other LULU studies.

3.2 Aspects to be considered

Several issues had to be defined before we could start to construct emission scenario: definition of areas, time horizon, level of detail of air traffic, emission compounds (in relation to the environmental themes for emission and effect evaluation), other source categories to relate air traffic emissions to, the type and the sets of policy measures (to be combined in a policy alternative), and the number of policy alternatives. Appendix A lists the options on these points. Also the number of scenarios, for air traffic as well as for surface sources, and the type of policy measures have been considered. Surface sources are required for the atmospheric models to create the proper 'background' of global 3D emissions.

Policy options which are specific at the global (i.e. international) level are *e.g.* emissions standards for aircraft in general or for specific aircraft or routes, or operational measures such as changes in cruise altitudes/cruise speed or of flight routes. Specific national measures, such as towing aircraft instead of taxiing, are in general not relevant for global emission calculations; therefore, they were not taken into consideration for this study.

In dealing with both an air traffic projection model for estimating future air traffic at the regional level and an aircraft movement database for generating gridded emissions, the coupling of regions and aircraft/range types used in these two separate models needs sufficient attention. However,

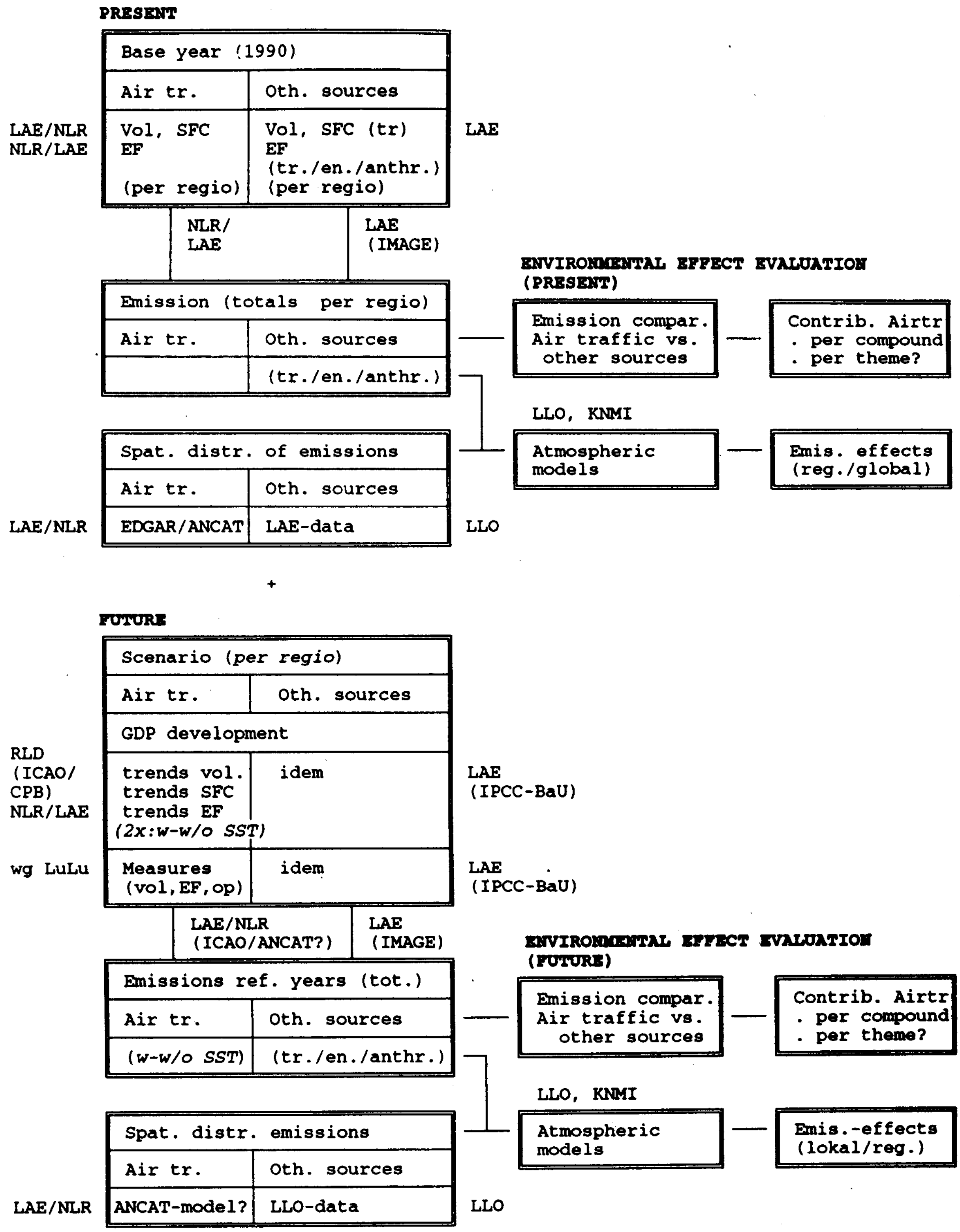


Figure 3.1: *Organization of environmental effect calculations for LULU.*

also the capabilities and timely availability of both regional projection model and gridded air traffic database pose restrictions to the type and level of detail of scenario calculations which can be done on a consistent basis.

3.3 Requirements within 'LULU'

The general approach of the study was discussed regularly during meetings of the Advisory Group **'LULU'** and with representatives of the Dutch Ministries of Environment and of Transportation. In particular the types of policy options that should be taken into account have been discussed intensively.

As the results of this study will be compared with or used by other studies carried out for **'LULU'**, in particular the air traffic scenarios for Schiphol Airport and atmospheric model studies of RIVM-LLO and of KNMI, the reference scenarios should preferably be consistent with the scenarios used to assess future *Dutch* air traffic emissions within the framework of the Project Mainport and Environment Schiphol (PMMS). This means selection of scenarios developed by the Central Planning Bureau (CPB), as well as the projection years used for these evaluations, i.e. 2003 and 2015.

Furthermore, the gridded 3D emissions data for atmospheric model calculations should comply with the aggregated (policy) scenarios used, and must be in a proper format to be used by RIVM-LLO and KNMI as input to their atmospheric models.

3.4 Outline of the approach

To generate the information needed, the following steps were distinguished (see also Figure 3.1):

1. Definition of reference scenarios

To fulfill the requirements within the **'LULU'** programme, the construction of air traffic (and surface source) scenarios based upon the three CPB scenarios used for national studies of air traffic. Since we also would need to construct gridded emissions inventories for future years, it was decided to use for this LULU analysis only a few aggregated regions and aircraft types/regions, a few reference years, and to focus on specific emission compounds (see Appendices G and H). Key assumptions of these scenarios (e.g. on GNP) were identified and used as an input for the scenario calculations (Chapter 4).

2. Selection of air traffic scenario model

For this study we could use either the air traffic model developed by the Dutch Directorate-General of Civil Aviation (RLD) or the projection model of the British Department of Trade and Industry (DTI). The RLD scenario model is not applicable for global air traffic scenario studies as it has been designed to project traffic to and from Schiphol only (no global coverage). The DTI model, though not fully covering global air traffic, could basically perform the required scenario calculations. Also, its model regions are comparable with the ones used in the CPB scenarios and its aircraft types/flight ranges could be related to the ones used in the WSL air traffic database, that was available and selected to generate spatial distributions of aircraft emissions. The DTI was willing to co-operate and to perform a number of scenario runs using our specifications, and also showed an interest in this study as the model was at the time also considered to be likely used to construct emission scenarios for the ANCAT group, to be applied in the AERONOX project of the European Union (see Section 2.1.2). This would also have the advantage of using an air traffic projection model that is widely used by the European modelling community (Chapter 4.3 and 4.4).

3. Air traffic model runs at regional level; input definition and aggregation of results
The DTI model was used to simulate three CPB reference scenarios by specifying economic growth rates per region from 1990 to 2015, with additional input assumptions regarding ticket prices and load factors by DTI and own estimates. The results - supplemented with own estimates for one LULU region not covered by the model - were converted to indexed growth rates for global air traffic (Passenger-kilometres) and for the LULU regions and LULU aircraft types, to be used in global aggregate analysis and to construct the gridded aircraft emissions inventory for future years, respectively.

4. Selection of gridded air traffic emissions inventory; data processing and extraction for 1990
Since the ECAC/ANCAT emissions inventory was not available in time we had to rely on another database: the WSL air traffic database, the first database of its kind. Although it has not such an extensive coverage of global air traffic as the ECAC/ANCAT or the NASA/HSRP database, it was made available with regional and aircraft cross sections that allowed us to construct gridded aircraft emission scenarios. The WSL base year emissions data for NO_x and - with support of NLR - of CO, calculated and aggregated to LULU regions/aircraft and to the 5°x5°x0.5 km LULU grid, were extracted from the database and included as Version 1 of EDGAR. Information on the monthly variation of air traffic provided by Mortlock completed the air traffic data required by atmospheric models of KNMI and LLO. Global total aircraft emissions for various compounds were calculated using global jet fuel consumption data for 1990 and aggregated emission factors from the WSL database and from other sources (see Chapter 2.1 and Appendix D).

5. Emission calculation for reference scenarios of air traffic on a global scale; policy alternatives
The results of the DTI model, the regional demand for seat-km per aircraft size band, together with assumptions on the autonomous development of parameters such as the load factor (occupancy rate), specific fuel consumption (fuel per passenger-km) and emission factors, were used to calculate the future emissions in the three reference scenarios. Per compound (except for nitrous oxide) the effect on emissions of one technical policy measure was added to illustrate the maximum impact of additional policy on aircraft emissions (Chapters 5 and 6). Subsequently, the cumulative effect

of additional policies - including technical, operational and economic measures - was calculated for the gases CO_2 and NO_x, which according to recent assessments of the Intergovernmental Panel on Climate Change (IPCC) appear to be of most importance for the contribution of air traffic emissions to the enhanced greenhouse effect (both gases) and to the formation of tropospheric ozone (NO_x) (Chapter 7).

6. Emission calculations for reference scenarios of other sources on a global scale
Next, present and future emissions from air traffic were compared with other anthropogenic emissions, that is: energy related emissions. As the uncertainty in some cases is quite high, we decided to use the consensus view of the IPCC estimate of current emissions. To compare future aircraft emissions with other (surface) sources, we had to estimate future surface emissions related to the three CPB scenarios. To this end, we compared the economic growth assumptions of each of the three CPB scenarios with the six IPCC '*IS92*' scenarios and selected per CPB scenario the IPCC scenario which had the most similarity with the regional economic development as defined for the CPB scenarios. This approach was taken because the IPCC emissions scenarios are internationally well recognized and are well documented. Also, the *IS92* scenarios cover a range of consistent sets of assumptions on how the world and the emissions may develop in time. The alternative of constructing new consistent emission scenarios would mean only using the precise economic growth rates of the CPB scenarios, while introducing many additional assumptions, which would be both highly time consuming and to some extent also arbitrary (Chapter 4.5).

7. Spatial (3D) emission calculations for reference scenarios of air traffic; data extraction
Using the EDGAR functionality, 3D distributions of emissions of NO_x and CO (and 3D fuel consumption) were calculated for the years 2003 and 2015 for three scenarios using different growth rates per region/aircraft type and a globally uniform development of emission factors and of specific fuel consumption. Subsequently, the results were extracted from the database and supplied to RIVM-LLO and KNMI, together with temporal information (monthly variation) (Chapter 6.1). Methane emissions of aircraft were not calculated, as they are negligible at cruising altitude and very small near airports (LTO cycles) compared to other surface sources of methane. Thus, by combining data from the air traffic database of WSL, supplemented with CO emissions by NLR, the results of the DTI model and the trend calculations of EDGAR we were able to create unique scenario results of aircraft emissions on a grid. Although a preliminary version of the ANCAT database is now (1995) available for NO_x emissions, the WSL data were also applied in the AERONOX project, thereby allowing comparison of LULU results with other atmospheric models.

8. Selection of gridded inventory of surface sources; data processing and extraction for 1990
We could use the database constructed by Müller with current emissions of anthropogenic and biogenic emissions on 5°x5°, including the monthly variation. The data provided by Müller were first converted to the appropriate 5°x5° LULU grid and then included as Version 1 of EDGAR (Chapter 2.2).

9. Spatial calculation for reference scenarios of surface sources; data extraction

Assumptions on the development of surface source emissions were also required to construct a set of present and future emissions data of surface sources for the atmospheric models. Another argument in step 6 for selecting IPCC scenarios to 'simulate' CPB scenarios for surface sources is that they also provide a consistent set of emissions for all other non-energy sources. From the emissions of IPCC source categories we derived indices for the development of emissions according to the sources distinguished in the Müller database. Using the EDGAR functionality, emissions for NO_x, CH_4 and CO were calculated for the years 2003 and 2015 for different scenarios using different, though globally uniform, growth rates per Müller category. Subsequently, as was done for aircraft emissions, the results were extracted from the database and supplied to RIVM-LLO and KNMI (Chapter 4.6).

An important result of this exercise is the creation of a comprehensive and consistent set of spatial and temporal emissions data for both aircraft and other sources for both CPB and IPCC scenarios, especially dedicated to spatial developments in aircraft activities, which has been achieved by a unique combination of spatial data from the air traffic database of WSL, detailed projections by the DTI scenario model, information of the monthly variation of air traffic by Mortlock, and spatial and temporal data from the surface source database of Müller, and integrated by trend calculations of EDGAR. This complements the aggregated comparison of global emissions from aircraft and other sources, such as presented in this report, and provides pivotal information for environmental assessments of the impact of the emissions by atmospheric models.

4. DEFINITION OF REFERENCE SCENARIOS

To define the reference scenarios for emissions of air traffic and of surface sources, different levels of detail can be used. For the global assessments within the framework of LULU, we recall that it was decided (1) that compliance with basic assumptions of the scenarios developed by the Dutch Central Planning Bureau (CPB) was desirable, since these are well described and well known in the Netherlands, and were also used to evaluate the development of local activities at Schiphol Airport, and (2) that the emphasis in the spatial scenario construction would be on the development of determinants of the 3D distribution of aircraft emissions, because of the *a priori* unknown sensitivity of atmospheric models of the spatial (3D) distribution of the air traffic emissions. Other aspects which were discussed regarding the required scope of the emissions scenarios are summarized in Appendix A.

4.1 CPB scenarios

4.1.1 Assumptions

As the development of GNP per world region is a key variable for both general economic scenarios, such as the CPB scenarios, as well as for the development of air traffic, we used the regional development of GNP of the three CPB scenarios "*European Renaissance*" (ER), "*Global Shift*" (GS) and "*Balanced Growth*" (BG) as one of the key assumptions to define the emission scenarios. These three scenarios are most commonly used of the four scenarios, which the CPB developed for the period 1990-2015 within their global study "Scanning the future" (CPB, 1992) [The fourth one, called *Global Crisis*, is seldomly referred to.] These scenarios distinguish 11 world regions, each with distinct economic growth rates per scenario (see Table 4.1). Details on the definition of the world regions can be found in Appendix G. For the LULU scenario calculations we only used the economic assumptions on GNP as used by CPB for these scenarios. The three sets of GNP growth rates do not differ so much in the world average growth figure, but they are quite dynamically defined per region for consecutive 5 year periods, resulting in three quite different scenarios as is illustrated in Figure 4.1.

4.1.2 General description of scenarios ER, GS and BG

The scenarios developed by the CPB are based on information from economic theories, a comparative-strength analysis of the various world regions, and on long term trends, which was combined to give a number of different possible future development. Although for this study we do not use other features of the scenarios than the assumptions on regional development, we will

Table 4.1: *GNP development per region in CPB scenarios ER, GS and BG (index; 1990= 1).*

Region	1990	2015: ER	GS	BG
North America	1.00	1.51	2.31	2.12
W. Europe	1.00	1.98	1.59	2.20
Japan	1.00	2.49	2.84	2.14
E. Europe	1.00	2.02	1.53	2.34
Former USSR	1.00	1.65	0.88	1.78
SE Asia (DAE)	1.00	4.46	5.75	5.43
China	1.00	3.55	4.83	4.55
Middle East	1.00	2.36	2.42	2.20
RoAsia (India+)	1.00	3.22	4.83	4.29
Africa	1.00	2.68	2.04	3.27
Latin America	1.00	1.99	2.83	3.90
World	1.00	2.06	2.30	2.44
World (avg. % p.a.)	–	*3.3*	*3.9*	*4.1*

Source: CPB, 1992.

describe them briefly so that the reader has some knowledge of what is included in the original CPB scenarios (as described in CPB, 1992):

* In *"Global Shift" (GS)* there is a quite rapid economic growth, much confidence in the working of the market and consequently a modest role for government. Little attention is paid to environmental questions or to energy savings, except for economic reasons. This means a rather rapid increase in energy demand. With little fear for an ever-increasing number of regulations and with a general faith in technological progress, nuclear power gets a new chance in this scenario, while coal is relatively favoured by its low production costs.
* *"European Renaissance" (ER)* is a scenario with a somewhat lower economic growth at global level. More emphasis is put on cooperation and coordination, at least in Europe, in this scenario the region with a rather good performance, as the name already indicates. This means in that part of the world (including Eastern Europe and the former Soviet Union) for instance more attention for energy savings. At global level the results in this field are much less marked, due to the poor record in America. As far as the fuel mix is concerned, natural gas gets a boost especially thanks to the successful development of the Russian gas resources.
* *"Balanced Growth" (BG)* explores under which conditions sustainable growth would be possible. On the one hand rapid economic growth is fostered by dynamic technical progress and by the removal of all kind of rigidifies in the functioning of the economy. On the other hand there is enough willingness to cooperate in the international field and to find solutions for global problems such as the greenhouse problem. A worldwide CO_2 tax is introduced, research and development in the field of energy saving is promoted as well as the transfer of the use of renewable energy sources is achieved. Notwithstanding a rapid economic growth, demand for energy increases less than in any other scenario while energy-related CO_2 emissions are nearly stabilized.

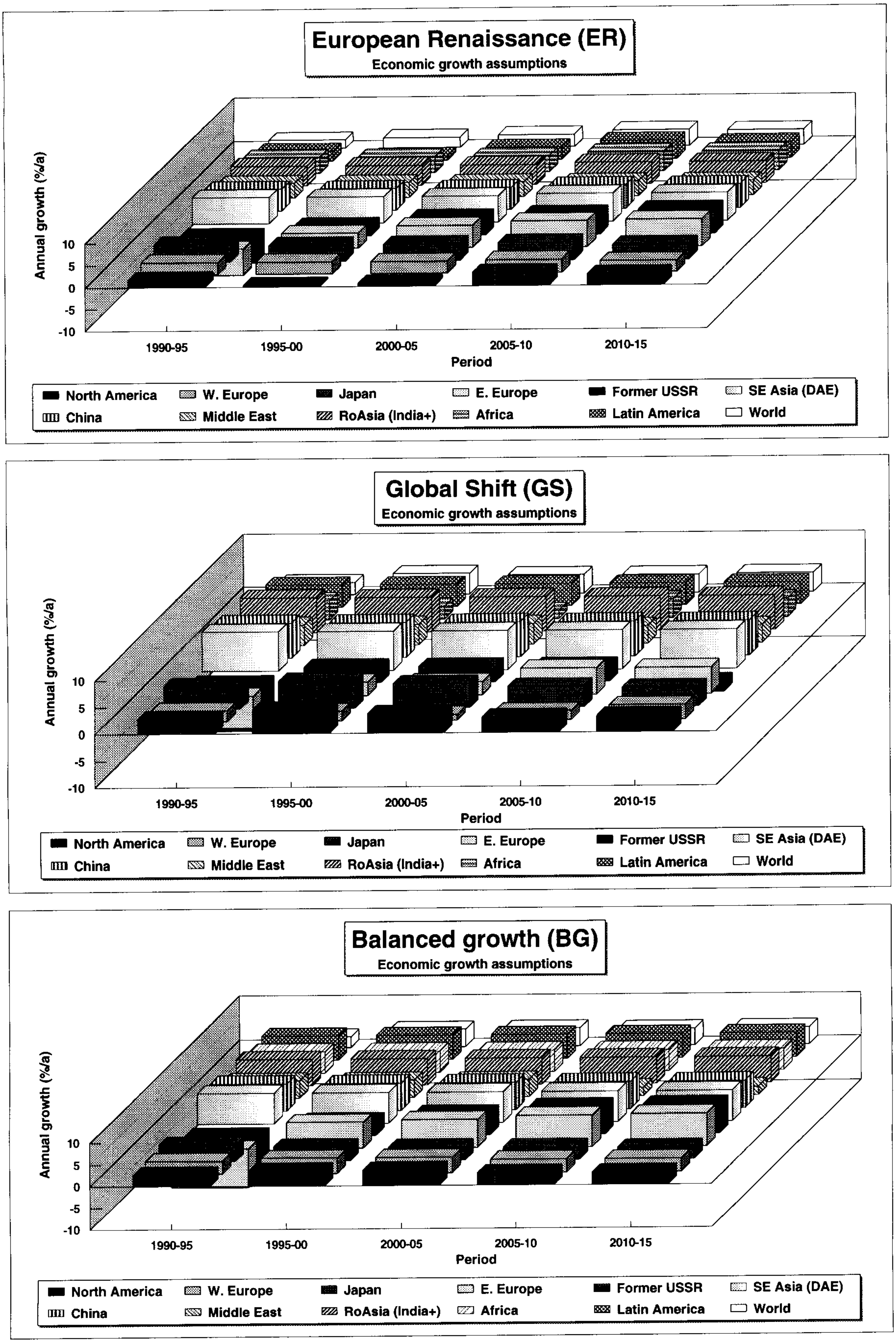


Figure 4.1: *Regional economic growth assumptions in CPB scenarios ER, GS and BG.*

In the Boxes 1, 2 and 3 in Appendix E the key characteristics are shown regarding the leading economic policy, regional developments, and of various trends. Summarizing these, the three scenarios can be characterized as follows (cited from CPB, 1992):

"Global Shift" (GS) and *"European Renaissance" (ER)* explore divergent developments with respect to the two most powerful economic blocs in the world: Western Europe and North America. The message is that both blocs are vulnerable, albeit on different grounds, and that their economic performance will have profound radiating effects on other regions, especially those located nearby.

"Balanced Growth" (BG) is the most optimistic scenario. It shows an annual growth rate of the world economy of more than 3 per cent, which is ecologically sustainable and embraces all the major regions of the world, is still a quite realistic possibility. The scenario will not easily be realized, as it demands formidable changes at the regional and at global levels.

This illustrates the wealth of other assumptions which were used to define the scenarios, of which we used only one determinant in our scenario analysis: regional economic growth.

4.2 Additional assumptions for air traffic scenarios

In addition to regional GNP growth rates, other assumptions are required to define an air traffic scenario. Analysis has shown that besides regional GNP, growth rates of air fares (ticket prices) and the load factor (fraction on seats occupied) are other key determinants of the development of the volume of air traffic. On could define various scenarios for ticket prices, based on the characteristics of the three scenarios (see e.g. Appendix F). However, due to time constraints for all three reference scenarios only one set of assumptions for development of ticket prices has been used, which was based on assumptions of DTI. In some cases these scenarios are therefore referred to as ER0, GS0 and BG0, as to recall that no scenario specific air fare assumptions were made. These and other assumptions on the autonomous development of load factors and of variables determining the emissions of air traffic, such as the specific fuel consumption (SFC) and emission factors (EF), are presented in Table 4.2. They are either defined by DTI (load factor) or based on figures reported in literature (Greene, 1992; Peper, 1993c).

4.3 Air traffic model selection

Several models can be used to generate aircraft emission scenarios: one group of models is aims at projecting the volume of air traffic, a second group aims at projecting aircraft emissions and a third group of models covers several source categories, including air traffic to some extent.

Appendix B gives an overview of the models identified at the start of the study. As it turns out, most specific air traffic projection models do not fully cover global air traffic: some exclude

Table 4.2: *Common assumptions about ticket prices, autonomous development of the fleet average Specific Fuel Consumption (SFC), Emission Factors (EF), and Load Factors (LF) for air traffic scenarios ER, BG and GS.*

ASSUMPTIONS FOR TICKET PRICES (in%/a)

DTI region	1990-1995	1995-2015	Reference
Europe	-1.500	-0.125	Newton, 1993
Others	-0.750	-0.125	Newton, 1993

ASSUMPTIONS FOR AUTONOMOUS DEVELOPMENT OF SFC, EMISSION FACTORS AND LOAD FACTOR

Variable	Total change in 2015 w.r.t. 1990 (50% penetration assumed *)	Reference
SFC	-12.5%	Peper, 1993a
EF-NOx	-17.5%	Peper, 1993a
EF-other	0%	Peper, 1993a
Load Factor	+4% points (+6%) (see below)	Newton, 1993

* Thus, for average new aircraft in 2015 the change with respect to the 1990 fleet average is twice the value mentioned here. In 2003 13/25 x 50% = 26% penetration was assumed. Put another way: changes in 2003 are assumed to be about half of the figures mentioned here for 2015.

Autonomous development of Load Factors (LF/LF90) common to the 3 scenarios (index: 1990=1).

LULU region	1990	1995	2000	2003	2005	2010	2015
North America	1.00	1.01	1.02	1.03	1.04	1.05	1.06
Europe	1.00	1.01	1.02	1.03	1.04	1.05	1.06
Far East	1.00	1.01	1.02	1.03	1.04	1.05	1.06
LDC+	1.00	1.01	1.02	1.03	1.04	1.05	1.06
Former CPE (Ea	1.00	1.01	1.02	1.03	1.04	1.05	1.06

Note:
* In 2003 13/25 x 50% = 26% penetration was assumed. Put another way: changes in 2003 are assumed to be about half of the figures mentioned here for 2015.

types of aircraft (e.g. military or charter), others do not cover all regions (e.g. not the former USSR or China), while the group of more general models only project the aggregate volume of regional air traffic without any further details such as distributions over short and long haul flights, larger and smaller aircraft, older and newer aircraft etc. It should be mentioned here, that projection models are always designed for specific purposes. Therefore, unavoidably, to model air traffic some characteristics were simplified or not taken into account at all. Examples are the impact of the development of hub and spoke structures within countries or regions on the volume of air traffic, the load factors, shares of short range and long range flights, or limitations on the growth of the number of flight movements at major airports on the development of the mix of smaller and larger aircraft, or the impact of development of high speed rail systems on regional air traffic. These aspects can only be simulated in dedicated models.

Criteria for model selection were: (i) availability, (ii) completeness of aircraft types and regions, (iii) similar level of detail in comparison with the spatial air traffic database of WSL, (iv) compliance of definitions of aircraft types and of regions with the WSL database, (v) use of economic scenario parameters such as regional GNP and ticket prices.

To fulfill the requirements within the '**LULU**' programme, we needed to construct air traffic (and surface source) scenarios based upon the three CPB scenarios used for national studies of air traffic.

For this study we could use either the RLD's air traffic model or the projection model of the British DTI. However, since the RLD's model used for scenario calculations is not suitable for global air traffic scenario studies as it has been designed for traffic to and from Schiphol only, it was concluded that the DTI model, though not covering Eastern Europe and the former USSR, could basically perform the required scenario calculations. Also, its model regions are comparable with the ones used in the CPB scenarios and its aircraft types/flight ranges can be related to the ones used in the WSL air traffic database, that was selected to generate spatially distributions of aircraft emissions. Since we also would need to construct gridded emissions inventories for future years, it was decided to use for this LULU analysis only a few aggregated regions and aircraft types/regions, which could be rather easily be connected with regions/aircraft types of the WSL inventory. In Appendix H details are given on how this was accomplished.

4.4 DTI civil aircraft market projection model

The civil aircraft market forecast model of the British Department of Trade and Industry (DTI) uses a *top down* approach - i.e. it projects the overall demand for air traffic per region/link (in Seat Kilometres Offered - SKO) as well as the distribution of aircraft per seat-size band and per range, rather than assessing the future requirements of individual airlines (*bottom-up* approach). A link is defined as all air traffic starting in one specific region and ending in another region (e.g. all traffic from North America to Western Europe). Figure 4.2 gives an overview of the inputs of the model. Key inputs are:

* GNP assumptions per region
* Assumptions on air fares (ticket prices and yield (earnings per SKO)
* Maturity: assumptions on how the market will react to changes costs.

Other inputs are based on historical fleet performance (see Figure 4.2).

In the runs simulating the three CPB scenarios, we used assumptions on GNP, load factor and ticket prices as specified in Table 4.1 and 4.2; all other assumptions were defined by DTI. The GNP growth rates for the 11 DTI regions were defined by relating the CPB regions to the regions distinguished by the DTI model (see Appendix G). Most regions are defined the same; only in the case of Rest of Asia (Indian sub-continent), Middle East and Africa there is no perfect match. In those cases we simply coupled these regions one to one and assumed the GNP index of the DTI region to be equal to the index of the related CPB region.

Taking these inputs DTI used their projection model to calculate the number of Seat-km Offered (S-km or SKO), by DTI region and by DTI aircraft type. By incorporating assumptions

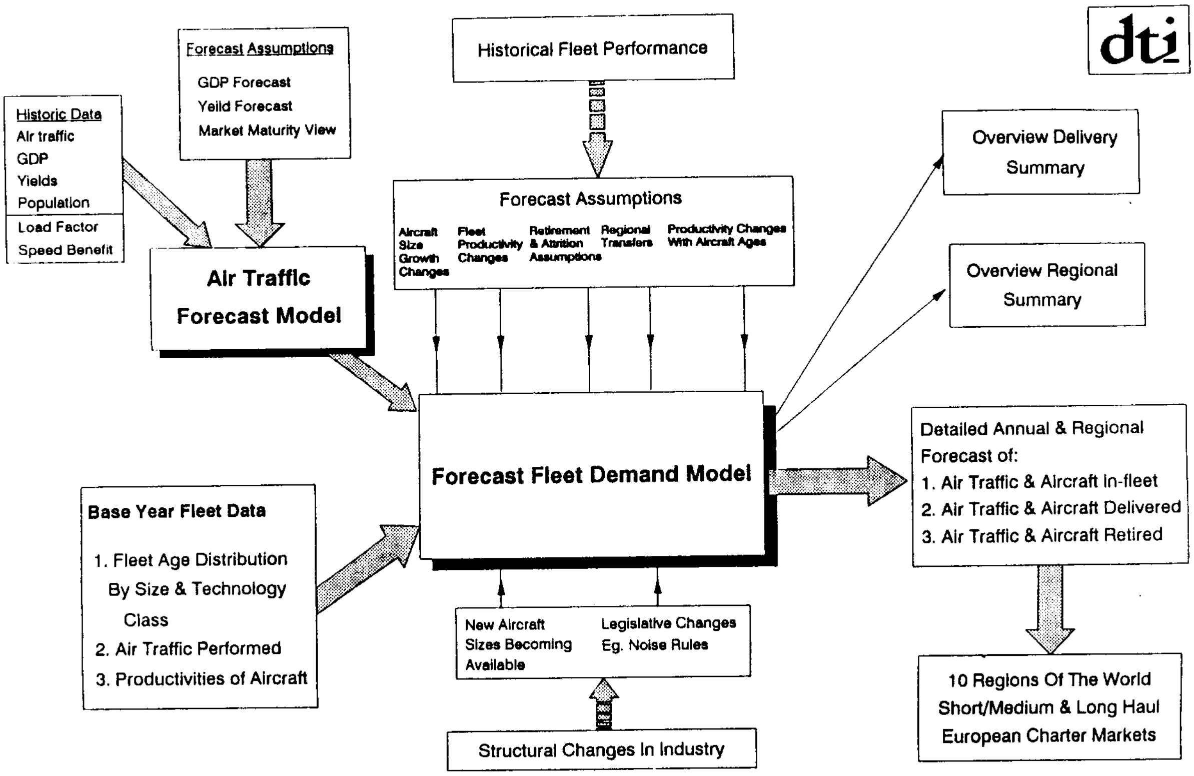


***Figure 4.2:** Outline of structure and data flows of civil aircraft market forecast model of DTI.*

about load factors we arrive at the indexed development of Passenger-km (P-km) per region. Next, DTI results were aggregated to LULU regions and LULU aircraft types (Tables 4.3 and 4.4), in order to facilitate the construction of gridded emissions using the spatial WSL aircraft database. In Figure 6.1 aggregated results of the indexed development of P-km for the three reference scenarios are presented. In Appendix I the index numbers are specified in a table and more details are provided on the output for the ER scenario and on the aggregation of the output to LULU regions/links and aircraft types.

The model did not (yet) include Eastern Europe and the Former USSR; for a complete the air traffic scenario, for these regions the development was estimated by comparison with other regions with a similar development of GNP (see Appendix I).

It is stressed that the model results are a function of the economic relations included in the model, here notably GNP, ticket prices and 'yields' as drivers for the volume development. The model does not take into account subtle effects such as possible substitution by High Speed Rail transport or development of airlines an explicit hub and spoke system, which affects both load factors and the ratio between short range and long range flights. Also possible saturation effects of upper limits technically or politically posed on the number flight movements of the major airports of the world are not explicitly taken into account.

The related emissions scenarios are based on the projection results in terms of total P-km per region/link and calculated using the additional assumptions on SFC and emission factors. This is described in more detail in Section 4.5.1. For the spatial 3D distribution of emissions the more detailed results of the projection model were used, specifying the development per aircraft type/distance range. The DTI model specifies demand in 10 seat bands, here indicated as A to J, and 2 distance ranges, indicated SH and LH. For this study the DTI aircraft/range definitions were coupled with the types distinguished in the WSL air traffic database by aggregation to 6 LULU types/ranges (see Appendix H).

Table 4.3: *Definition of LULU regions.*

	LULU Region/Link	ABC/WSL-DTI Entity
R1	North America 1)	USA + Canada
R2	(Western) Europe 1)	Europe
R3	Far East	Japan + South East Asia + China + Indian sub-continent
R4	LDC+ 2)	Central/Latin America + Africa + Middle East + Oceania
R5	Former CPE 3)	Eastern Europe + Former USSR
L1	North Am. -> W. Europe	USA + Canada -> (Western) Europe
L2	W. Europe -> North Am.	(Western) Europe -> USA + Canada

Notes:
1) Excluding the link North America to (Western) Europe and vice versa.
2) LDC = Less Developed Countries
3) CPE = Centrally Planned Europe

Table 4.4: *Definition of LULU aircraft types and ranges.*

LULU type/range	WSL type	WSL range	DTI type	DTI range
T1-AL	type 1+2	all ranges (= 1+2+3+4)	A+B	all ranges
T2-SH; T2-LH	type 3+4	range 1+2+3; range 4	C+D+1/2E+1/2F	SH; LH
T3-SH; T3-LH	type 5+6	range 1+2+3; range 4	G+H+I+J+1/2E+1/2F	SH;LH
T4-AL	type 7+8+9+10	all ranges (= '0')	N.A.	N.A.

Notes:
SH = Short Haul; LH = Long Haul; AL = All ranges. (see Appendix H for definition of WSL types/ranges and DTI ranges)
N.A. = Not Applicable.

4.5 Derivation of surface source emissions scenarios

To compare future aircraft emissions with other (i.e. surface) sources, we need to estimate future surface emissions related to the three CPB scenarios. However, the CPB scenarios are economic scenarios, which do not provide estimates of future emissions (except for CO_2). The 1992 Supplement Report of the Intergovernmental Panel on Climate Change (IPCC) on the other hand provides a port-folio of emission scenarios (IS92a-f) for seven greenhouse gases (and for CFCs) based on a variety of assumptions regarding the different source categories (Houghton *et al.*, 1992;

Pepper *et al.*, 1992). It is not simple and straightforward to create such an emission scenario from the three CPB scenarios under consideration. Since the surface source emissions serve to compare air traffic emissions with (aggregate analysis) and serve as background sources (atmospheric models), it was decided just to match each of the three CPB scenarios to one of the six *IS92* scenarios based on 'most' similarity of the regional annual GNP growth rates. This approach was taken because the IPCC emissions scenarios are internationally well recognized and are well documented. Also, the *IS92* scenarios cover a range of consistent sets of assumptions on how the world may develop in time. The alternative of constructing new consistent scenarios would mean only using the precise economic growth rates of the CPB scenarios, while introducing many additional assumptions, which would be both highly time consuming and to some extent also rather arbitrary.

Table 4.5 shows how per CPB scenario the selection was done by seeking three different IPCC scenarios with most regions (and global total) with a good correspondence and with least regions (and global total) with a bad correspondence with the CPB scenario in question: *IS92e* was used for the BG scenario since it has most correspondence and has the highest global total growth rate; *IS92f* was used for the ER scenario as it was closest to this scenario; *IS92a* was used to represent the GS scenario, because it had a (slightly) better correspondence with GS than the other two remaining options (*IS92c* and *IS92d*).

Table 4.5: *Comparison between GNP growth rates of CPB scenarios and IPCC IS92 scenarios.*

Region CPB/IPCC	CPB %/a (90-15)	IPCC [%/a (average over 90-15)] IS92a,b	c	d	e	f
ER scenario:						f
total	3.3	2.9	*1.9*	2.8	3.6	3
DC/OECD	2.5	2.7	*1.8*	2.5	*3.2*	2.7
NME/CPE	2.3	2.1	*1.2*	2.1	*3.1*	2.3
CHI/CHI+	5.2	5.3	*3.9*	5.1	*6.2*	5.3
rLDC/OTHER	4.3	4.0	*2.7*	3.8	4.8	4.2
GS scenario:		a				
total	3.9	2.9	1.9	2.8	3.6	3
DC/OECD	3	2.7	*1.8*	2.5	3.2	2.7
NME/CPE	0.2	2.1	1.2	2.1	3.1	2.3
CHI/CHI+	6.5	5.3	*3.9*	5.1	6.2	5.3
rLDC/OTHER	5.3	4.0	*2.7*	3.8	4.8	4.2
BG scenario					e	
total	4.1	2.9	1.9	2.8	3.6	3
DC/OECD	3.1	2.7	1.8	2.5	3.2	2.7
NME/CPE	2.7	2.1	*1.2*	2.1	3.1	2.3
CHI/CHI+	6.2	5.3	*3.9*	5.1	6.2	5.3
rLDC/OTHER	5.5	4.0	*2.7*	3.8	4.8	4.2

Source: CPB, 1992; Pepper et al., 1992.

Notes:
- Underline = good or best correspondance
- *Italic* = bad or worst correspondance
- box = selected set corresponding most to CPB scenario

Regions:

CPB:
- DC = Developed Countries
- NME = New Market Economies (Central Europe and CIS)
- CHI = China
- rLDC = Rest of Less Developed Countries

IPCC:
- OECD = Industrialized Countries
- CPE = Formerly Centrally Planned Europe (Eastern Europe and CIS)
- CHI+ China and other Centrally Planned Asia
- OTHER = Rest of Less Developed Countries

Table 4.6: *Global surface emissions per source category related to CPB scenarios ER, GS and BG (derived from selected IPCC scenarios).*

			ER scenario (IS92f)			GS scenario (IS92a)			BG scenario (IS92e)		
IPPC category	Unit of values	1990 value	2025 value	2003 index	2015 index	2025 value	2003 index	2015 index	2025 value	2003 index	2015 index
CO2 sources	Pg CO2										
Energy		22.0	49.5	1.46	1.89	22.0	1.29	1.56	46.2	1.41	1.79
Cement		0.7	1.8	1.56	2.07	0.7	1.37	1.71	1.5	1.37	1.71
Deforestation		4.4	4.0	0.97	0.94	4.8	0.94	0.89	4.8	1.00	1.00
TOTAL		26.8	55.4	1.40	1.76	27.1	1.24	1.46	52.8	1.35	1.68
CH4 sources	Tg CH4										
Energy		91.0	128	1.15	1.29	91.0	1.08	1.15	135.0	1.18	1.35
Cattle		84.0	140	1.25	1.48	84.0	1.24	1.46	138.0	1.24	1.46
Rice		60.0	85	1.15	1.30	60.0	1.11	1.21	78.0	1.11	1.21
Animal waste		26.0	44	1.26	1.49	26.0	1.24	1.47	43.0	1.24	1.47
Landfills		38.0	67	1.28	1.55	38.0	1.24	1.47	71.0	1.32	1.62
Biomass burning*		28.0	33	1.07	1.13	28.0	1.05	1.10	32.0	1.05	1.10
Sewage		25.0	45	1.30	1.57	25.0	1.22	1.43	40.0	1.22	1.43
Naturale		155.0	155	1.00	1.00	155.0	1.00	1.00	155.0	1.00	1.00
TOTAL		506.0	697	1.14	1.27	506.0	1.11	1.22	692.0	1.14	1.26
*o.w. fuelwood:		7.0	6.3	0.96	0.93	7.0	0.96	0.93	6.3	0.96	0.93
N2O sources	Tg N2O										
Energy		0.6	1.3	1.37	1.71	0.6	1.28	1.54	1.7	1.65	2.25
Industry		1.1	2.2	1.37	1.71	1.1	1.32	1.61	2.2	1.37	1.71
Biomass burning		0.8	1.1	1.15	1.29	0.8	1.15	1.29	1.1	1.15	1.29
Agriculture		4.7	7.9	1.25	1.48	4.7	1.22	1.43	7.5	1.22	1.43
Natural		13.0	13.0	1.00	1.00	13.0	1.00	1.00	13.0	1.00	1.00
TOTAL		20.3	25.5	1.10	1.18	20.3	1.08	1.16	25.6	1.10	1.19
NOx sources	Tg NO2										
Energy		82.1	151.1	1.31	1.60	82.1	1.27	1.51	161.0	1.36	1.69
Biomass burning*		29.6	36.1	1.08	1.16	29.6	1.04	1.08	32.9	1.04	1.08
Naturale		39.4	39.4	1.00	1.00	39.4	1.00	1.00	39.4	1.00	1.00
Lightning		29.6	29.6	1.00	1.00	29.6	1.00	1.00	29.6	1.00	1.00
TOTAL		180.7	256.3	1.16	1.30	180.7	1.02	1.04	266.1	1.18	1.34
*o.w. fuelwood:		7.6	6.9	0.97	0.94	7.6	0.97	0.94	6.9	0.97	0.94
SO2 sources	Tg SO2										
Energy		130.0	220.0	1.26	1.49	130.0	1.21	1.40	220.0	1.26	1.49
Industrial		16.0	34.0	1.42	1.80	16.0	1.37	1.71	34.0	1.42	1.80
Biomass burning		4.0	6.0	1.19	1.36	4.0	1.19	1.36	6.0	1.19	1.36
Natural		44.0	44.0	1.00	1.00	44.0	1.00	1.00	44.0	1.00	1.00
TOTAL		194.0	304.0	1.21	1.41	194.0	1.17	1.33	304.0	1.21	1.41
CO sources	Tg CO										
Energy		303.3	415.3	1.14	1.26	303.3	1.09	1.16	233.3	0.91	0.84
Biomass burning*		693.0	823.7	1.07	1.13	693.0	1.06	1.11	795.7	1.06	1.11
Natural		100.3	100.3	1.00	1.00	100.3	1.00	1.00	100.3	1.00	1.00
Oceans		39.7	39.7	1.00	1.00	39.7	1.00	1.00	39.7	1.00	1.00
Wildfires		30.3	30.3	1.00	1.00	30.3	1.00	1.00	30.3	1.00	1.00
TOTAL		1166.7	1407.0	1.08	1.15	1166.7	1.08	1.15	1199.3	1.01	1.02
*o.w. fuelwood:		174.3	157.7	0.96	0.93	174.3	0.96	0.93	157.7	0.96	0.93
VOC sources	Tg										
Energy		27.0	53	1.36	1.69	27.0	1.29	1.56	53.0	1.36	1.69
Industry		23.0	39	1.26	1.50	23.0	1.21	1.40	39.0	1.26	1.50
Biomass burning		53.0	55	1.01	1.03	53.0	1.01	1.01	55.0	1.01	1.03
Other		18.0	28	1.21	1.40	18.0	1.17	1.32	28.0	1.21	1.40
TOTAL		121.0	175	1.17	1.32	121.0	1.13	1.25	175.0	1.17	1.32

			ER scenario			GS scenario			BG scenario		
TPES *	Unit of values	1990 value	2025 value	2003 index	2015 index	2025 value	2003 index	2015 index	2025 value	2003 index	2015 index
Energy	EJ	344	741	1.43	1.82	344.0	1.39	1.76	837.0	1.53	2.02
Primary liquid	EJ	123	228	1.32	1.61	123.0	1.13	1.24	470.0	1.34	1.65
CO2	Pg CO2 C	22	49.5	1.46	1.89	6.0	1.29	1.56	46.2	1.46	1.89

* Total Primary Energy Supply.

source: Pepper et al; 1992; IS92a also in Houghton et al., 1992

Subsequently, the emission trend of those IPCC scenarios was used to simulate the emissions related to the CPB scenarios. The specified emissions in 1990 and 2025 were interpolated to estimate the surface source emissions in 2003 and 2015 (see Table 4.6).

For the spatially distributed emissions we used the indexed global total development of emissions of the source categories distinguished in the emission inventories for 1990, derived from the IPCC scenarios as mentioned above, to simulate the future spatial emission distribution pattern (see below under Section 5.2.2).

4.6 Regional emissions and gridded emissions

4.6.1 Air traffic

Regional and total emissions from air traffic are based on the projected fuel consumption and assumptions about future values of emission factors. The calculation procedure is summarized in Table 4.7.

Although for policy analysis aggregated regional and global total emissions from aircraft and from surface sources are sufficient, for assessment of the *environmental impacts* of aircraft emissions we need to define the emissions in three dimensions. Actually there are four dimensions, since the seasonal variation is also of importance here.

Table 4.7: *Calculation scheme for present and future levels of fuel consumption (FC) and emissions (EM), based on Seat-Km-Offered (SKO), Load factors (LF) and Emission Factors (EF).*

AL90 =	SKO90				
SFC =	FC/P-km				
FCt =	FC90*	SKOt/SKO90* (index)	LFt/LF90* (DTI ass.)	SFCt/SFC90 (own ass.)	
EMt =	EM90*	SKOt/SKO90* (index)	LFt/LF90* (DTI ass.)	dSFC/SFC90* (own ass.)	dEF/EF90 (ass. for NOx and the others)
=	EM90*	FCt/FC90* (index)	EFt/EF90 (ass. for NOx and the others)		
Dividing FCt and EMt by the levels in 1990 (FC90 and EM90, respectively) results in an indexed development.					
For emissions in 1990 of:					
	CO2	use WSL fuel*	scale to 90* EF (3188) (OECD/IPCC, 1995)		
	SO2	use WSL fuel*	scale to 90* EF (1)(Olivier, 1991)		
	NOx	use WSL*	scale to 90 (EF calculated = 11.4 (WSL, 1993))		
	CO	use WSL*	scale to 90 (EF calculated = 4.3 (WSL/NLR, 1994)		
	CH4	WSL-LTO ton*	scale to 90* EF (0.3) (Olivier; this report)		
	N2O	use WSL fuel*	scale to 90* EF(0.15) (Wiesen et al., 1994) (range: 0.05-0.5)		
	VOC	use WSL fuel*	scale to 90* EF (2.6) (average of NASA inventory; NASA, 1994)		

<u>Notes:</u>
AL = Activity Level
FC = Fuel consumption
EM = Emission
SKO = Seat-Km Offered
LF = Load Factor
SFC = Specific Fuel Consumption
EF = Emission Factor

In this study we do no assume structural changes in the vertical and horizontal flight distribution pattern, except for those resulting from a changed mix of flights between regions/links and per type of aircraft/range within regions/links as specified by the aggregated DTI projection of passenger kilometres. This means that we assume that new aircraft of a specific size will fly at the same cruise levels as the current fleet mix. This may not be true completely, e.g. part of the new fleet could be new Super Sonic Transport aircraft which are now under development, but in order to keep the gridded scenarios as transparent as possible we refrained from including this kind of effects. For the same reason the temporal distribution of air traffic was assumed to be the same as in the base year 1990.

We note that the regional and global total emissions of NO_x and CO of the gridded reference emission scenarios will unavoidably differ slightly from the aggregate global projections. This is due to the fact that the emissions of these compounds are calculated using aircraft/range specific emission factors and differentiated growth rates of P-km, whereas the aggregate projections were constructed using only the regional total development of passenger kilometres.

4.6.2 Surface sources

The surface emissions are for aggregate analysis only used on a global total level. For practical reasons and as the gridded distribution of surface emissions is 'only' used as background to the aircraft emission, we applied globally uniform multiplication factors per source category and per compound to generate the future gridded emission pattern, which the atmospheric chemists used as input for their models. As in the case for air traffic, the temporal distribution per source category (distribution of annual emissions over calender months) was also kept constant in time. As a result, future surface emissions *per sector* differ only from 1990 emissions by a scaling factor per compound - the spatial and temporal distribution pattern is kept constant in time. However, due to the use of different sectoral scaling factors the *composite* distribution patterns in 2003 and 2015 are not equal to the 1990 distribution.

5. POLICY ALTERNATIVES FOR AIR TRAFFIC SCENARIOS

In order to show the potential of additional policy measures, additional assumptions were made for policy alternatives each aiming at a specific compound, which are summarized in Table 5.1 (own estimates and estimates by Peper of NLR (Peper, 1993b, pers. comm.; see also Peper, 1993c; Greene, 1992; Schipper *et al.*, 1992). Shown here is the total change compared to the case where the variables are kept constant in time. Thus, the figures presented include the autonomous development described in Table 4.2. As an operational measure to reduce CO2 emissions, we considered an additional increase of the fleet average load factor with 6 per cent points to 75% in 2015 (instead of 69% in the autonomous case). The alternatives presented here aim at showing the effect of maximum technologically and operationally achievable emission reduction per compound.

To keep the analysis transparent, per compound we investigated the effect of just one measure, implemented at two levels:

(1) in new aircraft only, taking into account the slow replacement rate due to the long service life of aircraft, thereby achieving a penetration of the entire fleet in 2015 of about 50% (this is shown in Table 5.1);

(2) assuming also a partial implementation in the fleet of existing aircraft, by assuming a 50% retrofit of the engines, thus achieving a total penetration of the entire fleet of 75% (not shown in Table 5.1).

Table 5.1: *Additional assumptions on the effect of alternative policies in aircraft emission scenarios.*

Measure	Total change 2015 w.r.t. 1990	Reference
Technical measures/ Variable	(50% penetration assumed *)	
SFC	-20.0% (including -12.5% of baseline)	Own estimate
EF-NOx	-42.5% (including -17.5% of baseline)	Peper, 1993b,c
EF-SO2 **)	-37.5%	Own estimate
EF-CO/VOC/CH4	-25%	Own estimate
EF-N2O ***)	0%	Own estimate
Operational measures:		
Load Factor	4+6% pnts (to 75% total in 2015)	Own estimate

Notes:

* Thus, for average new aircraft in 2015 the change with respect to the 1990 fleet average is twice the value mentioned here. In 2003 13/25 x 50% = 26% penetration was assumed.

** For SO2, which emission factor is dependent on the fuel composition, we assume 50% penetration; i.e. that 50% of the refineries will produce jetfuel with a 75% lower sulphur content.

*** For N2O no measures are assumed due to lack of knowledge for this compound. Also the current global average emission factor is quite uncertain, since it is based on only a few measurements for a few engines.

**** This corresponds with -9% specific fuel consumption.

The effects of the assumed policy measures, although to some extent 'own estimates', are in line with other insights and illustrate the maximum of the range of effects that individual additional measures could have, provided that technological progress will indeed be realized to the assumed level *and* within the time frame assumed.
To conclude the analysis we have also investigated the combined effect of a package of these measures on CO_2 and NO_x. This will be discussed further in Chapter 7.

We emphasize that these policy alternatives assume a very strong technological development as well as immediate introduction of newly developed technologies, starting in about 2000. These alternatives could only be realized in optimal circumstances: by strong governmental support of R&D, technological developments within the time frame as assumed, and concrete policy measures for a timely introduction of the new technology. However, in all scenarios a gradual replacement of the existing fleet has been taken into account by assuming a 50% penetration of the total fleet by 2015, corresponding with the share of newest aircraft introduced after 2000 (see e.g. DTI, 1993). For 2003 we assumed an interpolated 13/25 x 50% = 26% penetration of new technology. Thus, the changes in 2003 are assumed to be about half of the changes mentioned for 2015.

For SO_2, of which the emission factor is not dependent on engine technology but on the fuel quality, we assume 50% penetration by 2015; i.e. that 50% of the refineries will produce jet fuel with a 75% lower sulphur content than the present average. For N_2O no measures are assumed due to lack of knowledge for this compound. Also the current global average emission factor for this compound is quite uncertain, since it is based only on a few measurements for a few engines (Wiesen *et al.*, 992) (see Section 2.1).

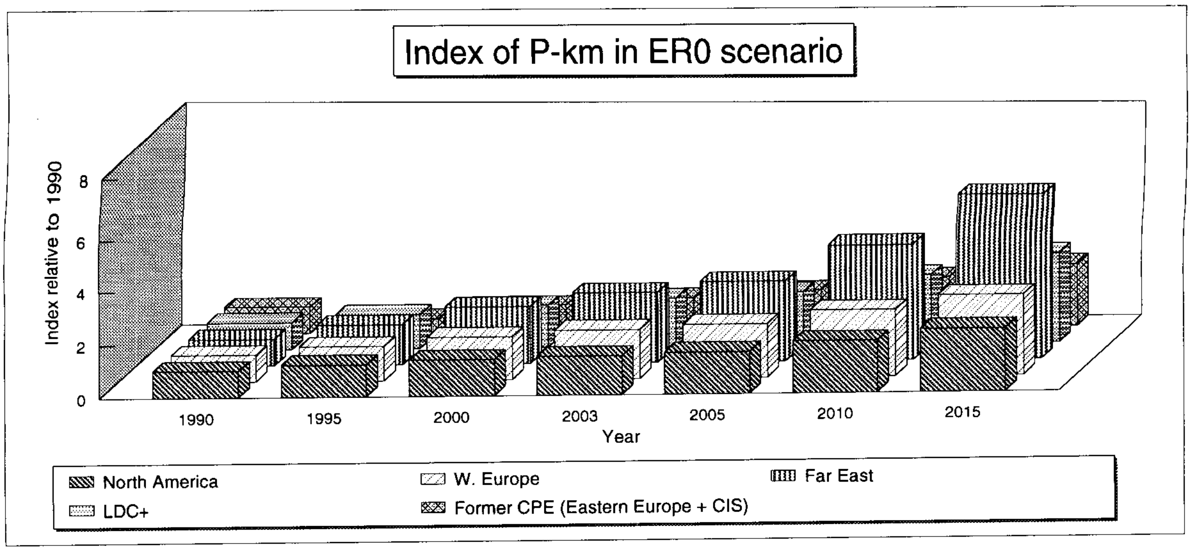
6. SCENARIO RESULTS

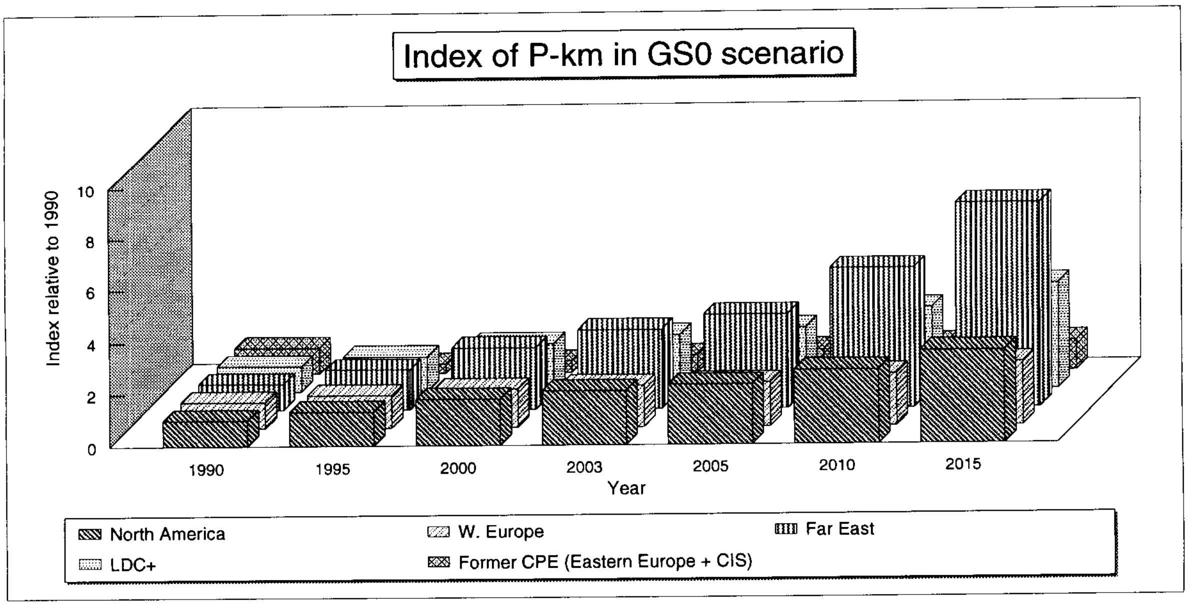
6.1 Projections of passenger-km

We started with the definition of the CPB scenarios in terms of assumptions for regional economic growth, which are illustrated in Fig. 4.1, as well as with (globally uniform) additional assumptions regarding ticket price development and autonomous development of the Specific Fuel Consumption (SFC), Emission Factors (EF), and Load Factors (LF) (see Table 4.2). Taking the inputs for the three CPB scenario's ER, GS and BG, DTI used its Air Traffic Demand Projection Model to calculate the number of Seat-km Offered (S-km or SKO), by DTI region and by DTI aircraft type. By incorporating the assumptions about load factors, we arrived at the indexed development of Passenger-km (P-km) per region. Next, DTI results were aggregated to LULU regions and LULU aircraft types (Tables 4.3 and 4.4), in order to facilitate the construction of gridded emissions using the spatial WSL aircraft database. As an example in Figure 6.1 the Seat-km projections in the ER scenario are presented in absolute figures, both by region and by aircraft/range type. Indexed results for the three scenarios in terms of P-km are presented in Table 6.1 and Figure 6.2. (More figures are given in Appendix I.) It shows, that the contribution of North America to total aircraft emissions will remain high, but in 2015 the share of the Far East has increased almost to a similar level. Also emissions of Western Europe still have a substantial share in global total in 2015. These strong regional differences are also visible in the historical development of jet fuel consumption (see Appendix M). The autonomous development of the global average load factor was presented in an indexed form in Table 4.2.

6.2 Global aircraft emission projections

Subsequently, the associated aircraft emissions were calculated. The method applied was summarized in Table 4.7. Surface emissions related to the three CPB scenarios were taken from selected IPCC scenarios (and interpolated to make estimates for 2003 and 2015) (Table 4.5). The results of the emissions estimates for both air traffic and energy-related sources are presented in Tables 6.2.a to c for CO_2, CH_4 and N_2O; for NO_x and SO_2; and for CO and VOC, respectively. It should be stressed that the regional sub-division of aircraft emissions shown in the upper part of the tables are only meaningful in the sense that the ratio between North America, Western Europe, Far East and the LDC+ region is more or less realistic. In particular former Centrally Planned Europe (CPE), i.e. Eastern Europe and the former USSR, are strongly underestimated due to missing data in the WSL database. Global total figures, however, are scaled to global jet fuel consumption by aircraft in 1990. The lower part of the tables shows the projection of energy-related emissions and the aircraft emissions expressed as percentage of energy-related emissions ('% aircraft of energy').





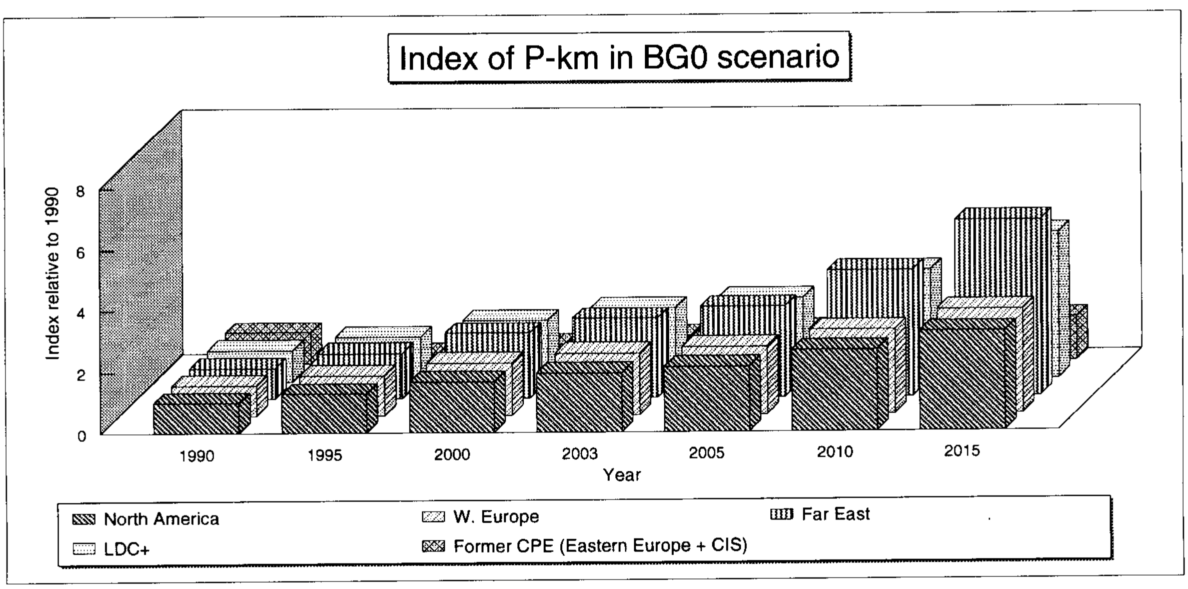


Figure 6.1: *Indexed development of Passenger-km in scenarios ER, BG and GS.*

Table 6.1: Indexed development of Passenger-km in the ER, BG and GS scenarios.

ER0 scenario (index of SKO*LF)

LULU region	1990	1995	2000	2003	2005	2010	2015
North America	1.00	1.21	1.36	1.46	1.57	1.95	2.36
W. Europe	1.00	1.29	1.61	1.84	2.00	2.48	3.02
Far East	1.00	1.48	2.13	2.63	3.03	4.36	6.18
LDC+	1.00	1.27	1.57	1.79	1.98	2.61	3.38
Former CPE (Eastern Europe + CIS)	1.00	0.49	0.98	1.21	1.45	1.91	2.36
Total	1.00	1.27	1.56	1.77	1.94	2.53	3.23

Note: CPE: period 90-95 about 50% negative growth, "opposite" of Far East
period 95-15 about factor 5 growth, in line with Far East

GS0 scenario (index of SKO*LF)

LULU region	1990	1995	2000	2003	2005	2010	2015
North America	1.00	1.32	1.79	2.10	2.32	2.89	3.61
W. Europe	1.00	1.24	1.48	1.60	1.70	2.01	2.45
Far East	1.00	1.55	2.39	3.04	3.59	5.33	7.85
LDC+	1.00	1.37	1.84	2.14	2.39	3.11	4.02
Former CPE (Eastern Europe + CIS)	1.00	0.40	0.49	0.68	0.87	1.05	1.13
Total	1.00	1.34	1.82	2.13	2.37	3.08	4.03

Note: CPE estimate based on Far East/LDC+ similarity.

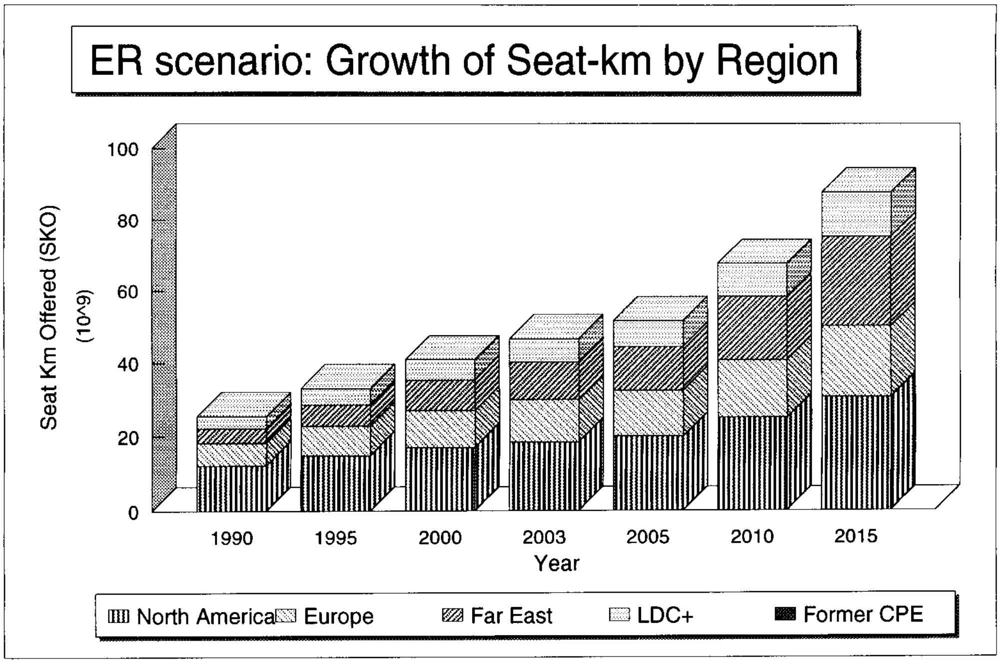
BG0 scenario (index of SKO*LF)

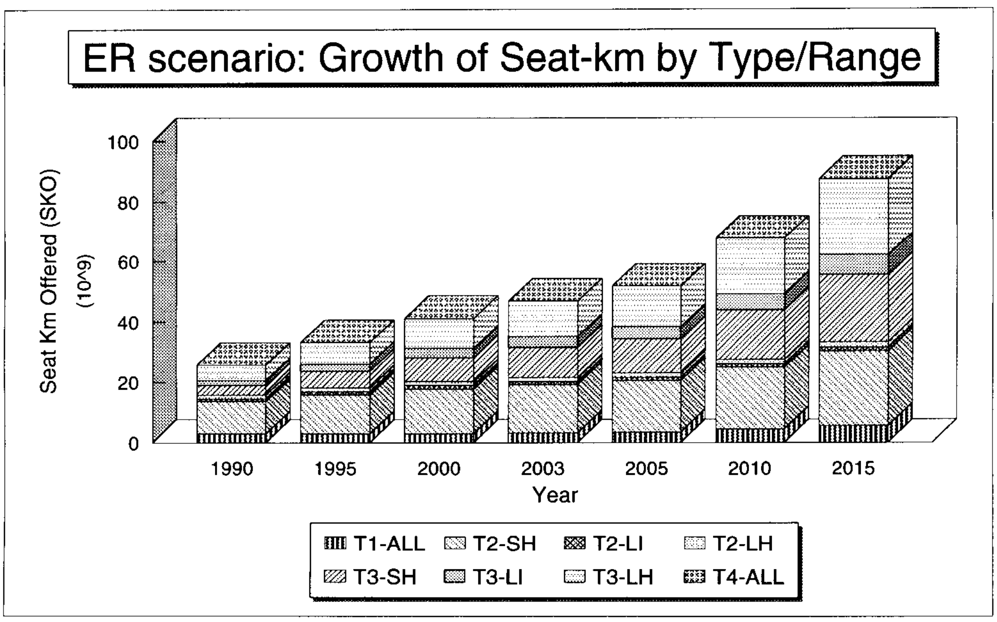
LULU region	1990	1995	2000	2003	2005	2010	2015
North America	1.00	1.29	1.67	1.94	2.14	2.64	3.23
W. Europe	1.00	1.31	1.71	1.99	2.19	2.73	3.39
Far East	1.00	1.46	2.09	2.57	2.95	4.12	5.74
LDC+	1.00	1.41	1.95	2.35	2.66	3.56	4.76
Former CPE (Eastern Europe + CIS)	1.00	0.30	0.59	0.87	1.06	1.24	1.42
Total	1.00	1.32	1.73	2.01	2.23	2.89	3.75

Note: CPE estimate based on Far East/LDC+ similarity

Emissions of methane can be neglected as they are extremely small, also compared to other source (Table 6.2). Emissions of nitrous oxide on the other hand are rather uncertain: as a percentage of other energy related emissions it could be of the order of 10%, but total energy related N_2O emissions are only a minor anthropogenic source (Tables 6.2 and 4.6).

The impact of additional technical measures to reduce emissions is simulated by assuming one measure per compound (except for N_2O). This is presented in the tables in the six *italic* lines, showing the impact of (1) a strong (maximum) implementation in new aircraft only, and (2) including also a partial implementation in the existing fleet (by retrofitting 50% the existing aircraft engines). This method of simulating the effect of one technical measure per compound and not of a package of measures was done for reasons of transparency.





Note:

T1 =	WSL types 1 and 2 (DTI types A and B)
T2 =	WSL types 3 and 4 (DTI types C and D and part of E and F)
T3 =	WSL types 5 and 6 (DTI types G to J and part of E and F)
T4 =	WSL types 7 to 10 (no DTI types)
SH =	Short Haul (< 2900 Nm)
LH =	Long Haul (> 2900 Nm)
ALL =	All distance ranges

Figure 6.2: *Indexed development of Seat-km by region and by aircraft type in ER scenario.*

Table 6.2.a: *Aircraft and energy-related emissions of CO_2, N_2O and CH_4 for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).* N.B. Policy alternatives are shown in *italics*.

(SKO indexed; autonomous development of SFC

CO2 (Mton)	1990	2003			2015		
Air traffic	**1990**	**2003-ER**	**2003-GS**	**2003-BG**	**2015-ER**	**2015-GS**	**2015-BG**
North America (o)	234.8	321.3	461.5	426.6	485.7	741.0	664.6
W. Europe (o)	97.5	167.3	145.7	181.7	257.5	209.2	289.0
Far East (o)	75.6	185.8	214.7	181.4	409.3	519.7	380.2
LDC+ (o)	80.6	134.9	161.3	177.0	238.4	283.1	335.5
Former CPE (u)	9.7	11.0	6.2	7.9	20.1	9.6	12.0
Total air traffic	498.2	820.3	989.3	974.6	1,411.0	1,762.6	1,681.3
Index autonomous dev.	1.00	1.65	1.99	1.96	2.83	3.54	3.37
Policy altern. 1 (max. techn.)	*498.2*	*786.1*	*948.1*	*934.0*	*1290.1*	*1611.5*	*1537.2*
Index policy alt. #1	*1.00*	*1.58*	*1.90*	*1.87*	*2.59*	*3.23*	*3.09*
Policy altern. 2 (50% retrofit)	*498.2*	*763.3*	*920.6*	*906.9*	*1209.5*	*1510.8*	*1441.1*
Index policy alt. #2	*1.00*	*1.53*	*1.85*	*1.82*	*2.43*	*3.03*	*2.89*
Energy:	22,000.0	31020.0	28380.0	32120.0	39380.0	34320.0	41580.0
Index	1.00	1.41	1.29	1.46	1.79	1.56	1.89
% of energy sources							
Autonomous development	2.3	2.6	3.5	3.0	3.6	5.1	4.0
Policy altern. 1 (max. techn.)	*2.3*	*2.5*	*3.3*	*2.9*	*3.3*	*4.7*	*3.7*
Policy altern. 2 (50% retrofit)	*2.3*	*2.5*	*3.2*	*2.8*	*3.1*	*4.4*	*3.5*

CH4 (kton)	1990	2003			2015		
Air traffic		**ER0**	**GS0**	**BG0**	**ER0**	**GS0**	**BG0**
North America (o)	2.5	3.4	4.9	4.5	5.2	7.9	7.1
W. Europe (o)	1.0	1.8	1.5	1.9	2.7	2.2	3.1
Far East (o)	0.8	2.0	2.3	1.9	4.3	5.5	4.0
LDC+ (o)	0.9	1.4	1.7	1.9	2.5	3.0	3.6
Former CPE (u)	0.1	0.1	0.1	0.1	0.2	0.1	0.1
Total air traffic	5.3	8.7	10.5	10.4	15.0	18.7	17.9
Index autonomous dev.	1.00	1.65	1.99	1.96	2.83	3.54	3.37
Policy altern. 1 (max. techn.)	*5.3*	*7.6*	*9.1*	*9.0*	*11.2*	*14.0*	*13.4*
Index policy alt. #1	*1.00*	*1.43*	*1.73*	*1.70*	*2.12*	*2.65*	*2.53*
Policy altern. 2 (50% retrofit)	*5.3*	*7.0*	*8.5*	*8.3*	*9.4*	*11.7*	*11.2*
Index policy alt. #2	*1.00*	*1.33*	*1.60*	*1.57*	*1.77*	*2.21*	*2.11*
Energy:	91,000.0	104650.0	98280.0	107380.0	117390.0	104650.0	122850.0
Index	1.00	1.15	1.08	1.18	1.29	1.15	1.35
% of energy sources							
Autonomous dev.	0.006	0.008	0.011	0.010	0.013	0.018	0.015
Policy altern. 1 (max. techn.)	*0.006*	*0.007*	*0.009*	*0.008*	*0.010*	*0.013*	*0.011*
Policy altern. 2 (50% retrofit)	*0.006*	*0.007*	*0.009*	*0.008*	*0.008*	*0.011*	*0.009*

N2O (kton)	1990	2003			2015		
Air traffic		**ER0**	**GS0**	**BG0**	**ER0**	**GS0**	**BG0**
North America (o)	11.0	15.1	21.7	20.1	22.9	34.9	31.3
W. Europe (o)	4.6	7.9	6.9	8.5	12.1	9.8	13.6
Far East (o)	3.6	8.7	10.1	8.5	19.3	24.5	17.9
LDC+ (o)	3.8	6.3	7.6	8.3	11.2	13.3	15.8
Former CPE (u)	0.5	0.5	0.3	0.4	0.9	0.5	0.6
Total (middle range)	23.4	38.6	46.6	45.9	66.4	82.9	79.1
Index (middle)	1.00	1.65	1.99	1.96	2.83	3.54	3.37
Lower range	7.8	12.9	15.5	15.3	22.1	27.6	26.4
Index lower range	1.0	1.6	2.0	2.0	2.8	3.5	3.4
Higher range	78.1	128.7	155.2	152.9	221.3	276.4	263.7
Index higher range	1.0	1.6	2.0	2.0	2.8	3.5	3.4
Energy:	628.6	886.3	810.9	917.7	1125.1	980.6	1188.0
Index	1.00	1.41	1.29	1.46	1.79	1.56	1.89
% of energy sources							
Autonomous development	3.7	4.4	5.7	5.0	5.9	8.5	6.7
Lower range	1.2	1.5	1.9	1.7	2.0	2.8	2.2
Higher range	12.4	14.5	19.1	16.7	19.7	28.2	22.2

Table 6.2.b: *Aircraft and energy-related emissions of NO_x and SO_2 for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).* N.B. Policy alternatives are shown in *italics*.

(SKO indexed; autonomous development of EF NOx;

NOx (kton NO2)	1990	2003			2015		
Air traffic		ER0	GS0	BG0	ER0	GS0	BG0
North America (o)	841.5	1046.9	1503.5	1389.7	1436.1	2190.9	1965.1
W. Europe (o)	349.3	545.1	474.7	592.0	761.5	618.6	854.4
Far East (o)	271.1	605.5	699.5	591.1	1210.4	1536.7	1124.1
LDC+ (o)	288.7	439.4	525.4	576.7	705.0	837.0	992.1
Former CPE (u)	34.8	35.9	20.1	25.8	59.3	28.5	35.6
Total air traffic	**1,785.5**	**2,672.6**	**3,223.2**	**3,175.2**	**4,172.3**	**5,211.7**	**4,971.3**
Index autonomous dev.	1.00	1.50	1.81	1.78	2.34	2.92	2.78
Policy altern. 1 (max. techn.)	1,785.5	*2290.4*	*2762.3*	*2721.1*	*2908.0*	*3632.4*	*3464.8*
Index policy alt. #1	*1.00*	*1.28*	*1.55*	*1.52*	*1.63*	*2.03*	*1.94*
Policy altern. 2 (50% retrofit)	*1,785.5*	*1965.5*	*2370.4*	*2335.1*	*1833.3*	*2290.0*	*2184.4*
Index policy alt. #2	*1.00*	*1.10*	*1.33*	*1.31*	*1.03*	*1.28*	*1.22*
Energy:	82,142.9	115821.4	105964.3	119928.6	147035.7	128142.9	155250.0
Index	1.00	1.41	1.29	1.46	1.79	1.56	1.89
% of energy sources							
Autonomous development	2.2	2.3	3.0	2.6	2.8	4.1	3.2
Policy altern. 1 (max. techn.)	*2.2*	*2.0*	*2.6*	*2.3*	*2.0*	*2.8*	*2.2*
Policy altern. 2 (50% retrofit)	*2.2*	*1.7*	*2.2*	*1.9*	*1.2*	*1.8*	*1.4*

SO2 (kton)	1990	2003			2015		
Air traffic		ER0	GS0	BG0	ER0	GS0	BG0
North America (o)	73.6	100.8	144.8	133.8	152.3	232.4	208.5
W. Europe (o)	30.6	52.5	45.7	57.0	80.8	65.6	90.6
Far East (o)	23.7	58.3	67.3	56.9	128.4	163.0	119.2
LDC+ (o)	25.3	42.3	50.6	55.5	74.8	88.8	105.2
Former CPE (u)	3.0	3.5	1.9	2.5	6.3	3.0	3.8
Total air traffic	**156.3**	**257.3**	**310.3**	**305.7**	**442.6**	**552.9**	**527.4**
Index autonomous dev.	1.00	1.65	1.99	1.96	2.83	3.54	3.37
Policy altern. 1 (strong techn.)	156.3	*207.1*	*249.8*	*246.1*	*276.6*	*345.5*	*329.6*
Index policy alt. #1	*1.00*	*1.33*	*1.60*	*1.57*	*1.77*	*2.21*	*2.11*
Policy altern. 2 (50% compliance)	*156.3*	*182.1*	*219.6*	*216.3*	*193.6*	*241.9*	*230.7*
Index policy alt. #2	*1.00*	*1.17*	*1.41*	*1.38*	*1.24*	*1.55*	*1.48*
Energy:	130,000.0	183300.0	167700.0	189800.0	232700.0	202800.0	245700.0
Index	1.00	1.41	1.29	1.46	1.79	1.56	1.89
% of energy sources							
Autonomous development	0.1	0.1	0.2	0.2	0.2	0.3	0.2
Policy altern. 1 (strong techn.)	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.2*	*0.1*
Policy altern. 2 (50% compliance)	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*	*0.1*

Table 6.2.c: *Aircraft and energy-related emissions of CO and VOC for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).* N.B. Policy alternatives are shown in *italics*.

(SKO indexed; autonomous development of SFC

CO (kton)	1990	2003			2015		
Air traffic		ERO	GSO	BGO	ERO	GSO	BGO
North America (o)	320.1	438.0	629.1	581.5	662.1	1010.0	905.9
W. Europe (o)	132.9	228.1	198.6	247.7	351.1	285.2	393.9
Far East (o)	103.1	253.3	292.7	247.3	558.0	708.4	518.2
LDC+ (o)	109.8	183.8	219.9	241.3	325.0	385.9	457.4
Former CPE (u)	13.2	15.0	8.4	10.8	27.3	13.1	16.4
Total air traffic	**679.1**	**1,118.3**	**1,348.6**	**1,328.6**	**1,923.5**	**2,402.7**	**2,291.8**
Index autonomous dev.	1.00	1.65	1.99	1.96	2.83	3.54	3.37
Policy altern. 1 (max. techn.)	679.1	*972.9*	*1173.3*	*1155.8*	*1442.6*	*1802.0*	*1718.9*
Index policy alt. #1	*1.00*	*1.43*	*1.73*	*1.70*	*2.12*	*2.65*	*2.53*
Policy altern. 2 (50% retrofit)	*679.1*	*900.2*	*1085.7*	*1069.5*	*1202.2*	*1501.7*	*1432.4*
Index policy alt. #2	*1.00*	*1.33*	*1.60*	*1.57*	*1.77*	*2.21*	*2.11*
Energy:	303,333.3	427700.0	391300.0	442866.7	542966.7	473200.0	573300.0
Index	1.00	1.41	1.29	1.46	1.79	1.56	1.89
% of energy sources							
Autonomous development	0.22	0.26	0.34	0.30	0.35	0.51	0.40
Policy altern. 1 (max. techn.)	*0.22*	*0.23*	*0.30*	*0.26*	*0.27*	*0.38*	*0.30*
Policy altern. 2 (50% retrofit)	*0.22*	*0.21*	*0.28*	*0.24*	*0.22*	*0.32*	*0.25*

VOC (kton)	1990	2003			2015		
Air traffic		ERO	GSO	BGO	ERO	GSO	BGO
North America (o)	191.5	262.1	376.4	347.9	396.1	604.3	542.0
W. Europe (o)	79.5	136.4	118.8	148.2	210.0	170.6	235.7
Far East (o)	61.7	151.6	175.1	148.0	333.8	423.9	310.0
LDC+ (o)	65.7	110.0	131.5	144.4	194.4	230.9	273.6
Former CPE (u)	7.9	9.0	5.0	6.5	16.4	7.8	9.8
Total air traffic	**406.3**	**669.0**	**806.9**	**794.9**	**1,150.8**	**1,437.5**	**1,371.2**
Index autonomous dev.	1.00	1.65	1.99	1.96	2.83	3.54	3.37
Policy altern. 1 (max. techn.)	406.3	*582.1*	*702.0*	*691.5*	*863.1*	*1078.1*	*1028.4*
Index policy alt. #1	*1.00*	*1.43*	*1.73*	*1.70*	*2.12*	*2.65*	*2.53*
Policy altern. 2 (50% retrofit)	*406.3*	*538.6*	*649.5*	*639.9*	*719.2*	*898.4*	*857.0*
Index policy alt. #2	*1.00*	*1.33*	*1.60*	*1.57*	*1.77*	*2.21*	*2.11*
Energy:	27,000.0	38070.0	34830.0	39420.0	48330.0	42120.0	51030.0
Index	1.00	1.41	1.29	1.46	1.79	1.56	1.89
% of energy sources							
Autonomous development	1.50	1.76	2.32	2.02	2.38	3.41	2.69
Policy altern. 1 (max. techn.)	*1.50*	*1.53*	*2.02*	*1.75*	*1.79*	*2.56*	*2.02*
Policy altern. 2 (50% retrofit)	*1.50*	*1.41*	*1.86*	*1.62*	*1.49*	*2.13*	*1.68*

Notes:

1. Regional data are incomplete, notably for Former CPE, but scaled to 1990

2. Policy alternatives are individual changes w.r.t. the variable of interest:
Alternative 1 assumes a strong technical development, with 50% penetration.
Alternative 2 assumes, on top of this, 100% penetration (by retrofit), except for CO_2 where we assume 75% penetration (other part assumed to be aircraft related, not to the engine).
That is: for CO_2 additional improvement of the SFC has been assumed; for other compounds only a change in the corresponding emission factor was assumed (no policy on change in the SFC).
In conclusion, CO_2 emissions could decrease more, if one adds operational measures such as additional increase of the load factor, whereas other emissions may drop by assuming additionally the SFC effect as showed for CO_2 emissions, plus an increase of the load factor.
Also, an economic measure such as increasing air fares will have a volume effect, with an associated impact on emissions. This is not shown in the tables/figures.

Technical improvements estimated to be feasible for new aircraft from 2000/2005, and retrofits for existing aircraft, assumed to be penetrated 50% in 2015 and 13/25 x 505 in 2003; for SO_2 we also assumed 50% and 100%compliance, corresponding to 50 and 100% of refineries producing fuels with the requested decreased S-content.

(o) = Overestimated, due to incomplete coverage of air traffic of CIS and scaling to global total fuel consumption.
(u) = Underestimated, due to incompete coverage of regional air traffic.

As mentioned in Chapter 5, these policy alternatives represent the maximum assumed to be technologically achievable within a few decades. Therefore, the practical potential for reducing emissions is likely to be smaller. On the other hand, a somewhat stronger emission reduction is possible by combining operational measures (LF) to further reduce CO_2 emissions and operational and/or technical measures (SFC) to further reduce the other emissions (see the notes at the end of Table 6.2.c.) Also cost measures, such as an increase in air fares, may reduce emissions by their direct negative effects on the volume of air traffic (and indirectly, when taxes are based on fuel consumption and/or emissions). These have not been evaluated here, since DTI has not performed scenario runs with different price assumptions (see Chapter 7 for an illustration of the impact of economic policy options). We recall, that for air fares an autonomous decrease of about 1% per year was assumed (Table 4.2).

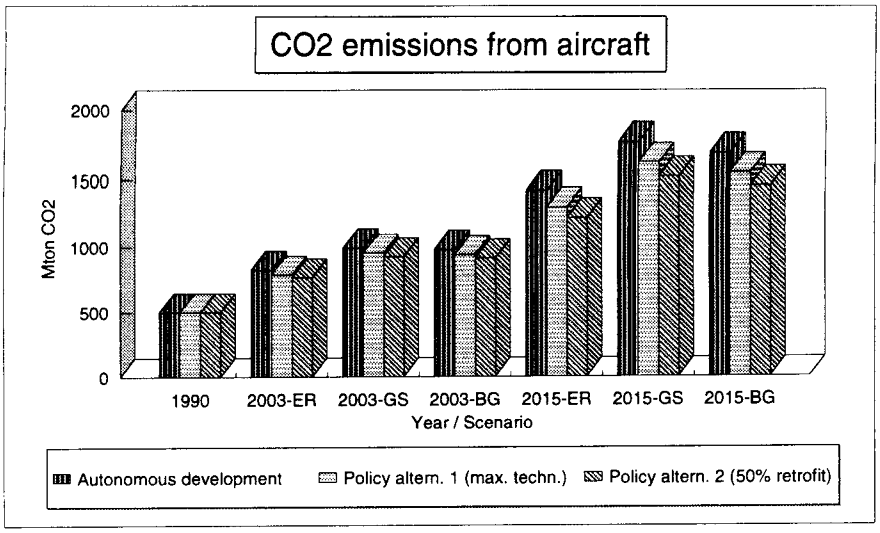
With this definition of the policy alternatives in mind, we show in Figures 6.3.a to 6.3.c the development of global aircraft emissions as presented in the tables, i.e. for the autonomous development case and for the policy alternative cases as described above. Note, as mentioned earlier in Chapter 5, that for the first case ('max techn.') we assumed 50% penetration in 2015 (and 13/25 x 50% in 2003) of the technical measures available per compound. from these figures the following conclusions can be drawn:

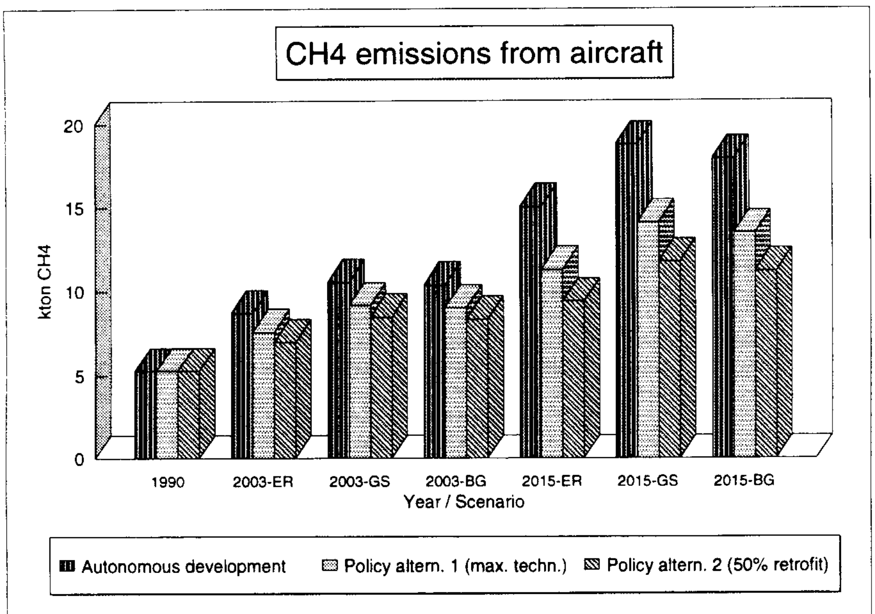
* for aircraft emissions as such it can be tentatively concluded that the *autonomous growth* by 2015 of global air traffic emissions is somewhere between 140-190% for NO_x and between 180-250% for other compounds;
* For most compounds the *growth* of emissions would be *restricted* to 20 to 120%, if the technical measures as described were to be implemented to the degree assumed;
* The growth of NO_x and SO_2 emissions may be controlled technically most effectively (controlled growth 5/20-50%), whereas CO_2 emissions appear to be more difficult to control (the controlled growth of CO_2 is about 170%).

In addition, we see that there are differences between the three reference scenarios, with ER showing lowest emission levels in 2015, GS showing the highest levels, and BG falling somewhere in between. For comparison, the reference scenario for fuel consumption - i.e. CO_2 emissions - by aircraft in the USA as published by the US Energy Information Administration, corresponds well with the ER figure for North America (Table 6.2.a), provided we compare the growth figure for civil air traffic (see Appendix L) (EIA, 1994a,b).

6.3 Comparison of aircraft emissions with other sources

The development of the share of aircraft emissions relative to energy-related sources is presented in Figures 6.4.a-c for the three reference scenarios and the policy alternative per compound. This presentation of aircraft emissions as a *fraction* of energy-related emissions indicates that, except for CO_2 emissions, by 2015 the *autonomous* growth of the shares is somewhere between 30 and





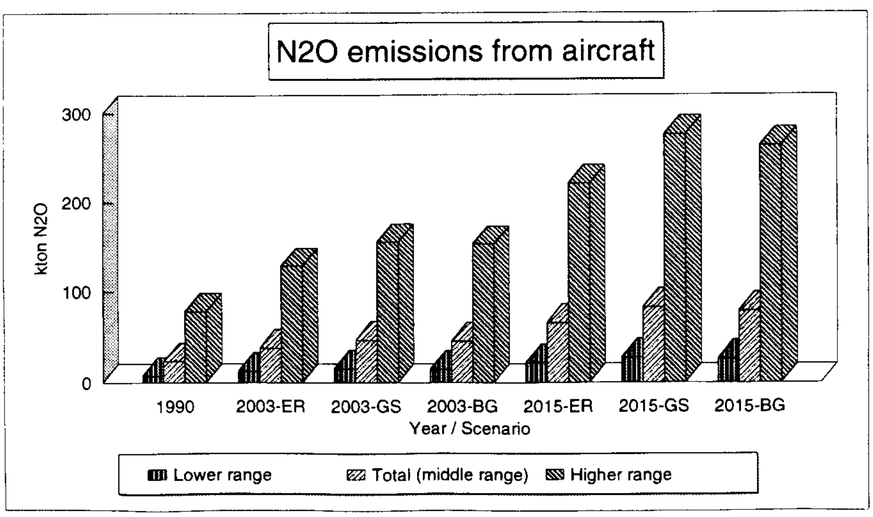
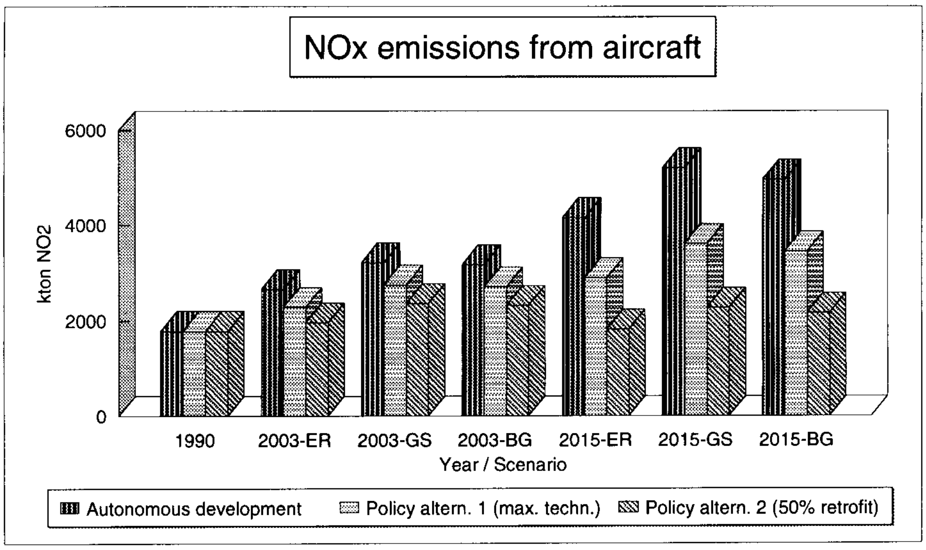


Figure 6.3.a: *Global aircraft emissions of CO_2, N_2O and CH_4 for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).*



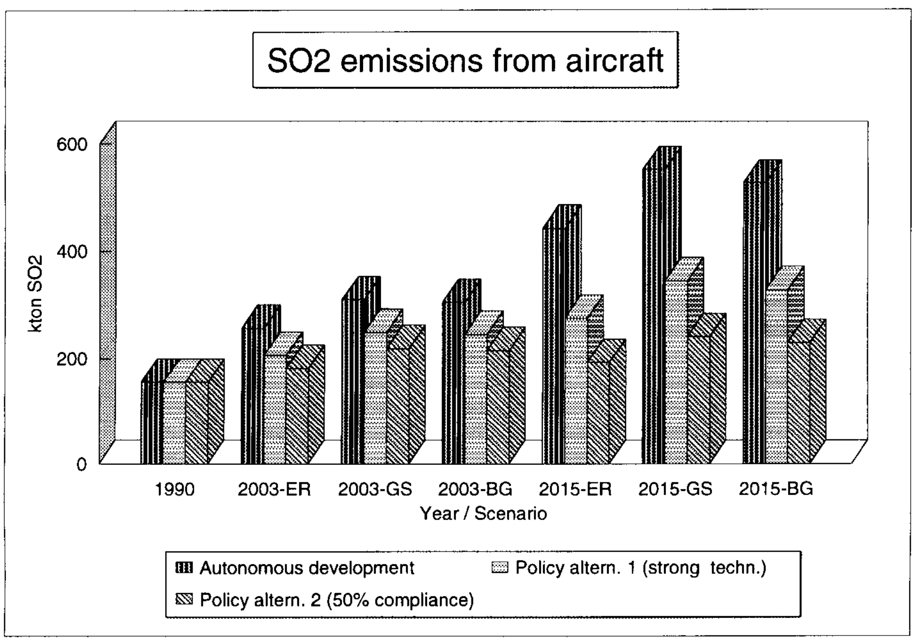
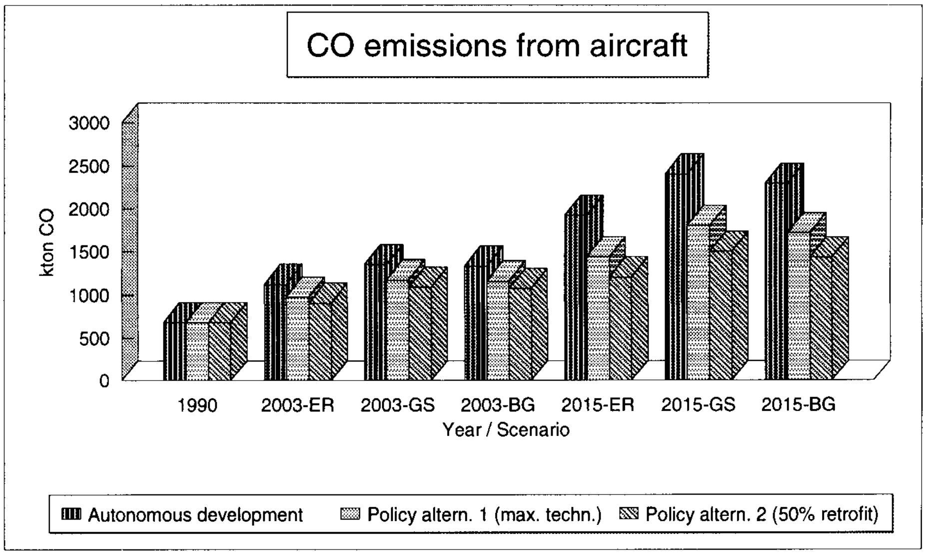


Figure 6.3.b: *Global aircraft emissions of NO_x and SO_2 for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).*



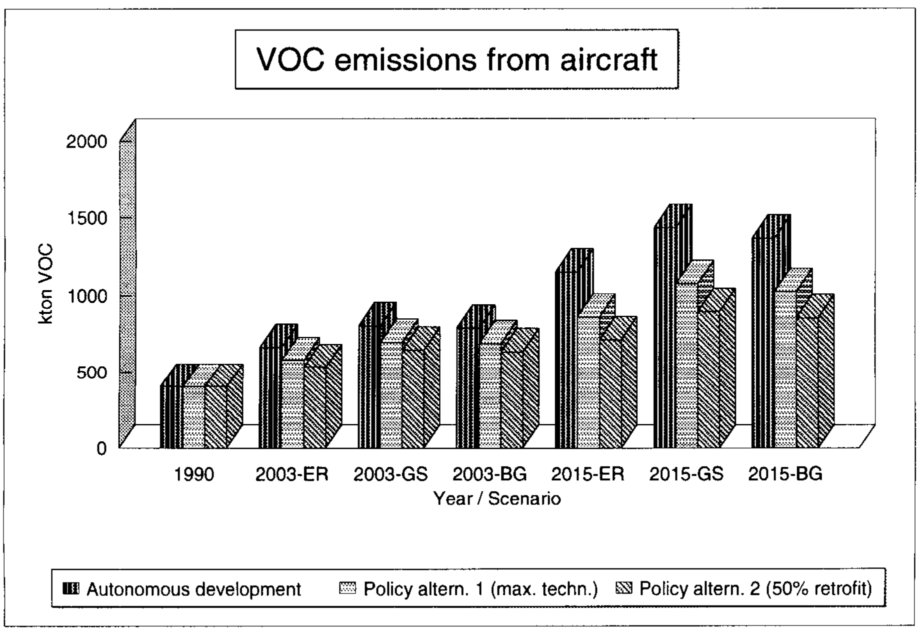


Figure 6.3c: *Global aircraft emissions of CO and VOC for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).*

200% (Table 6.3). If technical measures are implemented to the degree assumed (and assuming no change in other energy-related emissions), for most compounds the emissions shares would be more or less stabilized or even reduced in the case of NO_x and SO_2:

* NO_x and SO_2: controlled emissions share may be stabilized (GS), or reduced up to 40% (ER);
* CO and VOC: controlled emissions share may be stabilized (ER), or growth limited up to 40% (GS);
* CO_2, CH_4 and N_2O: controlled growth of the share limited to 40% (ER) to 90% (GS), except for N_2O in GS (130%).

The only exception is again the contribution to CO_2 emissions, which by its nature appears to be more difficult to control. (If we neglect the negligible emissions of methane, and disregard nitrous oxide emissions, for which only very little information exists, not to mention control options for this compound.)

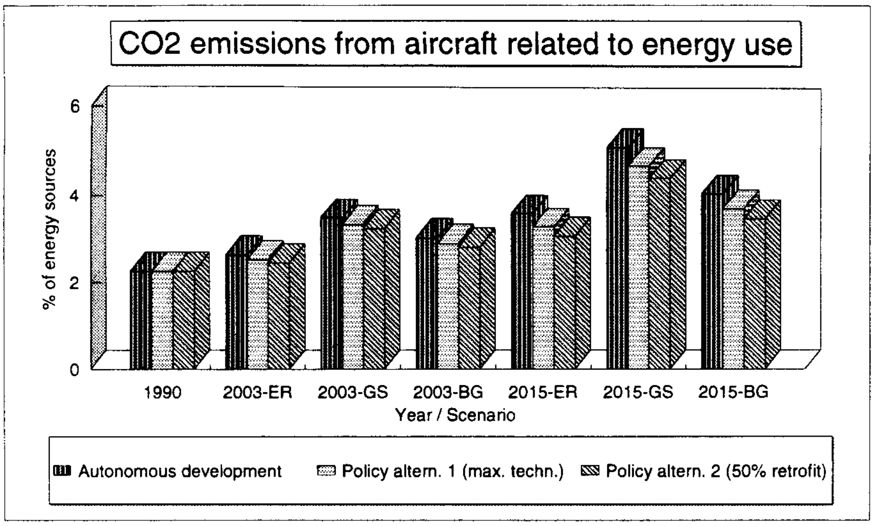
With regard to the effect of the policy alternatives as defined above, remember that the alternatives presented here are the 'maximum' cases, which will only be realized when all conditions are met.

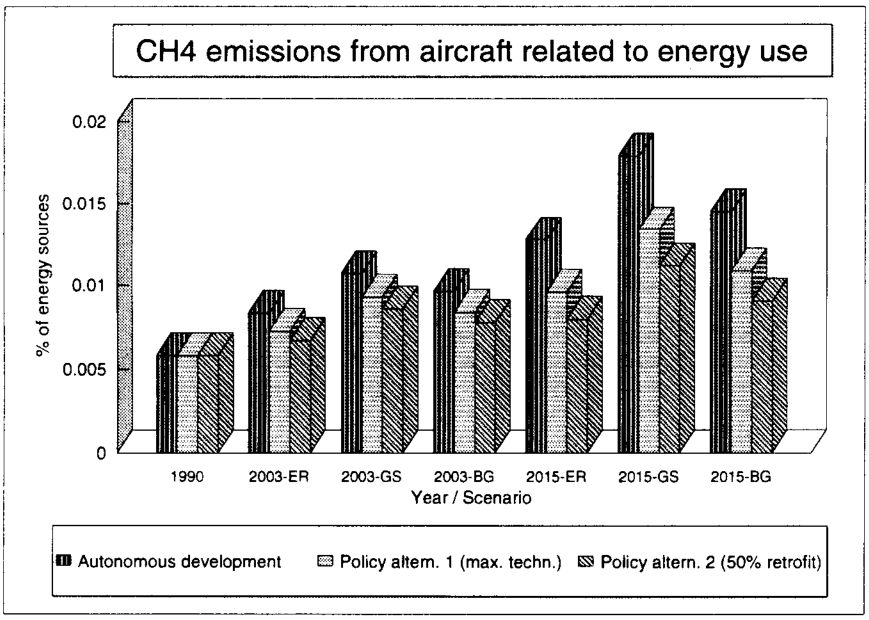
We recall that these conclusions will be modified, when more measures, including economic and operational measures, are combined instead of assuming only one measure per compound (see next chapter). This is also the case when the more stringent emission and SFC regulation measures would be introduced earlier, resulting in higher penetration rates in 2003 and 2015. However, as mentioned before, the practical potential for implementing emission controls will be only a part of the technical potential.

Finally we note the marked differences between the three reference scenarios, with ER showing lowest global emission share levels in 2015, GS showing the highest levels, and BG falling somewhere in between. These more pronounced differences in the fractions of energy-related emissions, rather than in the air traffic emissions themselves originate in the selected IPCC emission scenarios, which were 'related' to each of CPB scenarios, for which economic growth assumptions the development of air traffic was estimated.

Table 6.3: *Index of aircraft emissions as fraction of energy-related emissions for reference scenarios and alternative policies.*

Compound/policy	1990	2003			2015		
		ER0	GS0	BG0	ER0	GS0	BG0
CO2 - autonomous dev.	**1.00**	**1.17**	**1.54**	**1.34**	**1.58**	**2.27**	**1.79**
Policy altern. 1 (max. techn.)	1.00	*1.12*	*1.48*	*1.28*	*1.45*	*2.07*	*1.63*
Policy altern. 2 (50% retrofit)	1.00	*1.09*	*1.43*	*1.25*	*1.36*	*1.94*	*1.53*
CH4 -auton. dev.	**1.00**	**1.43**	**1.84**	**1.66**	**2.20**	**3.08**	**2.50**
Policy altern. 1 (max. techn.)	1.00	1.25	1.60	1.44	1.65	2.31	1.87
Policy altern. 2 (50% retrofit)	1.00	1.15	1.48	1.33	1.37	1.92	1.56
N2O - autonomous dev.	**1.00**	**1.17**	**1.54**	**1.34**	**1.58**	**2.27**	**1.79**
Lower range	1.00	*1.17*	*1.54*	*1.34*	*1.58*	*2.27*	*1.79*
Higher range	1.00	*1.17*	*1.54*	*1.34*	*1.58*	*2.27*	*1.79*
NOx - autonomous dev.	**1.00**	**1.06**	**1.40**	**1.22**	**1.31**	**1.87**	**1.47**
Policy altern. 1 (max. techn.)	1.00	*0.91*	*1.20*	*1.04*	*0.91*	*1.30*	*1.03*
Policy altern. 2 (50% retrofit)	1.00	*0.78*	*1.03*	*0.90*	*0.57*	*0.82*	*0.65*
SO2 - autonomous dev.	**1.00**	**1.17**	**1.54**	**1.34**	**1.58**	**2.27**	**1.79**
Policy altern. 1 (strong tech	1.00	*0.94*	*1.24*	*1.08*	*0.99*	*1.42*	*1.12*
Policy altern. 2 (50% compli	1.00	*0.83*	*1.09*	*0.95*	*0.69*	*0.99*	*0.78*
CO - autonomous dev.	**1.00**	**1.17**	**1.54**	**1.34**	**1.58**	**2.27**	**1.79**
Policy altern. 1 (max. techn.)	1.00	*1.02*	*1.34*	*1.17*	*1.19*	*1.70*	*1.34*
Policy altern. 2 (50% retrofit)	1.00	*0.94*	*1.24*	*1.08*	*0.99*	*1.42*	*1.12*
VOC - autonomous dev.	**1.00**	**1.17**	**1.54**	**1.34**	**1.58**	**2.27**	**1.79**
Policy altern. 1 (max. techn.)	1.00	*1.02*	*1.34*	*1.17*	*1.19*	*1.70*	*1.34*
Policy altern. 2 (50% retrofit)	1.00	*0.94*	*1.24*	*1.08*	*0.99*	*1.42*	*1.12*





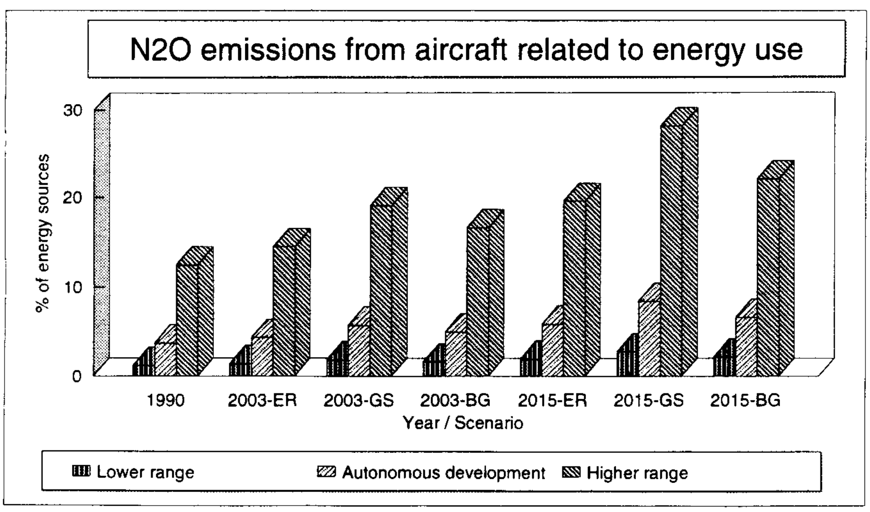
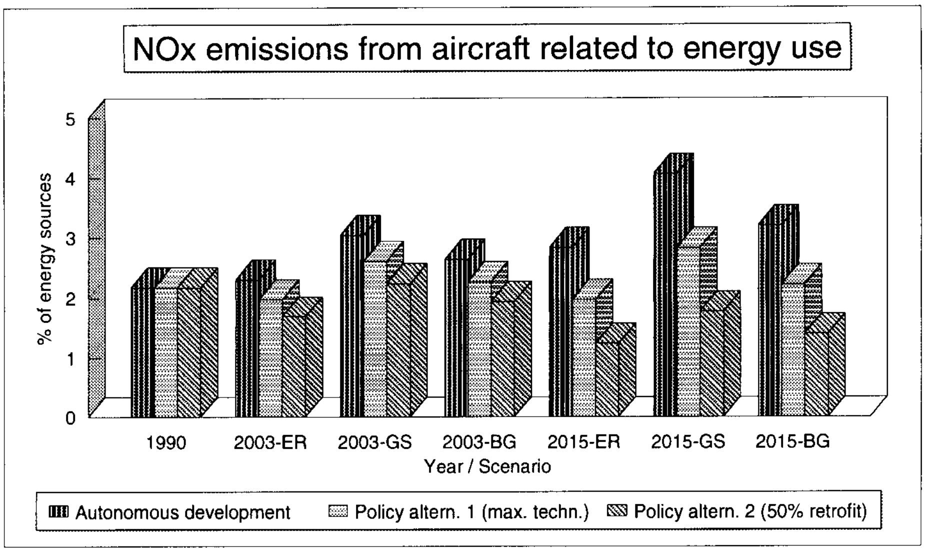


Figure 6.4.a: *Global emissions of CO_2, N_2O and CH_4 from aircraft related to energy use for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).*



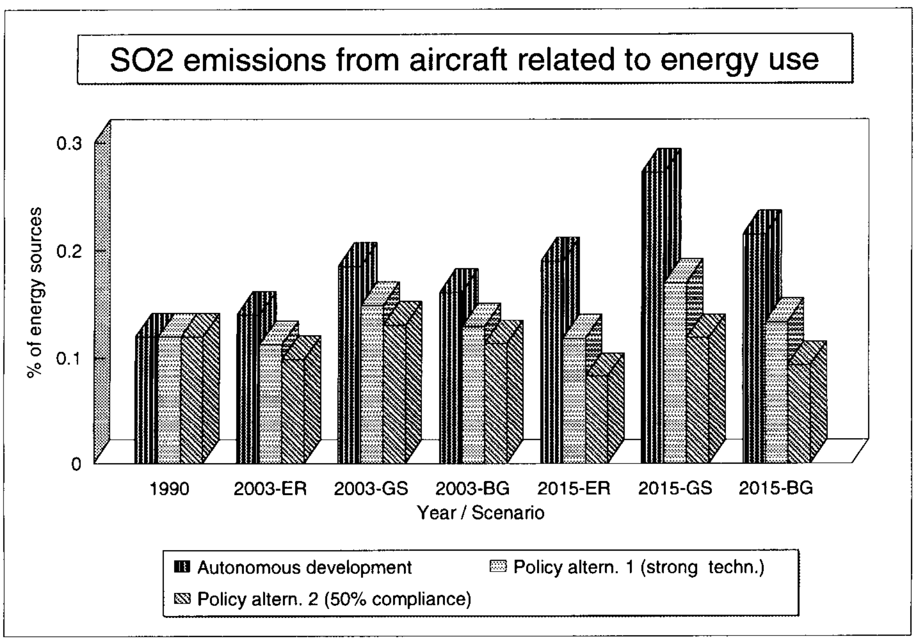
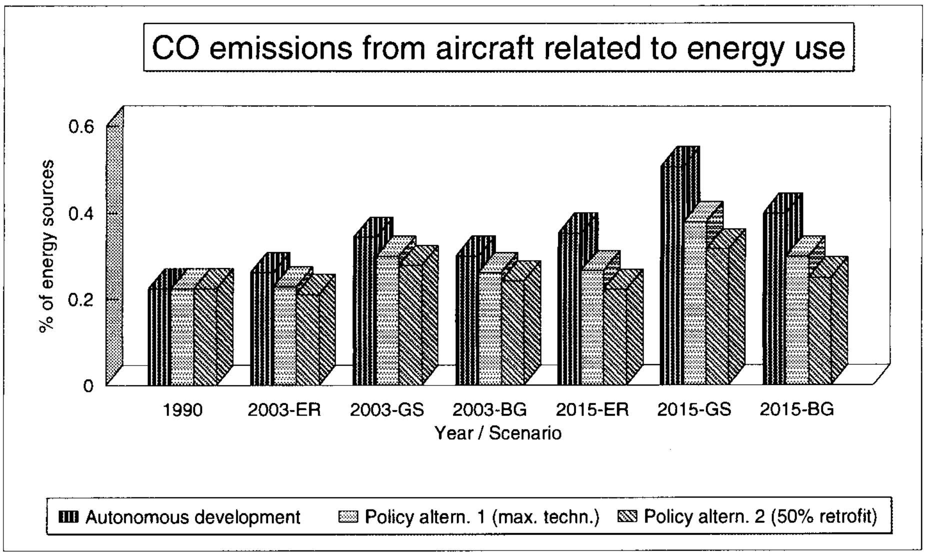


Figure 6.4.b: *Global emissions of NO_x and SO_2 from aircraft related to energy use for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).*



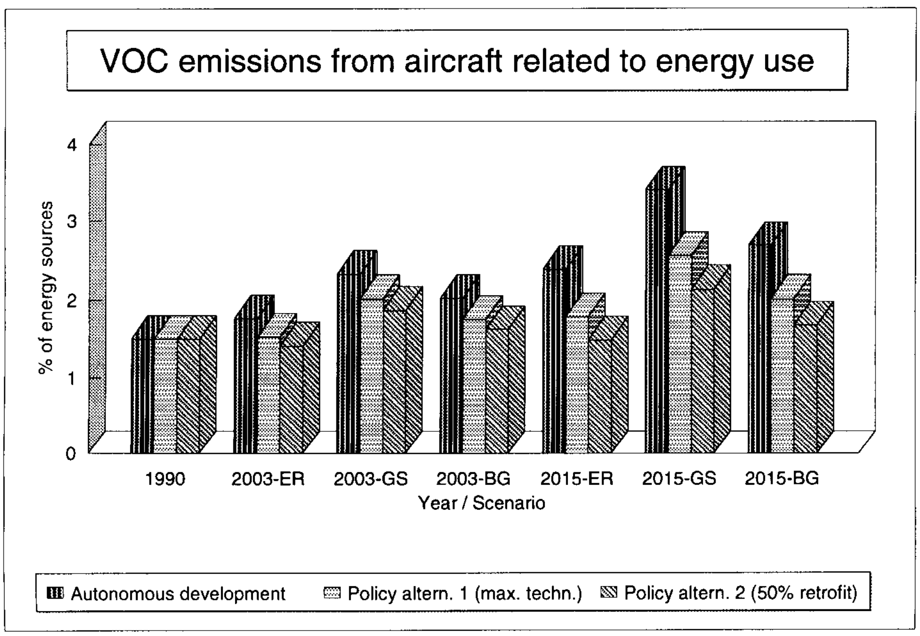


Figure 6.4.c: Global emissions of CO and VOC from aircraft related to energy use for 3 reference scenarios and 2 policy alternatives (50% and 75% implementation of technical measure).

7. INTEGRATED POLICIES FOR CO_2 AND NO_X EMISSIONS

In the previous chapters the influence of isolated technical or operational measures on the emissions of air traffic was discussed. Clearly, policy alternatives in which a group a measures is combined will have a stronger effect on emissions. To illustrate how the combined effect of a port-folio of control measures on emissions may work out, we shall illustrate this for its effect on CO_2 and NO_x emissions. These gases were selected as according to recent assessments of the IPCC they are of most importance for their contribution to the enhanced greenhouse effect and they are assumed to have roughly the same impact when considering the increased global warming effect of these compounds as emitted by aircraft. Also, NO_x emissions by aircraft are of most importance in relation to the formation of tropospheric ozone (Beck *et al., 1992)*.

The measures taken into consideration are presented individually for CO_2 and NO_x in Tables 7.1 and 7.2. They are both of a technical, operational, and of a economic nature, to give a feeling of the potential of each of these type of control options. The first two types relate in general to the measures described before, but are now combined to analyze the cumulative effect.

Table 7.1: *Factors affecting future CO_2 from aircraft and fleet average changes in 2015.* N.B. Policy alternatives are shown in *italics.*

Factor	Change of factor in 2015 (see notes)	Impact on emissions in 2015
0. Passenger-km (P-km) (autonomous, excluding load factor)	NA	+198% for ER (***)
1a. Load factor (fraction of seats occupied) (autonomous development)	+4% (to 69%) (*)	see below
1b. Passenger-km (P-km) (autonomous, incl. load factor)	-6.15%	-6.15%
2a. SFC of new aircraft (kg/P-km) [50% engine; 50% body] (autonomous)	-25% (*)	see below
2b. SFC of average fleet (kg/P-km) [50% engine; 50% body] (autonomous)	-12.5% (*)	-12.5%
3. Development of lowest SFC aircraft (engine and body)	*-15% (**)*	*see below*
3a. Development of lower SFC aircraft; moderate implementation	-2.5% (**)	-2.5%
3b. Development of low SFC aircraft; maximum implementation	*-7.5% (**)*	*-7.5%*
4. Ibidem; plus 50% retrofit of existing engines by 2015	*-5% (**)*	*-5.0%*
5. Additional load factor improvement	*+6% (to 75%) (**)*	*-8.7%*
6. Cost measures (increasing airfares)	*+15% (**)*	*-7.5%*

Notes:
(*) Relative to 1990. NA Not Applicable
(**) Relative to 2015 reference case. SFC Specific Fuel Consumption (kg fuel/P-km)

Table 7.2: *Factors affecting future NO_x from aircraft and fleet average changes in 2015.* N.B. Policy alternatives are shown in *italics.*

Factor	Change of factor in 2015 (see notes)	Impact on emissions in 2015 (per factor)
0. Passenger-km (P-km) (autonomous, excluding load factor)	NA	+198% for ER (***)
1a. Load factor (fraction of seats occupied) (autonomous development)	4% (to 69%) (*)	see below
1b. Passenger-km (P-km) (autonomous, incl. load factor)	-6.15%	-6.15%
2a. SFC of new aircraft (kg/P-km) [50% engine; 50% body] (autonomous)	-25% (*)	see below
2b. SFC of average fleet (kg/P-km) [50% engine; 50% body] (autonomous)	-17.5% (*)	-17.5%
3. Development of lowest NOx engines	*-85% (*)*	*see below*
3a. Development of lower NOx engines; moderate implementation	-25% (*)	-7.5%
3b. Development of lowest SFC aircraft; maximum implementation	*-42.5% (*)*	*-25.0%*
3c. Lowest NOx engines and lowest SFC aircraft ; maximum implement.	*-46.8% (*)*	*-30.6%*
4a. Lowest NOx engines: 50% retrofit of existing engines by 2015	*-63.8% (*)*	*-12.5%*
4b. Lowest NOx/SFC engines: 50% retrofit of existing engines by 2015	*-68.4% (*)*	*-9.6%*
5. Additional load factor improvement	*+6% (to 75%) (**)*	*-8.7%*
6. Cost measures (increasing airfares)	*+15% (**)*	*-7.5%*

Notes:
(*) Relative to 1990. NA Not Applicable
(**) Relative to 2015 reference case. SFC Specific Fuel Consumption (kg fuel/P-km)

In Tables 7.3 and 7.4 the cumulative effect of assumptions regarding the development of the Specific Fuel Consumption (SFC) and of the average emission factor for NO_x is summarized. Table 7.5 shows the combined effect on the development of the average emission factor for NO_x, including the SFC development. Presented are factors affecting the autonomous development and different types of policy options (the latter in italics) and their effect on new engines (bottom part) and on the fleet average (upper part).

Table 7.3: *Assumptions on the development of Specific Fuel Consumption (kg fuel/P-km).*

% of 1990	% diff. of 1990	Description
100%	0%	1990 average fleet
93.5%	-6.5%	2003 average fleet (13/25 of 2015 autonomous development)
87.5%	-12.5%	2015 average fleet (autonomous development)
85.0%	-15.0%	*2015 average fleet with lower SFC aircraft (moderate implementation)*
80%	*-20%*	*2015 average fleet with 50% penetration of lowest SFC aircraft (maximum implementation)*
75%	*-25%*	*Ibidem, plus 50% retrofit of existing engines*
75%	-25%	New aircraft (engines/bodies) in 2015 (autonomous development)
70%	-30%	*New, lower NOx engines in 2015 (developed with 'extra' R&D)*
60%	*-40%*	*New, lowest SFC aircraft (engines/bodies) in 2015 (developed with maximum R&D)*

Table 7.4: *Assumptions on the development of average NO_x emission factor (g NO2/kg fuel).*

% of 1990	% diff. of 1990	Description
100%	0%	1990 average fleet
90.9%	-9.1%	2003 average fleet (13/25 of 2015 autonomous development)
82.5%	-17.5%	2015 average fleet (autonomous development)
75.0%	-25.0%	*2015 average fleet with lower SFC aircraft (moderate implementation)*
57.5%	*-42.5%*	*2015 average fleet with 50% penetration of lowest SFC aircraft (maximum implementation)*
36.2%	*-63.8%*	*Ibidem, plus 50% retrofit of existing engines*
65%	-35%	New engines in 2015 (autonomous development)
50%	-50%	*New, lower NOx engines in 2015 (developed with 'extra' R&D)*
15%	*-85%*	*New, lowest NOx engines in 2015 (developed with maximum R&D)*

Table 7.5: *Development of average NO_x emission index (gNO2/P-km), including SFC development.*

% of 1990	% diff. of 1990	Description
100%	0%	1990 average fleet
85.5%	-14.5%	2003 average fleet (13/25 of 2015 autonomous development)
72.2%	-27.8%	2015 average fleet (autonomous development)
65.6%	*-34.4%*	*2015 average fleet with lower NOx aircraft (moderate implementation)*
50.3%	*-49.7%*	*2015 average fleet with 50% penetration of lowest NOx aircraft (maximum implementation)*
31.8%	*-68.2%*	*Ibidem, plus 50% retrofit of existing engines*
46.0%	*-54.0%*	*2015 average fleet with 50% penetration of low NOx engines and low SFC aircraft*
27.2%	*-72.8%*	*Ibidem, plus 50% retrofit of existing engines*
49%	-51%	New engines in 2015 (autonomous development of emission factor and SFC)
35%	-65%	*New, lower NOx engines in 2015 (developed with 'extra' R&D)*
9%	*-91%*	*New, lowest NOx/lowest SFC engines in 2015 (developed with maximum R&D)*

Cost measures, such as an increase in air fares, are considered as they may reduce emissions through their direct negative effects on the volume of air traffic (and indirectly, when taxes are based on fuel consumption and/or emissions). With regard to price measures, a global ticket price increase of 15% was taken into consideration - having an effect on the volume of air traffic of about -7.5% (using an assumed elasticity of -0.5) (Olivier and Veldhuis, 1993; pers. comm.). This percentage was selected as it corresponds roughly to:

* an increase of the fuel costs of 100%: ticket price +15%; or
* introduction of VAT (15 to 20%) added to the ticket price: ticket price about +15%.

Also, the effect of an increase of the landing costs of 100%, leading to an increase of ticket prices of about 5%, can easily be derived from the case of a ticket price increase of 15% since it is just one third of it. We recall, that in the reference scenarios for air fares an autonomous decrease was assumed of about 1% per year (Table 4.2).

The results are presented for the years 2003 and 2015 in absolute figures and indexed relative to 1990 in Tables 7.6 and 7.7 and graphically in Figures 7.1 and 7.2 for CO_2 and NO_x, respectively. The results of the ER0 scenario were used as the reference case. Shown is the cumulative impact of the port-folio of control options relative to the base line, applied in the order of their appearance in the tables/legends: technical options first, then load factor improvements, followed by cost measures. The effect of the technical and operational measures was again simply calculated by interpolation (for 2003 by taking 13/25 of the effect in 2015); the cost measure was assumed to be fully implemented in 2000.

It shows that the effect of autonomous development of both SFC and load factor is substantial and should not be neglected in comprehensive emissions assessments. Thus, emissions are rather strongly influenced by the assumptions made regarding these parameters. Our assumptions were based on Peper (1993b,c) and Newton (1993) and are in agreement with findings of Greene *et al.* (1992) and - for the USA, which accounts for over 40% of global jet fuel consumption - with results of the EIA scenario (see Appendix L), when compared with development in the ER0 reference case of CO_2, thus fuel consumption, in North America. As mentioned in Chapter 5, the technical policy options represent the maximum assumed to be technologically achievable within a few decades. Therefore, the practical potential of this group for reducing emissions is probably be smaller. Having said this, we see that in this example the effects on CO_2 emissions of technical, operational and cost measures, respectively, are roughly of the same order.

Comparison of the results for the two gases shows that the potential for reduction of NO_x emissions is quite larger than of CO_2 emissions. In particular the impact of the technical measures - assuming they are fully implemented, also as partial retrofit of the existing fleet - is substantial. Being placed on top of these measures, the effect of additional load factor increase and cost measures on NO_x emissions does not show up very pronounced. This is, however, also due to the order of accumulation presented here and due to the large assumed effect of the technical measures.

Table 7.6: *Emission scenarios for CO_2 from air traffic for different policy alternatives (Mton CO_2 and index).* Shown here is the cumulative impact of control options applied in the order of their position in the table.

	1990	2003			2015		
CO2 emissions (Mton)	**1990**	**2003-ER**	**2003-GS**	**2003-BG**	**2015-ER**	**2015-GS**	**2015-BG**
0. Passenger-km (autonomous, excluding load factor)	498	906	1,093	1,077	1,718	2,146	2,047
1. Passenger-km (P-km) (autonomous, incl. load factor)	498	877	1,058	1,042	1,613	2,014	1,921
2. SFC of average fleet (kg/P-km) (autonomous)	498	820	989	975	1,411	1,763	1,681
3a. Development of lower SFC aircraft; moderate implementation	498	*809*	*976*	*961*	*1,371*	*1,712*	*1,633*
3b. Development of lowest SFC aircraft; maximum implementation	498	*786*	*948*	*934*	*1,290*	*1,611*	*1,537*
4. Ibidem; plus 50% retrofit of existing engines by 2015	498	*763*	*921*	*907*	*1,209*	*1,511*	*1,441*
5. Additional load factor improvement	498	*729*	*879*	*866*	*1,104*	*1,379*	*1,316*
6. Cost measures (increasing airfares, effective from 2000)	498	*674*	*813*	*801*	*1,021*	*1,276*	*1,217*
CO2 emissions (index relative to 1990)	**1990**	**2003-ER**	**2003-GS**	**2003-BG**	**2015-ER**	**2015-GS**	**2015-BG**
0. Passenger-km (autonomous, excluding load factor)	1	1.82	2.19	2.16	3.45	4.31	4.11
1. Passenger-km (P-km) (autonomous, incl. load factor)	1	1.76	2.12	2.09	3.24	4.04	3.86
2. SFC of average fleet (kg/P-km) (autonomous)	1	1.65	1.99	1.96	2.83	3.54	3.37
3a. Development of lower SFC aircraft; moderate implementation	1	*1.62*	*1.96*	*1.93*	*2.75*	*3.44*	*3.28*
3b. Development of lowest SFC aircraft; maximum implementation	1	*1.58*	*1.90*	*1.87*	*2.59*	*3.23*	*3.09*
4. Ibidem; plus 50% retrofit of existing engines by 2015	1	*1.53*	*1.85*	*1.82*	*2.43*	*3.03*	*2.89*
5. Additional load factor improvement	1	*1.46*	*1.76*	*1.74*	*2.22*	*2.77*	*2.64*
6. Cost measures (increasing airfares, effective from 2000)	1	*1.35*	*1.63*	*1.61*	*2.05*	*2.56*	*2.44*

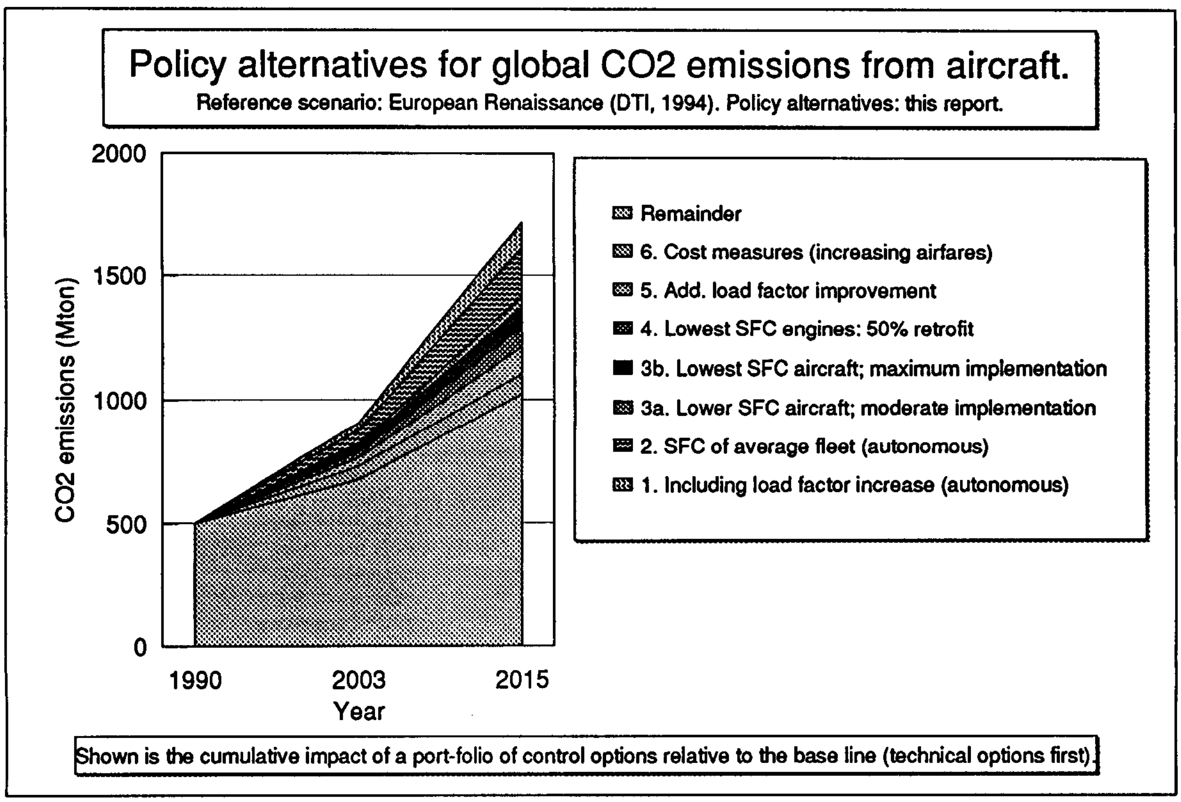


Figure 7.1: *Policy alternatives for global emissions of CO_2 from air traffic. Shown is the cumulative impact of a port-folio of control options relative to the base line scenario, applied in the order of their number.*

Table 7.7: *Emission scenarios for NO_x from air traffic for different policy alternatives (kton NO_x and index).* Shown here is the cumulative impact of control options applied in the order of their position in the table.

	1990	2003			2015		
NOx emissions (kton)	1990	2003-ER	2003-GS	2003-BG	2015-ER	2015-GS	2015-BG
0. Passenger-km (autonomous, excluding load factor)	1,786	2,953	3,561	3,508	5,081	6,347	6,054
1. Passenger-km (P-km) (autonomous, incl. load factor)	1,786	2,858	3,447	3,396	4,768	5,956	5,681
2. SFC of average fleet (kg/P-km) (autonomous)	1,786	2,673	3,223	3,175	4,172	5,212	4,971
3a. Development of lower NOx engines; moderate implementation	1,786	*2,558*	*3,085*	*3,039*	*3,793*	*4,738*	*4,519*
3b. Development of lowest SFC aircraft; maximum implementation	1,786	*2,290*	*2,762*	*2,721*	*2,908*	*3,632*	*3,465*
3c. Lowest NOx engines and lowest SFC aircraft ; maximum implement.	1,786	*2,195*	*2,305*	*2,270*	*2,742*	*3,425*	*3,267*
4a. Lowest NOx engines: 50% retrofit of existing engines by 2015	1,786	*1,966*	*2,370*	*2,335*	*1,833*	*2,290*	*2,184*
4b. Lowest NOx/SFC engines: 50% retrofit of existing engines by 2015	1,786	*1,829*	*2,206*	*2,173*	*1,571*	*1,963*	*1,872*
5. Additional load factor improvement	1,786	*1,746*	*2,106*	*2,075*	*1,435*	*1,792*	*1,709*
6. Cost measures (increasing airfares, effective from 2000)	1,786	*1,615*	*1,948*	*1,919*	*1,327*	*1,658*	*1,581*
NOx emissions (index relative to 1990)	1990	2003-ER	2003-GS	2003-BG	2015-ER	2015-GS	2015-BG
0. Passenger-km (autonomous, excluding load factor)	1	1.65	1.99	1.96	2.85	3.55	3.39
1. Passenger-km (P-km) (autonomous, incl. load factor)	1	1.60	1.93	1.90	2.67	3.34	3.18
2. SFC of average fleet (kg/P-km) (autonomous)	1	1.50	1.81	1.78	2.34	2.92	2.78
3a. Development of lower NOx engines; moderate implementation	1	*1.43*	*1.73*	*1.70*	*2.12*	*2.65*	*2.53*
3b. Development of lowest SFC aircraft; maximum implementation	1	*1.28*	*1.55*	*1.52*	*1.63*	*2.03*	*1.94*
3c. Lowest NOx engines and lowest SFC aircraft ; maximum implement.	1	*1.23*	*1.29*	*1.27*	*1.54*	*1.92*	*1.83*
4a. Lowest NOx engines: 50% retrofit of existing engines by 2015	1	*1.10*	*1.33*	*1.31*	*1.03*	*1.28*	*1.22*
4b. Lowest NOx/SFC engines: 50% retrofit of existing engines by 2015	1	*1.02*	*1.24*	*1.22*	*0.88*	*1.10*	*1.05*
5. Additional load factor improvement	1	*0.98*	*1.18*	*1.16*	*0.80*	*1.00*	*0.96*
6. Cost measures (increasing airfares, effective from 2000)	1	*0.90*	*1.09*	*1.07*	*0.74*	*0.93*	*0.89*

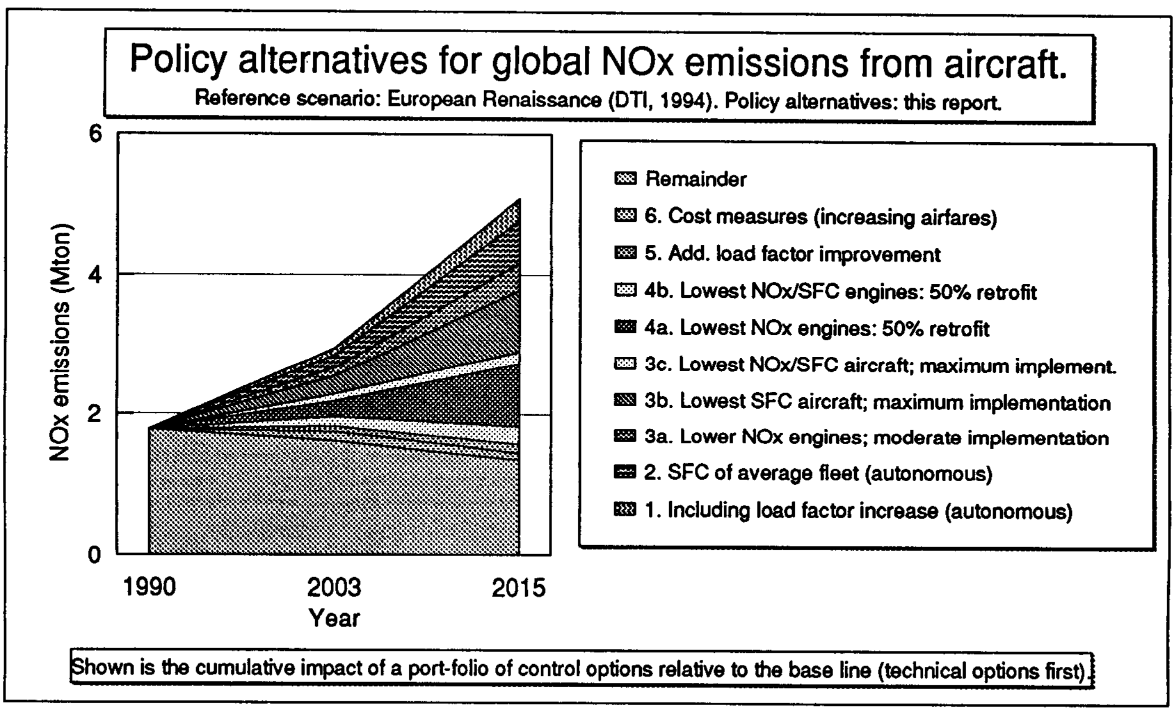


Figure 7.2: *Policy alternatives for global emissions of NO_x from air traffic.* Shown is the cumulative impact of a port-folio of control options relative to the base line scenario, applied in the order of their number.

By and large, we can conclude that - assuming it will be possible to develop new aircraft with both improved SFC and lower emission factors for NO_x - there will be a synergy in NO_x reducing options. Realizing that improvement of the Specific Fuel Consumption is not only a matter of improving the combustion efficiency of the engine, but also reducing the aerodynamic drag of the aircraft itself, this assumption may be a sensible one. Taking into account that with regard to the greenhouse effect of aircraft emissions the impact of CO_2 and NO_x emissions are roughly of the same order, the cases presented here suggest that it is unlikely that the CO_2 equivalent emissions from air traffic will decrease in the near future. The effects of individual policy options, either being technical, or operational or economic, are limited (Figure 7.1 and 7.2). However, through the combined impact of these different types of measures, a substantial reduction of the foreseen continued growth of emissions as illustrated by the reference scenarios may be quite possible.

8. CONCLUSIONS

We have studied the development of global emissions of various gases by air traffic in relation to the emission by other sources. Using GNP assumptions of three CPB scenarios "ER", "GS" and "BG", together with some other specific assumptions regarding air traffic and with the assistance of DTI, it was possible to generate three reference aircraft emissions scenarios. By simply relating one of the IPCC IS92 scenarios to each of the CPB scenarios, we compared estimates of future global aircraft emissions with global surface source emissions (Table 6.2). From our scenario studies we tentatively conclude that there will likely be a substantial growth of global aircraft emissions in the base case of autonomous development (varying from 140-190% for NO_x to 180-250% for other compounds), also including the substantial effects of the assumed autonomous improvement of the fleet average Specific Fuel Consumption and load factor (Table 6.3). The contribution of North America to total aircraft emissions will remain high, but by 2015 the share of the Far East has increased almost to a similar level (Figure I.1). If the environmental impact of emissions is rather dependent on the spatial distribution, this factor should be included carefully.

Emissions of methane can be neglected as they are extremely small, also compared to other sources (Table 6.2). Emissions of nitrous oxide on the other hand are rather uncertain, but total energy related N_2O emissions are only a minor anthropogenic source (Tables 6.2 and 4.6).

Strong technological measures may reduce emissions substantially, when implementation to a high degree is realized. In this respect we can distinguish three groups of compounds with rather similar effects on the share in energy-related emissions (assuming no change in other energy-related emissions) (Table 6.3):

* NO_x and SO_2: controlled emissions share may be stabilized (GS), or reduced up to 40% (ER);
* CO and VOC: controlled emissions share may be stabilized (ER), or growth limited up to 40% (GS);
* CO_2, CH_4 and N_2O: controlled growth of the share limited to 40% (ER) to 90% (GS), except for N_2O in GS (130%).

These percentages are only meant to give an indication of what could be achieved 'at maximum' by technical control options; the practical potential is a fraction of this. However, we conclude that the growth of NO_x and SO_2 emissions may be controlled technically most effectively, whereas CO_2 emissions are most difficult to control. It was illustrated that the cumulative effect of different control options - either being technical, or operational or economic - can be substantial, in particular with regard to NO_x emissions (Table 7.7; Figure 7.2).

With respect to CO_2 emissions the selected examples showed that the effect of each type of control option can be of a similar size (Table 7.6; Figure 7.1) and that the combined effect on CO_2 and NO_x emissions could result in a substantial limitation, or even a reduction in absolute figures, of the uncontrolled growth of emissions - if the assumed strong technological development is indeed taking place and is implemented to a high degree.

With the available gridded emission inventories for air traffic and for surface sources (including temporal information), through the process of aggregating the air traffic and surface source emission scenarios and coupling to the aggregated inventories, we were able to generate 3D emission fields related to the regional emission scenarios as input for atmospheric modellers. Regarding the temporal distribution of air traffic, it was shown that in particular flights between North America and (Western) Europe show a very strong seasonality effect, as is the case for flights within Europe. This is an important factor since the height of the tropopause does also vary per season.

This study appeared to be unique in that it combined the results of an air traffic projection model with a gridded air traffic emissions database to generate for future years three dimensional spatial distributions of aircraft emissions using well recognized and documented reference scenarios, thus allowing a comprehensive assessment of the atmospheric impact of aircraft emissions relative to other sources (e.g. by Veenstra *et al., 1995)*.

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APPENDIX A: Decision points for scenarios for global environmental assessments of air traffic.

1 ***Definition of areas*:**
For calculation of global emissions from air traffic and other emission sources we may use aggregated world regions such as the four world regions distinguished by the IPCC in its greenhouse gas scenarios:
- OECD,
- (former) Centrally Planned Europe (Eastern Europe and the former USSR),
- China and other Asian Centrally Planned Economies,
- Rest of the World.

For more detailed emission calculations about ten regions could be used, such as: the CPB regions, the IMAGE/EDGAR regions, the ABC regions (also used in the WSL air traffic database, and the regions used in the DTI scheduled air traffic projection model (IATA regions).

2 ***Time horizon*:**
Base year: 1990
Reference year: 2000, 2003, 2015 [comply with the PMMS assessment].

3 ***Level of detail of air traffic*:**
Civil air traffic (sum of civil aviation, scheduled and charter flights); military air traffic
For global emission assessments rather large categories will do; for effects calculations (e.g. tropospheric and stratospheric ozone) more detail is required amongst others with respect to the altitude resolution which is demanded by the atmospheric modellers groups.

4 ***Compounds*:**
NO_x, CO, VOC, SO_2, CO_2, CH_4; N_2O and aerosols (when possible); plus H_2O and soot.
[N.B. It is acknowledged that emission calculations for N_2O and aerosols have a very large uncertainty.]

5 ***Environmental themes for emissions and effect evaluation*:**
Ozone (tropospheric; stratospheric), acidification and climate. For calculation of effects on ozone (tropospheric) by RIVM/LLO and KNMI information on the spatial distribution of emissions of NO_x, CO, CH_4 and VOC is required (3D grid of 5x5 degree x 0,5 km altitude). [Evaluation of the effects on stratospheric ozone and climate is only possible by analysis and literature study.]

6 ***Relate emissions to*:**
Comparison of air traffic emissions with other emissions, e.g. from total transportation, total energy use, total anthropogenic emissions (per compound and by environmental theme)

7 ***Baseline scenario*:**
Air traffic:
* **Basic-1:** *without large SST fleet in 2015*;
* **Basic-2:** *with SST fleet in 2015 cf. HSRP-scenario of NASA*;

activities for both scenarios from CPB studies for 'Scanning the Future', extrapolated from 2015 to 2025; emissions factors from IPCC reports and from NLR study, and from NASA scenarios for SST, respectively.
Other sources: a Business as Usual scenario of IPCC.
Preferably, both should have the same assumptions on key variables, e.g. regional development of GNP.

8 ***Policy alternatives: sets of policy measures:***
Type of measures: (a) technical (e.g. emissions standards), (b) operational (e.g. taxiing), and (c) volume/price (economic measures).

APPENDIX B: Overview of models to generate emissions scenarios for air traffic.

Model (owner)	Spatial coverage	Base year	Reference year	Key variables	Output	Concluding remarks	Reference
RLD (IEE)	Schiphol	1990	2003, 2015	network conc., prices, transportprod., envir. policy measures	aircraft movements, destinations, distances, passenger movem., tonnes of freight, economic effects	- Not fully covering the Netherlands, - Includes substit. by High Speed Trains - No fuel and emissions as output (off-line calculation)	Veldhuis, 1993
ICAO	World excluding China, former USSR excl. military	1990	2000, 2010	location-km, load factor, SFC, fleet mix, costs, internat. trade	P-km, t-km international and domestic, regional	- No charters - No China, former USSR - No military - No emissions	ICAO, 1989
DTI	World excluding China, former USSR excl. military	1990	1991.. 2015	GNP, prices, other costs, fleet mix, policy measures, aircraft types/ranges	seat-km offered, per size band/range, per region	- No China, former USSR (yet) - No military - 10 world regions - No emissions	Newton, 1993
Boeing	Sub-sonic, world, scheduled only	1987	2000, 2015	? fleet mix, load factor, SFC emission factors	fuel consumption, emissions (3 *) per altitude and latitude zone	- No freight - No charters - No military - No China, former USSR, E. Eur. - Based on 29 000 city pairs	Wuebbles, 1992
McDonnel Douglas	Sub-sonic, world excluding ..	?	?	?	?	- P.M.	
Boeing	Supersonic	-	2015	625 HSCTs, Mach 2.4 load factor 0.65 ?	fuel consumption, emissions (3 *) per altitude and latitude zone	- 235 city pairs - cruising altitude 18 km	Wuebbles, 1992
McDonnel Douglas	Supersonic, between 10 regions	-		x HSCTs, Mach 3.2 load factor +- 0.70 ?	fuel consumption, emissions (3 *) per altitude and latitude zone	- 10 city pairs - cruising altitude 18-24 km	Wuebbles, 1992
FAA/ATC	?	?	?	?	?	- P.M.	
IMAGE (ESCAPE version) (RIVM)	World, 4 regions	1990	until 2100	p-km, t-km, SFC, load factor, fuel price elasticity, emission factors	fuel consumption, emissions (6 **), fuel costs, per regions	- No military - Distinction in 2 aircraft types - Includes China and former USSR	CRU/ERL, 1992
CPB	World, 12 regions	1990	2015	GNP, interreg. trade?		Aggregated calculation of air traffic	Veldhuis, 1993

Notes:

* NOx, CO and VOC.

** All greenhouse gases: CO_2, CH_4, N_2O, CO, NOx, VOC

APPENDIX C: Emissions and fuel consumption in the NASA/HSRP global total air traffic inventory.

Table C.1: NASA/HSRP base year data on aircraft activities (1990).

Altitude (in km) up to..	Fuel consumption (10^9 kg)	Fuel consumption (PJ/yr)	Emissions NOx (10^30 molec.)	NOx (Tg/yr)	VOC (10^30 molec.)	VOC (Tg/yr)	CO (10^30 molec.)	CO (Tg/yr)	Emission factors NOx (g/kg)	VOC (g/kg)	CO (g/kg)	Altitude (in km) up to..
<1 = LTO	15.1	673.2	2387.6	0.182	1766.6	0.047	4111.7	0.191	12.1	3.1	12.7	<1 = LTO
1-2	4.9	217.8	760.6	0.058	319.1	0.008	1018.9	0.047	11.9	1.7	9.7	1-2
3	3.9	174.7	696.9	0.053	307.2	0.008	699.5	0.033	13.6	2.1	8.3	3
4	4.2	187.4	818.1	0.062	292.3	0.008	653.6	0.030	14.9	1.8	7.2	4
5	3.6	161.7	666.6	0.051	290.8	0.008	624.2	0.029	14.0	2.1	8.0	5
6	3.4	152.3	623.1	0.048	304.7	0.008	638.2	0.030	13.9	2.4	8.7	6
7	4.4	196.7	640.7	0.049	317.1	0.008	1028.4	0.048	11.1	1.9	10.8	7
8	4.9	218.8	678.7	0.052	426.2	0.011	1177.9	0.055	10.6	2.3	11.2	8
9	4.4	194.8	636.3	0.049	551.2	0.015	1050.7	0.049	11.1	3.4	11.2	9
10 \	10.2	453.4	1350.7	0.103	855.7	0.023	2187.2	0.102	10.1	2.2	10.0	10 \
11 cruise	39.5	1760.7	4865.7	0.372	2845.2	0.076	5210.3	0.242	9.4	1.9	6.1	11 cruise
12 /	30.6	1362.4	4527.5	0.346	2815.0	0.075	3815.0	0.177	11.3	2.4	5.8	12
13	3.2	141.9	328.5	0.025	1175.1	0.031	1290.5	0.060	7.9	9.8	18.9	13 /
14	1.0	45.1	128.0	0.010	459.2	0.012	322.7	0.015	9.7	12.1	14.8	14
15	0.2	10.2	16.4	0.001	381.0	0.010	227.0	0.011	5.5	44.3	46.2	15
16	0.2	8.5	20.6	0.002	97.4	0.003	76.6	0.004	8.2	13.6	18.7	16
17	0.038	1.7	3.0	0.000	10.9	0.000	54.9	0.003	6.1	7.7	68.0	17
18	0.050	2.2	3.9	0.000	15.4	0.000	77.4	0.004	6.0	8.2	72.3	18
19	0.014	0.6	1.1	0.000	4.6	0.000	23.1	0.001	5.9	8.5	74.9	19
Total:	133.75	5964.3	19154.0	1.46	13234.7	0.35	24287.8	1.13	10.94	2.63	8.44	Total
Global total/average <13 km:	132.22	5896.0	18981.0	1.45	12266.2	0.33	23506.1	1.09	10.97	2.46	8.27	< 13 km
> 13 km:	1.53	68.3	173.0	0.01	968.5	0.03	781.7	0.04	8.63	16.80	23.73	> 13 km

source: NASA, HSRP (1993); analyzed by EDGAR/RIM+ (RIVM, 1994)

Table C.2: Summary table of HSRP fuel consumption 1990 by altitude ranges.

Flight mode/altitude	kg	PJ	%	% of NOx	Tg NOx	% of VOC	Tg VOC	% of CO	Tg CO	EF NOx	EF VOC	EF CO	Flight mode/altitude
sum of LTO (< 1):	15.1	673.2	11.3	12.5	0.18	13.3	0.05	16.9	0.19	12.08	3.11	12.66	sum of LTO (< 1)
sum of climb_approach:	33.7	1504.4	25.2	28.8	0.42	21.2	0.07	28.4	0.32	12.50	2.21	9.50	sum of climb_approach
sum of cruise (9-13):	83.4	3718.4	62.3	57.8	0.85	58.1	0.20	51.5	0.58	10.14	2.45	6.97	sum of cruise (8-13)
sum of 13 km up:	1.5	68.3	1.1	0.9	0.01	7.3	0.03	3.2	0.04	8.63	16.80	23.73	sum of SST (?)
Total:	133.8	5964.3	100.0	100.0	1.46	100.0	0.35	100.0	1.13	10.94	2.63	8.44	Total

source: NASA, HSRP (1993); analyzed by EDGAR/RIM+ (RIVM, 1994)

N.B. 1 6247 cells for LTO activities (< 1km)
26225 cells (= maximum) in 11-12 km band

N.B. 2 1 lb = 0.4536 kg
1 mol = 6.022*10^23
1 mol NO2 = 46 g
1 mol CO = 28 g
1 mol VOC = 16 g (all VOC expressed as CH4)

APPENDIX C: Continued.

Table C.3: Altitude distribution of fuel consumption and emissions per hemisphere.

Northern Hemisphere

Altitude (up to .. km)	Fuel cons. 10^6 kg	NOx 10^6 kg	VOC 10^6 kg	CO 10^6 kg
<1	14230.0	172.4	42.7	176.1
1-2	4550.0	53.8	7.4	43.4
3	3619.0	49.2	7.2	29.6
4	3930.0	58.1	6.9	28.0
5	3390.0	47.4	6.9	26.7
6	3190.0	44.2	7.2	27.3
7	4094.0	45.8	7.5	42.4
8	4658.0	48.7	10.3	51.5
9	4156.0	45.8	13.8	46.7
10	9719.0	97.4	21.8	99.3
11	37480.0	349.2	73.0	234.5
12	28340.0	318.9	69.7	166.3
13	3044.0	24.2	28.0	56.3
14	978.2	9.6	10.9	13.6
15	228.3	1.2	10.1	10.5
16	190.9	1.6	2.6	3.6
17	37.6	0.2	0.3	2.6
18	49.8	0.3	0.4	3.6
19	14.3	0.1	0.1	1.1
Total NH:	125899.1	1368.0	326.6	1063.1

Southern Hemisphere

Altitude (up to .. km)	Fuel cons. 10^6 kg	NOx 10^6 kg	VOC 10^6 kg	CO 10^6 kg
<1	885.3	10.0	4.2	15.1
1-2	339.3	4.3	1.1	4.0
3	302.1	4.0	1.0	2.9
4	275.9	4.4	0.9	2.4
5	240.9	3.5	0.8	2.3
6	228.6	3.4	0.9	2.4
7	321.2	3.2	0.9	5.4
8	254.3	3.2	1.0	3.3
9	217.2	2.8	0.9	2.1
10	457.8	5.8	0.9	2.4
11	2035.0	22.5	2.6	7.7
12	2239.0	26.9	5.1	11.1
13	142.4	0.9	3.3	3.7
14	33.6	0.2	1.4	1.4
15	0.5	0.0	0.0	0.0
16	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0
Total SH:	7973.0	95.1	25.1	66.2

Table C.4: Distribution of fuel consumption and emissions over the hemispheres.

Altitude Hemisphere	Fuel cons. 10^6 kg/%	NOx 10^6 kg/%	VOC 10^6 kg/%	CO 10^6 kg/%
NH + SH:	133872.1	1463.1	351.6	1129.3
% NH	94.0	93.5	92.9	94.1
% SH	6.0	6.5	7.1	5.9

Table C.5: Altitude distribution of fuel consumption and emissions over the hemispheres.

Altitude (up to .. km)	Fuel consumption NH %	SH %	NOx emission NH %	SH %
<1	94.1	5.9	94.5	5.5
1-2	93.1	6.9	92.5	7.5
3	92.3	7.7	92.4	7.6
4	93.4	6.6	93.0	7.0
5	93.4	6.6	93.0	7.0
6	93.3	6.7	92.9	7.1
7	92.7	7.3	93.6	6.4
8	94.8	5.2	93.9	6.1
9	95.0	5.0	94.2	5.8
10	*95.5*	*4.5*	*94.3*	*5.7*
11	*94.9*	*5.1*	*94.0*	*6.0*
12	*92.7*	*7.3*	*92.2*	*7.8*
13	*95.5*	*4.5*	*96.3*	*3.7*
14	96.7	3.3	98.1	1.9
15	99.8	0.2	99.9	0.1
16	100.0	0.0	100.0	0.0
17	100.0	0.0	100.0	0.0
18	100.0	0.0	100.0	0.0
19	100.0	0.0	100.0	0.0
Global total:	94.0	6.0	93.5	6.5

APPENDIX D: Emission factors for NO_x and CO used in the WSL civil air traffic inventory.

Table D.1: Emission factors for NOx and CO, TIM's and flight altitudes of WSL aircraft types

Short Range (< 500 Nm)

Type 1: Short/medium range - narrow body - High NOx
Range: < 500 nm (268 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	14	Climb start	1.5	Taxi	5	2.8
Take-off	1.7	Climb end	29	Take-off	5	22.4
Climb	9.7	Cruise alt.	29	Climb start	1	18.5
Descend	17	Cruise alt. 2	-	Cruise	1	7.5
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	7	-
				Appr./landing	1	7.5

Type 2: Short/medium range - narrow body - Low NOx
Range: < 500 nm (258 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	14	Climb start	1.5	Taxi	14	2.5
Take-off	1.5	Climb end	29	Take-off	0	17.4
Climb	12.6	Cruise alt.	29	Climb start	0	14.2
Descend	14.2	Cruise alt. 2	-	Cruise	1	6.7
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	12	-
				Appr./landing	3	6.4

Type 3: Longe range - narrow body
Range: < 500 nm (258 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out		Climb start		Taxi		2.3
Take-off		Climb end		Take-off		13.1
Climb		Cruise alt.		Climb start		10.0
Descend		Cruise alt. 2	-	Cruise		10.5
Appr./landing		Descend end		Climb 2		-
				Descend		-
				Appr./landing		5.5

Type 4: Medium range - wide body
Range: < 500 nm (300 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	12	3.9
Take-off	1.4	Climb end	29	Take-off	0	34.5
Climb	10.1	Cruise alt.	29	Climb start	1	29.4
Descend	16.1	Cruise alt. 2	-	Cruise	3	10.5
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	9	-
				Appr./landing	0	10

Type 5: Lang range - wide body - High NOx
Range: < 500 nm (288 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	21	3.4
Take-off	1.9	Climb end	29	Take-off	1	40.2
Climb	8.5	Cruise alt.	29	Climb start	5	26.7
Descend	16.6	Cruise alt. 2	-	Cruise	3	7.8
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	44	-
				Appr./landing	1	8.8

Type 6: Lang range - wide body - Low NOx
Range: < 500 nm (258 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	11	3.5
Take-off	1.9	Climb end	29	Take-off	1	37.5
Climb	14.1	Cruise alt.	29	Climb start	2	29.7
Descend	12.7	Cruise alt. 2	-	Cruise	2	10.2
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	10	-
				Appr./landing	1	10

Medium Range (500-1500 Nm)

Type 1: Short/medium range - narrow body - High NOx
Range: 500-1500 nm (814 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	5	2.8
Take-off	14	Climb end	37	Take-off	0	22.4
Climb	1.8	Cruise alt.	37	Climb start	1	16.8
Descend	21	Cruise alt. 2	-	Cruise	6	6.7
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	8	-
				Appr./landing	1	7.5

Type 2: Short/medium range - narrow body - Low NOx
Range: 500-1500 nm (702 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	14	Climb start	1.5	Taxi	14	2.5
Take-off	1.6	Climb end	33	Take-off	0	17.4
Climb	16.3	Cruise alt.	33	Climb start	0	13.6
Descend	16.6	Cruise alt. 2	-	Cruise	2	6
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	15	-
				Appr./landing	3	6.4

Type 3: Longe range - narrow body
Range: 500-1500 nm (702 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out		Climb start		Taxi		2.3
Take-off		Climb end		Take-off		13.1
Climb		Cruise alt.		Climb start		10.0
Descend		Cruise alt. 2	-	Cruise		9.2
Appr./landing		Descend end		Climb 2		-
				Descend		-
				Appr./landing		5.5

Type 4: Medium range - wide body
Range: 500-1500 nm (866 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	12	3.9
Take-off	1.4	Climb end	39	Take-off	0	34.5
Climb	16.3	Cruise alt.	39	Climb start	2	25.9
Descend	20.7	Cruise alt. 2	-	Cruise	9	9.2
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	12	-
				Appr./landing	0	10

Type 5: Lang range - wide body - High NOx
Range: 500-1500 nm (827 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	21	3.4
Take-off	1.9	Climb end	39	Take-off	1	40.2
Climb	15.3	Cruise alt.	39	Climb start	8	26.1
Descend	21.7	Cruise alt. 2	-	Cruise	14	8.4
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	132	-
				Appr./landing	1	8.8

Type 6: Lang range - wide body - Low NOx
Range: 500-1500 nm (924 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	11	35
Take-off	1.7	Climb end	39	Take-off	1	37.5
Climb	27.4	Cruise alt.	39	Climb start	3	25.5
Descend	21.6	Cruise alt. 2	-	Cruise	8	9.8
Appr./landing	6	Descend end	1.5	Climb 2		-
				Descend	17	-
				Appr./landing	1	10

Medium Range (1500-3000 Nm)

Type 1: Short/medium range - narrow body - High NOx
Range: 1500-3000 nm (1770 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	14	Climb start	1.5	Taxi	5	3.4
Take-off	2	Climb end	35	Take-off	0	2.8
Climb	19.2	Cruise alt.	35	Climb start	1	22.4
Descend	20	Cruise alt. 2	-	Cruise	6	17
Appr./landing	6	Descend en	1.5	Climb 2		-
				Descend	8	-
				Appr./landing	1	7.5

Type 2: Short/medium range - narrow body - Low NOx
Range: N.A.

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out		Climb start		Taxi		
Take-off		Climb end		Take-off		
Climb		Cruise alt.		Climb start		
Descend		Cruise alt. 2		Cruise		
Appr./landing		Descend end		Climb 2		
				Cruise 2		
				Appr./landing		

Type 3: Longe range - narrow body
Range: N.A.

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out		Climb start		Taxi		2.3
Take-off		Climb end		Take-off		13.1
Climb		Cruise alt.		Climb start		10.0
Descend		Cruise alt. 2		Cruise		9.2
Appr./landing		Descend end		Climb 2		-
				Descend		-
				Appr./landing		5.5

Type 4: Medium range - wide body
Range: 1500-3000 nm (1974 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	12	3.9
Take-off	1.5	Climb end	37	Take-off	0	34.5
Climb	16.2	Cruise alt.	37	Climb start	2	26.4
Descend	19.7	Cruise alt. 2	-	Cruise	27	9.2
Appr./landing	6	Descend en	1.5	Climb 2		-
				Descend	11	-
				Appr./landing	0	10

Type 5: Lang range - wide body - High NOx
Range: 1500-3000 nm (2153 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	21	3.4
Take-off	2	Climb end	39	Take-off	1	40.2
Climb	18.3	Cruise alt.	39	Climb start	9	26.4
Descend	21.7	Cruise alt. 2	-	Cruise	50	9
Appr./landing	6	Descend en	1.5	Climb 2		
				Descend	113	
				Appr./landing	1	8.8

Type 6: Lang range - wide body - Low NOx
Range: 1500-3000 nm (2136 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	11	3.5
Take-off	1.9	Climb end	37	Take-off	1	37.5
Climb	30.3	Cruise alt.	37	Climb start	4	26.1
Descend	19.7	Cruise alt. 2	37	Cruise	26	9.5
Appr./landing	6	Descend en	1.5	Climb 2		-
				Descend	17	-
				Appr./landing	1	10

Long Range (> 3000 Nm)

Type 1: Short/medium range - narrow body - High NOx
Range: N.A.

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out		Climb start		Taxi		
Take-off		Climb end		Take-off		
Climb		Cruise alt.		Climb start		
Descend		Cruise alt. 2		Cruise		
Appr./landing		Descend end		Climb 2		
				Cruise 2		
				Appr./landing		

Type 2: Short/medium range - narrow body - Low NOx
Range: N.A.

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out		Climb start		Taxi		
Take-off		Climb end		Take-off		
Climb		Cruise alt.		Climb start		
Descend		Cruise alt. 2		Cruise		
Appr./landing		Descend end		Climb 2		
				Cruise 2		
				Appr./landing		

Type 3: Longe range - narrow body
Range: N.A.

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out		Climb start		Taxi		2.3
Take-off		Climb end		Take-off		13.1
Climb		Cruise alt.		Climb start		10.0
Descend		Cruise alt. 2		Cruise		10.9
Appr./landing		Descend end		Climb 2		10.0
				Cruise 2		10.0
				Appr./landing		5.5

Type 4: Medium range - wide body
Range: >3000 nm (3859 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	12	3.9
Take-off	1.7	Climb end	33	Take-off	0	34.5
Climb	16.5	Cruise alt.	33	Climb start	2	28
Descend	19.7	Cruise alt. 2	37	Cruise	13	9.2
Appr./landing	6	Descend end	1.5	Climb 2	0	18.3
				Cruise 2	47	10.0
				Desc;Appr./la	11; 0	10.0

Type 5: Lang range - wide body - High NOx
Range: >3000 nm (4493 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	22	3.4
Take-off	2.2	Climb end	33	Take-off	1	40.2
Climb	18.2	Cruise alt.	33	Climb start	12	27.9
Descend	20.8	Cruise alt. 2	37	Cruise	45	10.6
Appr./landing	6	Descend end	1.5	Climb 2	3	19.6
				Cruise 2	71	9.2
				Desc.;Appr./la	13;1	8.8

Type 6: Lang range - wide body - Low NOx
Range: >3000 nm (4173 nm)

TIM's:	(min.)	Altitude:	(1000 ft)		EF (g/kg) CO	NOx
Taxi in/out	18	Climb start	1.5	Taxi	12	3.5
Take-off	2.5	Climb end	33	Take-off	1	37.5
Climb	39.1	Cruise alt.	33	Climb start	4	27.7
Descend	19.7	Cruise alt. 2	37	Cruise	13	12.2
Appr./landing	6	Descend end	1.5	Climb 2	1	18.0
				Cruise 2	51	10.6
				Desc.;Appr./la	16;1	10

Source: Walker, 1993

Note: TIM = Time-In-Mode
Emission factors for CO were added to the WSL database as defined by Peper (NLR) (Peper, 1993b).

APPENDIX E: Characterization of CPB scenarios ER, GS and BG.

Box E.1: Key characteristics of Global Shift

* **Dominant Perspective:**	o Free-Market
* **Regional Developments**	
- USA	o strong recovery
- Western Europe	o new Euro-sclerosis break-through after 2000-2005
- Japan and DAE	o continual rise
- Rest of Asia	o start of Asian Era
- Latin America	o sustained growth
- Africa	o delinking
- NMEs	o economic reconstruction fails o backlash in CIS (former USSR)
* **Trends**	
- Technology	o strong dynamism
- Demography	o rapidly declining fertility in Asia o migration from East and South to Western Europe and USA
- Cooperation	o only to free market forces o leadership of USA goes unchallenged
- Environment/Energy	o economic development top priority o no global cooperation; no global feedbacks o large local problems o shift to nuclear energy after 2000
- World Food	o Africa continent of hunger
- Internationalization	o rapid globalization
- and Market Structures	o very competitite

source: CPB, 1992.

Box E.2: Key characteristics of European Renaissance

* **Dominant Perspective:**	o Coordination
* **Regional Developments**	
- USA	o economic decline until 2000-2005 o fortress America o loss of leadership
- Latin America	o another decade of crisis
- Western Europe	o favourable development
-	o policy-led integration process o EC expands to include EFTA and Central Europe
- CIS	o break-through at end of nineties
- Africa	o benefits from European development
- Asia	o rise restrained
* **Trends**	
- Technology	o economies of scale dominant
- Cooperation	o multipolar world o strong regional cooperation o strained relations with USA
- Environment/Energy	o no global approach; no global feedback o mounting local problems o exception: Europe including Central Europe and European republics of CIS o European Energy Community: shift to gas
- World Food	o 'pockets' of hunger
- Internationalization	o trade blocs
- and Market Structures	o strategic-trade/industrial policies o evolves in less competitive direction

source: CPB, 1992.

Box E.3: Key characteristics of Balanced Growth

* **Dominant Perspective:**	o equilibrium
* **Regional Developments**	
- World	o transition to sustainable growth o growth also multipolar, including Africa
- Japan	o socio-cultural catching up to the West
- Western Europe	o integration based on market forces
* **Trends**	
- Technology	o strong dynamism
- Demography	o rapidly declining fertility
- Cooperation	o to free market forces; o to respond to global changes
- Environment/Energy	o leadership role of DCs o global cooperation o introduction of global CO_2 tax; LDCs compensated through aid o 50% reduction in energy intensity o start transition to renewmable energy
- World Food	o breaking paradox of hunger amidst plenty
- Internationalization	o unhampered
- and Market Structures	o very competitite o break-through in GATT

source: CPB, 1992.

APPENDIX F: Example of ticket price assumptions related to CPB scenarios.

Assumptions in conjunction with the GDP growth figures for CPB scenarios ER, BG and GS.
The figures mentioned here were not used in this study (see Table 4.2).
Some assumptions reflect price changes for travellers only (while not affecting net yield of airlines), other changes affect both.
These assumptions coincide with the assumptions made for application of the CPB scenarios to RLD's IEE model in scenario runs made specifically for projections of Schiphol Airport (for IMER).

Table F.1: Ticket price index in Balanced Growth scenario (BG)

DTI region	1990	1992	1995	2000	2003	2005	2010	2015
ALL REGIONS	**1.00**	1.00	0.95	0.88	**0.83**	0.85	0.86	**0.86**

Note: BG assumes a global liberalization of air traffic and introduction of an energy tax on oil products:
- Liberalization will enhance competition and thus result in lower fares;
- An energy tax on oil products ($20/bbl in 2005 and $33/bbl in 2015) will partially compensate this price effect.
N.B. Disregard the impact of the energy tax within this price index on the yield of the airlines, since:
a. the tax factor incl. in the index cannot be separated well; b. it is the impact on the demand that matters here.

Table F.2.a: Ticket price index in Global Shift scenario (GS)

DTI region	1990	1992	1995	2000	2003	2005	2010	2015
ALL REGIONS	**1.00**	1.00	1.01	1.03	**1.04**	1.04	1.03	**1.02**

Table F.2.b: Ticket price index in European Renaissance scenario (ER)

DTI region	1990	1992	1995	2000	2003	2005	2010	2015
WITHIN EUROPE	**1.00**	1.00	0.96	0.88	**0.84**	0.85	0.88	**0.90**
OTHERS	**1.00**	1.00	0.96	0.88	**0.84**	0.86	0.90	**0.95**

Note: ER assumes in Europe a liberalization of air traffic and introduction of an energy tax on oil products.
Liberalization will enhance competition and thus result in lower fares, whereas the energy tax has the opposite effect (see also footnote of Table 1.b).

Table F.2.c: Ticket price index in scenario European Renaissance/Global Price Increase (ER-GPI)

DTI region	1990	1992	1995	2000	2003	2005	2010	2015
WITHIN EUROPE	**1.00**	1.00	0.96	0.95	0.94	0.98	1.01	1.04
OTHERS	**1.00**	1.00	0.96	0.95	0.94	0.99	1.04	1.09

Note: ER assumes in Europe a liberalization of air traffic and introduction of an energy tax on oil products.
In this scenario alternative ER-GPI we additionally assume a GLOBAL increase of ticket prices of 15% in 2005:
Globally: linear increase of ticket prices from 1995 to 2005 (to 15%) and constant thereafter.
The net yield for the airlines is assumed to be equal to the prices without the additional increase (as in Table 3.b).

Table F.2.d: Ticket price index in scenario European Renaissance/European Price Increase (ER-EPI)

DTI region	1990	1992	1995	2000	2003	2005	2010	2015
WITHIN EUROPE	**1.00**	1.00	0.96	0.95	0.94	0.98	1.01	1.04
OTHERS	**1.00**	1.00	0.96	0.88	**0.84**	0.86	0.90	**0.95**

Note: ER assumes in Europe (only) a liberalization of air traffic and introduction of an energy tax on oil products.
In this scenario alternative ER-GPI we additionally assume an increase of ticket prices of 15% in 2005:
For Europe only: additional linear increase from 1995 to 2005 to 15% and constant thereafter.
The net yield for the airlines is assumed to be equal to the prices without the additional increase (as in Table 3.b).

Note to all tables: Bold figures are specified in documentation of IEE runs by RLD; other figures are interpolated values.

Table F.3: Price index development for introduction of an additional 15% price increase from 1995 to 2005

	1990	1992	1995	2000	2003	2005	2010	2015
Price index:	1.00	1.00	**1.00**	1.08	1.12	**1.15**	1.15	1.15

Note: This index table is used to create Tables F2..c and F.2.d from Table F.2.b:
values in Table F.2.b are multiplied by the factor specified in Table F.3 (both lines and upper line, respectively)

Note 2: The figure of 15% has been chosen since it corresponds roughly with *:
a) a doubling of the fuel costs (about 15%)
b) a doubling of the airport taxes for landings (about 5%)
c) the introduction of VAT on air tickets (about 15 to 20%).
* See memorandum of Olivier/Veldhuis no. 93.105 d.d. 22-11-93.

APPENDIX G: Regional subdivisions of CPB, DTI, ABC/WSL and IATA.

Table G.1: CPB model regions

	Region	Entities	Associated DTI region
NAM	North America	- USA, Canada, also including Australia, New Zealand, and South Africa	USA, Canada, Oceania
WEU	Western Europe	- Western, Northern and Southern Europe, including the former Yugoslavia, Israel and Turkey, but not including Albania	Europe
JAP	Japan	- Japan	Japan
CE	Central Europe	- new market economies in central Europe: Poland, Czechoslovakia, Hungary, Bulgaria, Romania, and Albania	(Eastern Europe) 1)
CIS	Commonwealth of Ind. St.	- Commonwealth of Independent States (former USSR)	(Former USSR) 1)
DAE	Dynamic Asian Economies	- Hong Kong, Singapore, Taiwan, South Korea, Malaysia, Philippines, Indonesia and Thailand	Asia SE
CHI	China	- China	China
ME	Middle East	- North Africa, the Arabian Pensinsula, Iran, Iraq, Jordan Lebanon and Syria, not including Israel	Middle East
rASIA	Rest of Asia	- This region also includes Melanesia, Micronesia and Polynesia	Indian sub-continent
AFR	Africa	- Sub-saharan Africa: East, Central and Southern Africa, not including South Africa	Africa
LAT	Latin America	- South America, Central America, and the Carribbean	Central & Latin America

1) Not (yet) in DTI model.

Table G.2: DTI model regions

	Region	Entities	Associated LULU region
1	USA 1)	- USA	North America (+ link to Eur.)
2	Canada 1)	- Canada	North America (+ link to Eur.)
3	Central & Latin America	- Mexico southwards (including Carribbean)	LDC+
4	Europe 1) 2)	- Western Europe (including Scandinavia, former Yugoslavia and Turkey, excluding former communist block states)	Europe (+link to North Am.)
5	Africa	- Continental Africa (upto Egypt, includes: Madagascar & Seychelles)	LDC+
6	Middle East	- Lebanon, Israel, Syria, Jordan, Arabian peninsular, Iran, Iraq	LDC+
7	China	- PRC and Mongolia	Far East
8	Indian sub-continent	- Afghanistan, Pakistan, India, Sri Lanka, Bangladesh, Burma, Nepal, Maldives	Far East
9	Asia SE	- Thailand, Malaysia, Indonesia, Korea, Taiwan, Cambodia, Laos, Vietnam, Philippines etc	Far East
10	Japan	- Japan	Far East
11	Oceania	- Australia, New Zealand, Papua New guinea and Pacific Islands	LDC+
12	Eastern Europe 3)	- Poland, Czechoslovakia, Hungar, Bulgaria, Romania, Albania	Former CPE
13	Former USSR 3)	- Former USSR	Former CPE

1) Divided into the link North America to (Western) Europe and vice versa and other traffic from these regions.
2) Divided into scheduled flight and charter flights.
3) Not (yet) in DTI model.

Table G.3: WSL (ABC) regions

	ABC/WSL region	Entities	Associated LULU region
1	USA	USA	North America (+ link to Eur.)
2	Canada	Canada	North America (+ link to Eur.)
3	Latin America	Central and South America, including the Carribbean	LDC+
4	Europe	Western Europe, including Yugoslavia and Turkey	Europe (+link to North Am.)
5	Eastern Europe	Poland, Czechoslovakia, Hungary, Bulgaria, Romania, and Albania	Former CPE
6	Middle East	Lebanon, Israel, Syria, Jordan, Arabian peninsular, Iran, Iraq	LDC+
7	Africa	Africa, (upto Egypt, includes Madagascar and Seychelles)	LDC+
8	USSR	Former USSR	Former CPE
9	China	China	Far East
10	Indian sub-continent	Afghanistan, Pakistan, India, Sri Lanka, Bangladesh, Myanmar, Nep Bhutan, Maldives	Far East
11	Asia	Rest of Asia (excluding China, Papua new Guinea)	Far East
12	Japan	Japan	Far East
13	Oceania	Australia, New Zealand, Papua New Guinea, Pacific Islands	LDC+

APPENDIX G: Continued.

Table G.4 IATA regions

Traffic Conf. Area	Region	Entities
TC1	North America	Canada, United States (including Alaska and Hawaii, but exluding Puerto Rico and Virgin Islands).
	Central America	Anguilla, Antigua and Barbuda, Aruba, Bahamas, Barbados, Belize, Bermuda, British Virgin Islands, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guadaloupe, Guatemala, Haiti, Honduras, Jamaica, Martinique, Mexico, Netherlands Antilles, Nicaragua, Panama, Puerto Rico, St. Chrisopher- Nevis, Saint Lucia, Saint Vincent and the Grenadines, Virgin Islands of the United States.
	South America	Argentina, Bolivia, Brazil, Chile, Colombia (including San ANdres Islands), Ecuador, French Guiana, Guyana, Paraguay, Peru, Surinam, Uruguay, Venezuela.
TC2	Northern Europe	Austria, Belgium, Bulgaria, Commonwealth of Indepent States(West of the Urals), Czech Republic, Denmark, Estonia, Faroe Islands, Finland, France, Germany, Greenland, Hungary, Iceland, Ireland, Latvia, Liechtenstein, Lithuania, Luxembourg, Netherlands, Norway, Poland, Romania, Slovakia, Sweden, Switzerland, United Kingdom.
	Southern Europe	Albania, Algeria, Andorra, Azores, Canary Islands, Croatia, Gibraltar, Greece, Italy, Madeira, Malta, Monaco, Morocco, Portugal, San Marino, Slovenia, Spain, Tunis, Turkey (in Europe and Asia), Yugoslavia.
	Middle East	Bahrain, Cyprus, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Sudan, Syrian Arab Republic, United Arab Emirates, Yemen (Republic).
	Eastern Africa	Burundi, Comoros, Djibouti, Ethiopia, Kenya, Libyan Arab Jamahiriya, Madagascar, Mauritius, Reunion, Rwanda, Seychelles, Somalia, Tanzania (United Republic ot), Uganda.
	Western Africa	Angola, Benin, Burkino Faso, Cameroon (Republic ot), Cape Verde, Central African Republic, Chad, Congo, Cote d'Ivoire, Equatorial Guinea, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, St. Helena, Sao Tome and Principe, Senegal, Sierra Leone, Togo, Western Sahara, Zaire.
	Southern Africa	Botswana, Lesotho, Malawi, Mozambique, Namibia, South Africa, Swaziland, Zambia, Zimbabwe.
TC3	Far East	Afghanistan, Bangladesh, Bhutan, Brunei Darussalam, Burma, China, Commonwealth of Indepent States (East of the Urals), Hong Kong, India, Indonesia, Japan, Kampuchea (Democratic), Korea (Democratic People's Republic ot), Korea (Republic ot), Lao People's Democratic Republic, Macau, Malaysia, Maldives, Mongolia, Nepal, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan (Province of China), Thailand, VietNam.
	Southwest Pacific	Australia, New Zealand, Papua New Guinea, and all othr islands of the Pacific including Amreican Samoa, Christmas Island, Cocos (Keeling) Islands, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Micronesia, Nauru, New Caladonia, Niue, Norfolk Island, Northern Mariana Islands, Palau, Pitcairn, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, United States Minor Outlying Islands, Vanuatu, Wallis and Fortuna Islands.

APPENDIX H: Aircraft types and distance ranges of DTI (seat bands/ranges) and WSL (types/ranges).

Table H.1: DTI seat band classes

	Seat band	Examples of aircraft types in seat band
A	80-99	F100, BAe 146, DC-9, F-28, MD-95
B	100-124	B737-500, MD-87, F100, B737-200, A319, DC-9
C	125-159	B737-300/400, MD-80, A320, B727-200, MD-90
D	160-199	B757, A321
E	200-249	B767, A310, DC-10, L1011
F	250-314	A300, B767, MD-11, L-1011, A340
G	315-399	B777, A330, B747-200, MD-11
H	400-499	B747-400, MD-12?
I	500-624	B747-500, MD-12?, A350
J	625-799	UHCA (Ultra-High Civil Air transport; not yet in existance)

Table H.2: WSL aircraft type description

	Range 1)	Types	Examples of aircraft types
1	SR/MR	Narrow-bodied high NOx	DC9, MD80, B737, B727, A320, BAC1-11, Trident
2	SR/MR	Narrow-bodied low NOx	F28, F100, BAe146
3	LR	Narrow-bodied	DC8, B707
4	MR	Wide-bodied	B757, B767, A300, A310
5	LR	Wide-bodied low NOx	DC10, L1011
6	LR	Wide-bodied high NOx	B747
7-10	VSR	General aviation aircraft	-

1) SR = Short Range; MR = Medium Range; LR = Long Range; VSR = Very Short Range

Table H.3.a: Relation between DTI, WSL and LULU aircraft types

DTI	WSL	LULU
B	1	T1
A	2	
C	3	T2
D+1/2E+1/2F	4	
1/2E+1/2F	5	T3
G+H+I+J	6	
*)	7-10	T4

*) Not in DTI model (general aviation aircraft (propellor):
2/3 prop. engine commuter; light propellor; 2 prop. engine; 4 prop. engine;);
has been set equal to total regional index.

Table H.3.b: Relation between DTI, WSL and LULU range definitions

WSL		DTI		LULU
1	< 500 Nm	SH	<2900 Nm	SH
2	500-1500 Nm			
3	1500-3000 Nm			
4	>3000 Nm	LH	>2900 Nm	LH

Note: 1 Nm = 1609 m

APPENDIX I: Example of DTI scenario results and aggregation to LULU regions, links and aircraft/distance types.

WORLD SUMMARY REGION
Run Number = 98 Run Date : 10 Feb 1994
Comment : RIVM Scenarios - European Renaissance

Economic scenario growth rate : Central
P factor : Mid
Replacement proportion : 1.00
Frustrated demand : not satisfied
Number of forecast years : 25
Number of size class bands : 7
Number of technology groups : 3

ER0 LULU region: North America
Aggregated types & selected years: Seat Kilometres Offered by Fleet (100 million)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	1671	1763	1860	1956	2107	2790	3522
T2-SH	6606	7814	8648	9228	9774	11806	13759
T2-L1	669	716	728	731	736	758	840
T2-LH	362	379	377	375	400	478	588
T3-SH	1219	1936	2512	2883	3228	4522	5820
T3-L1	648	916	1133	1299	1434	2008	2561
T3-LH	1100	1487	1846	2059	2286	2941	3884
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	12276	15013	17102	18629	19980	25091	30768

ER0 LULU region: Europe
Aggregated types & selected years: Seat Kilometres Offered by Fleet (100 million)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	703	659	714	779	841	1022	1228
T2-SH	1926	2532	3116	3477	3742	4496	5397
T2-L2	389	396	379	359	349	353	394
T2-LH	336	361	412	434	445	492	579
T3-SH	532	975	1462	1812	2088	2880	3696
T3-L2	939	1366	1908	2270	2528	3310	4180
T3-LH	1249	1606	2086	2366	2596	3256	3973
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	6074	7920	10019	11499	12589	15808	19444

ER0 LULU region: Far East
Aggregated types & selected years: Seat Kilometres Offered by Fleet (100 million)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	164	119	108	102	98	105	133
T2-SH	770	934	1071	1171	1236	1475	1928
T2-LI	NA	NA	NA	NA	NA	NA	NA
T2-LH	215	212	186	149	128	84	59
T3-SH	954	1718	2752	3570	4223	6324	9089
T3-LI	NA	NA	NA	NA	NA	NA	NA
T3-LH	1736	2771	4262	5402	6346	9541	13991
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	3836	5758	8371	10394	12081	17527	25147

ER0 LULU region: LDC+
Aggregated types & selected years: Seat Kilometres Offered by Fleet (100 million)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	421	348	324	346	367	463	579
T2-SH	1221	1546	1856	2083	2287	2861	3676
T2-LI	NA	NA	NA	NA	NA	NA	NA
T2-LH	326	335	338	358	389	442	540
T3-SH	540	898	1316	1609	1857	2692	3661
T3-LI	NA	NA	NA	NA	NA	NA	NA
T3-LH	926	1279	1698	1948	2167	2970	3970
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	3435	4408	5629	6342	7048	9368	12315

ER0 LULU region: Former CPE (Eastern Europe)
Aggregated types & selected years: Seat Kilometres Offered by Fleet (100 million)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	NA	NA	NA	NA	NA	NA	NA
T2-SH	NA	NA	NA	NA	NA	NA	NA
T2-LI	NA	NA	NA	NA	NA	NA	NA
T2-LH **	NA	NA	NA	NA	NA	NA	NA
T3-SH	NA	NA	NA	NA	NA	NA	NA
T3-LI	NA	NA	NA	NA	NA	NA	NA
T3-LH **	NA	NA	NA	NA	NA	NA	NA
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	NA	NA	NA	NA	NA	NA	NA

ER0 LULU region: WORLD SUMMARY REGION
Aggregated types & selected years: Seat Kilometres Offered by Fleet (100 million)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-ALL	2959	2669	3001	3184	3413	4360	5462
T2-SH	10524	12828	14690	15988	17021	20456	24757
T2-LI	1056	1114	1108	1080	1086	1108	1234
T2-LH	1240	1306	1311	1313	1341	1495	1766
T3-SH	3244	5529	8041	9874	11394	16358	22104
T3-LI	1587	2266	3086	3569	3962	5313	6731
T3-LH	5011	7144	9838	11776	13413	18708	25617
T4-ALL *	0	0	0	0	0	0	0
Total	25621	33092	41021	46794	51828	67812	87869

NOTE: * Index for T4-ALL has been set equal to the total regional index. For L1 and L2 (Link 1 and 2) the same assumption mas made for T1-AL.
In addition, for L1 and L2 (Link 1 and 2) and for Former CPE (R5) the indices for T2-SH and T2-LH were assumed to be equal; the same assumption was made for T3-SH and T3-LH.
** Assumptions for specific aircraft types in the Former CPE are rough assumptions made by comparing the global growth indices of the these types with the global overall growth index (ER0 about 3.5 in 2015 for global total, where T2 index is about 2 and T3 is about 5). For 2003 we choose tentatively some intermediate values, in line with the development of the total regional index.

WORLD SUMMARY REGION
Run Number = 98 Run Date : 10 Feb 1994
Comment : RIVM Scenarios - European Renaissance

Economic scenario growth rate : Central
P factor : Mid
Replacement proportion : 1.00
Frustrated demand : not satisfied
Number of forecast years : 25
Number of size class bands : 7
Number of technology groups : 3

ER0 LULU region: North America
Aggregated types & selected years: Seat Kilometres Offered by Fleet (index: 1990 = 1.00)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	1.00	1.06	1.11	1.17	1.26	1.67	2.11
T2-SH	1.00	1.18	1.31	1.40	1.48	1.78	2.08
T2-L1	1.00	1.07	1.09	1.09	1.10	1.13	1.26
T2-LH	1.00	1.05	1.04	1.03	1.10	1.32	1.62
T3-SH	1.00	1.59	2.06	2.37	2.65	3.71	4.78
T3-L1	1.00	1.42	1.75	2.00	2.21	3.09	3.94
T3-LH	1.00	1.35	1.68	1.87	2.08	2.67	3.35
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	1.00	1.22	1.39	1.51	1.63	2.04	2.51

ER0 LULU region: Europe
Aggregated types & selected years: Seat Kilometres Offered by Fleet (index: 1990 = 1.00)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	1.00	0.94	1.02	1.11	1.20	1.45	1.75
T2-SH	1.00	1.31	1.62	1.81	1.94	2.33	2.80
T2-L2	1.00	1.02	0.97	0.92	0.90	0.91	1.01
T2-LH	1.00	1.13	1.22	1.29	1.32	1.46	1.71
T3-SH	1.00	1.83	2.75	3.41	3.93	5.42	6.95
T3-L2	1.00	1.46	2.03	2.42	2.69	3.53	4.45
T3-LH	1.00	1.29	1.69	1.90	2.08	2.61	3.18
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	1.00	1.30	1.65	1.89	2.07	2.60	3.20

ER0 LULU region: Far East
Aggregated types & selected years: Seat Kilometres Offered by Fleet (index: 1990 = 1.00)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	1.00	0.73	0.66	0.62	0.60	0.64	0.81
T2-SH	1.00	1.21	1.39	1.52	1.61	1.92	2.50
T2-LI	NA	NA	NA	NA	NA	NA	NA
T2-LH	1.00	0.99	0.86	0.69	0.59	0.39	0.28
T3-SH	1.00	1.80	2.89	3.74	4.43	6.63	9.46
T3-LI	NA	NA	NA	NA	NA	NA	NA
T3-LH	1.00	1.60	2.46	3.11	3.66	5.50	8.07
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	1.00	1.50	2.18	2.71	3.14	4.57	6.56

ER0 LULU region: LDC+
Aggregated types & selected years: Seat Kilometres Offered by Fleet (index: 1990 = 1.00)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	1.00	0.83	0.77	0.83	0.87	1.10	1.38
T2-SH	1.00	1.00	1.00	1.00	1.00	1.00	1.00
T2-LI	NA	NA	NA	NA	NA	NA	NA
T2-LH	1.00	1.03	1.04	1.09	1.13	1.36	1.66
T3-SH	1.00	1.66	2.44	2.98	3.44	4.87	6.58
T3-LI	NA	NA	NA	NA	NA	NA	NA
T3-LH	1.00	1.38	1.83	2.10	2.36	3.20	4.28
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	1.00	1.28	1.61	1.85	2.05	2.73	3.59

ER0 LULU region: Former CPE (Eastern Europe)
Aggregated types & selected years: Seat Kilometres Offered by Fleet (index: 1990 = 1.00)

Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	NA	NA	NA	NA	NA	NA	NA
T2-SH	NA	NA	NA	NA	NA	NA	NA
T2-LI	NA	NA	NA	NA	NA	NA	NA
T2-LH	NA	NA	NA	1.25	NA	NA	1.50
T3-SH	NA	NA	NA	NA	NA	NA	NA
T3-LI	NA	NA	NA	NA	NA	NA	NA
T3-LH	NA	NA	NA	2.00	NA	NA	3.50
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	1.00	0.50	1.00	1.25	1.50	2.00	2.50

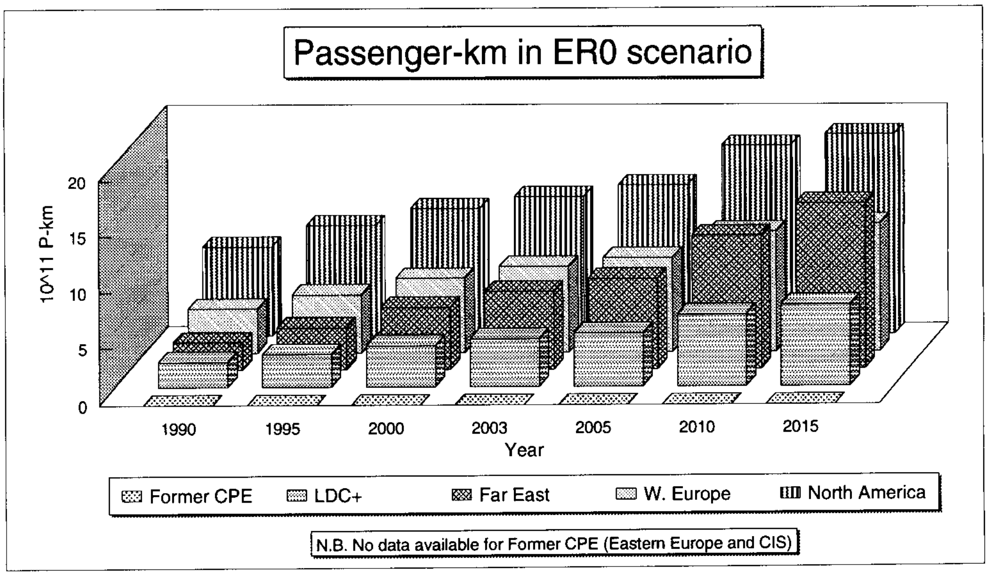
ER0 LULU region: WORLD SUMMARY REGION
Aggregated types & selected years: Seat Kilometres Offered by Fleet (index: 1990 = 1.00)

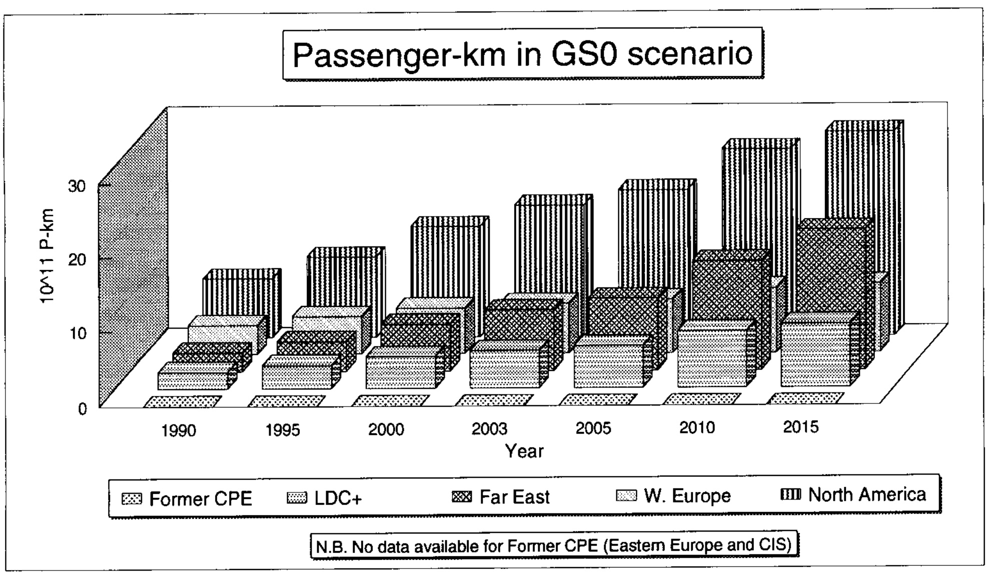
Size Band	1990	1995	2000	2003	2005	2010	2015
T1-AL	1.00	0.98	1.01	1.08	1.15	1.48	1.85
T2-SH	1.00	1.22	1.40	1.52	1.62	1.94	2.35
T2-LI	1.00	1.05	1.05	1.03	1.03	1.05	1.17
T2-LH	1.00	1.05	1.06	1.06	1.08	1.21	1.42
T3-SH	1.00	1.70	2.48	3.04	3.51	5.04	6.81
T3-LI	1.00	1.44	1.91	2.25	2.50	3.35	4.24
T3-LH	1.00	1.43	1.96	2.35	2.68	3.73	5.11
T4-AL *	NA	NA	NA	NA	NA	NA	NA
Total	1.00	1.29	1.60	1.83	2.01	2.65	3.42

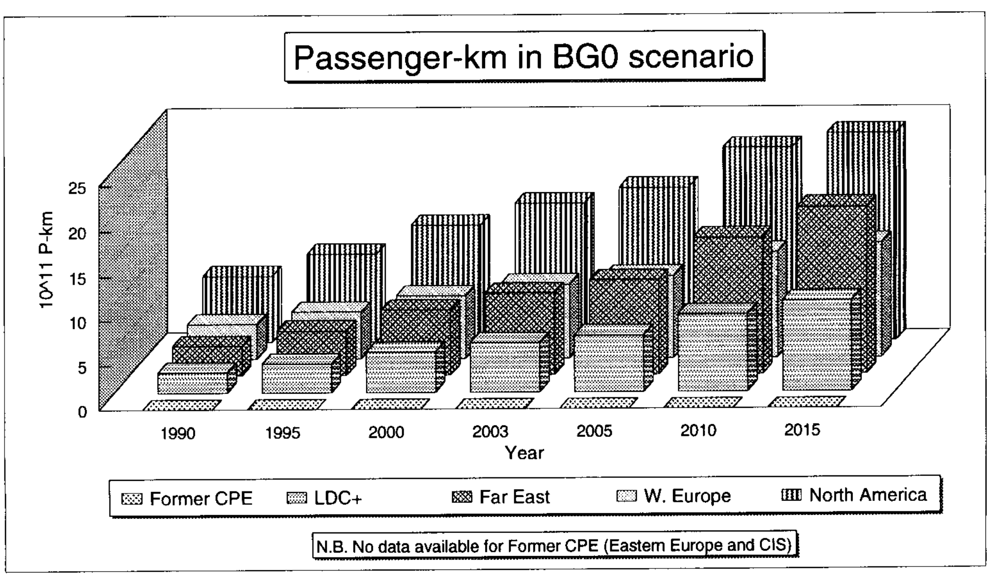
NOTE: * Index for T4-AL has been set equal to the total regional index. For L1 and L2 (Link 1 and 2) the same assumption mas made for T1-AL.
In addition, for L1 and L2 (Link 1 and 2) and for Former CPE (R5) the indices for T2-SH and T2-LH were assumed to be equal; the same assumption was made for T3-SH and T3-LH.
** Assumptions for specific aircraft types in the Former CPE are rough assumptions made by comparing the global growth indices of the these types with the global overall growth index (ER0 about 3.5 in 2015 for global total, where T2 index is about 2 and T3 about 5). For 2003 we choose tentatively some intermediate values, in line with the development of the total regional index.

APPENDIX I: Continued

Figure I.1: Development of Passenger-km in scenarios ER0, GS0 and BG0.







Note: A uniform load factor and load factor development has been assumed in converting SKO to P-km.

APPENDIX I: Continued

Table I.1: Development of Passenger-km in scenarios ER0, GS0 and BG0.

Scenario ER0: 10^9 P-km/yr

Region	1990	1995	2000	2003	2005	2010	2015
Former CPE	NA	NA	NA	NA	NA	NA	NA
LDC+	223	290	368	425	475	640	727
Far East	249	379	558	697	811	1195	1484
W. Europe	395	521	667	771	848	1078	1147
North America	798	988	1139	1243	1345	1711	1815

Scenario GS0: 10^9 P-km/yr

Region	1990	1995	2000	2003	2005	2010	2015
Former CPE	NA	NA	NA	NA	NA	NA	NA
LDC+	220	308	424	500	563	750	848
Far East	251	399	630	810	968	1470	1895
W. Europe	394	502	612	670	720	872	930
North America	796	1080	1498	1781	1981	2528	2762

Scenario BG0: 10^9 P-km/yr

Region	1990	1995	2000	2003	2005	2010	2015
Former CPE	NA	NA	NA	NA	NA	NA	NA
LDC+	224	323	458	560	640	876	1025
Far East	250	375	548	683	792	1132	1382
W. Europe	393	529	706	835	926	1183	1282
North America	797	1052	1395	1648	1829	2310	2481

Notes: For Former CPE no data are available.
A uniform load factor and load factor development has been assumed in converting SKO to P-km.

APPENDIX J: Documentation provided with the EDGAR/LULU air traffic results for the ER0 scenario (1990, 2003 and 2015).

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EMISSIONS OF NOX AND CO AND FUEL CONSUMPTION OF AIRCRAFT
========================================================I
The spatial distribution of aircraft activity and related emissions has been
based on the information contained in the WSL database, supplemented with a
calculation for CO emissions. Methane emissions are not calculated, since
recent research indicates that emission factors during cruise flight are zero
or even negative. WSL has extracted the data on a 5x5 degree grid for LULU
regions/links and aircraft types/ranges. This information has been used to
estimate the spatial distribution of future emissions derived from activity
estimates by bthe DTI aircraft model and additional assumptions to calculate
future emissions (autonomous development of emission factors, specific fuel
consumption, load factors). For atmospheric models the seasonal variation is
also important to take into account. For this purpose the calculations results
are split in 3 world regions with different seasonal time profiles.

Scenarios on grid are constructed by globally scaling up of WSL emissions per
region and source category with an index based on growth indices as calculated
by DTI. We greatly acknowledge the assistance of the DTI staff to perform these
calculations and Charles Walker of WSL to convert the data of the WSL database
in the proper format to be handled within the EDGAR database system.

FILES
=====
name:            contents:
----             --------
pkunzip.exe      programme to unpack the *.zip files
a_90_15.doc      information on files, format, units, scenarios and data sources
a90er0no.zip     NOx emissions for LI, WE, OT and AL in 1990
a90er0co.zip     CO emissions for LI, WE, OT and AL in 1990
a90er0fu.zip     Fuel consumption for LI, WE, OT and AL in 1990
a03er0no.zip     NOx emissions for LI, WE, OT and AL in 2003
a03er0co.zip     CO emissions for LI, WE, OT and AL in 2003
a03er0fu.zip     Fuel consumption for LI, WE, OT and AL in 2003
a15er0no.zip     NOx emissions for LI, WE, OT and AL in 2015
a15er0co.zip     CO emissions for LI, WE, OT and AL in 2015
a15er0fu.zip     Fuel consumption for LI, WE, OT and AL in 2015
a_timepr.mon     seasonality of 3 different regions/links

contents of ZIP-files:
---------------------
A90ER0CO.ZIP
 LI-90CO.00..LI-90CO.15
 WE-90CO.00..WE-90CO.15
 OT-90CO.00..OT-90CO.15
 AL-90CO.00..AL-90CO.15

A90ER0FU.ZIP
 LI-90.00..LI-90.15
 WE-90.00..WE-90.15
 OT-90.00..OT-90.15
 AL-90.00..AL-90.15

A90ER0NO.ZIP
 LI-90NOX.00..LI-90NOX.15
 WE-90NOX.00..WE-90NOX.15
 OT-90NOX.00..OT-90NOX.15
 AL-90NOX.00..AL-90NOX.15

A03ER0CO.ZIP
 LI-03CO.00..LI-03CO.15
 WE-03CO.00..WE-03CO.15
 OT-03CO.00..OT-03CO.15
 AL-03CO.00..AL-03CO.15

A03ER0FU.ZIP
 LI-03.00..LI-03.15
 WE-03.00..WE-03.15
 OT-03.00..OT-03.15
 AL-03.00..AL-03.15

A03ER0NO.ZIP
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Dec 30 1994 14:38:45 a_90_15.doc

```
 LI-03NOX.00..LI-03NOX.15
 WE-03NOX.00..WE-03NOX.15
 OT-03NOX.00..OT-03NOX.15
 AL-03NOX.00..AL-03NOX.15

A15ER0CO.ZIP
 LI-15CO.00..LI-15CO.15
 WE-15CO.00..WE-15CO.15
 OT-15CO.00..OT-15CO.15
 AL-15CO.00..AL-15CO.15

A15ER0FU.ZIP
 LI-15.00..LI-15.15
 WE-15.00..WE-15.15
 OT-15.00..OT-15.15
 AL-15.00..AL-15.15

A15ER0NO.ZIP
 LI-15NOX.00..LI-15NOX.15
 WE-15NOX.00..WE-15NOX.15
 OT-15NOX.00..OT-15NOX.15
 AL-15NOX.00..AL-15NOX.15

FILE CODES, FORMATS AND UNITS
=============================
File names "ayysssccc" of ZIP files correspond with:
        a  = source name (a = aircraft sources)
        yy  = year, last 2 digits only (90=1990, 03=2003, 15=2015)
        sss = scenario (er0 = European Renaissance, "0" refers to price path)
        cc  = compound (no = NOx, co = CO, fu = fuel consumption)

Data files are labeled "rr-yyccc.##" in which:
        rr  = regio/link:
                LI = Link NA <-> WE and v.v.
                WE = W. Europe (short/medium range)
                OT = OTHER (all other egions/links)
                AL = Global total (sum of all links and regions: LI, WE and OT)
        yy  = year, last 2 digits only:
                90 = 1990
                03 = 2003
                15 = 2015
        ccc = compound:
                no = NOx, expressed as NO2
                co = CO
                fu = fuel consumption
        ##  = index of altitude band:
                00 = 00-01  km
                01 = 01-02  km
                ..
                07 = 07-08  km
                08 =  8.0- 8.5 km
                09 =  8.5- 9.0 km
                ..
                15 = 11.5-12.0 km

* For specific sources of methane see par. on scenario definition

Units on files: Tg of NOx-NO2/cell/month
                Tg of CO/cell/month
                ton of fuel/cell/month

Data are write in a block in the following order:
-180,85      -175,85 ....
-180,80      -175,80 ....
(longitude,latitude of lower left corner of 5x5 cell)

TIME PROFILES
=============
For all regions/links emissions estimates are presented for a whole year.
Analysis by RIVM and NLR of data on seasonality (monthly variation) of air
traffic showed that only for 2 links/regions monthly fractions exceed the
```

APPENDIX J: Continued

annual average fraction substantially, i.e. more than +- 10 to 15%:
- North Transatlantic flights (the link NA <-> W. Europe v.v.)
- flights within W. Europe.

Thus, to take account of the seasonal variation of aircraft emissions we divided global aircraft activities in three parts, for which we defined monthly fractions (one month being defined as 1/12 of a year):
- LI: the link NA <-> WE
- WE: W. Europe, resticted to short and medium range flights
- OT: the remaining part.

For "OT(HER)" we simply assume a uniform distribution in time, which can be presented in the file "a_timepr.mon". For future years we assumed the same time profile as for 1990.
For more information we refer to research note to DGM (ref. 94.049 d.d. 8 June 1994).

DEFINITION SCENARIO ER0
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INPUT FOR DTI AIRCRAFT MODEL TO GENERATE SEAT-KM OFFERED:
----
* REGIONAL ECONOMIC GROWTH: see CPB, Scanning the future.
* TICKET PRICES (in $/a)

Region	1990-1995	1995-2015
Europe	-1.500	-0.125
Others	-0.750	-0.125

* LOAD FACTOR (index 1990 = 1):
  1990: 1.00
  2003: 1.03
  2015: 1.06
  The corresponds to an increase from 65% in 1990 to 69% in 2015.

ADDITIONAL ASSUMPTIONS TO CALCULATE EMISSIONS:
----
* AUTONOMOUS DEVELOPMENT OF SFC AND EMISSION FACTORS

Variable	Change in 2015 (50% penetration assumed *)
SFC:	-12.5 %
EF-NOx:	-17.5 %
EF-other:	-0 %

ADDITIONAL ASSUMPTIONS FOR ALTERNATIVE POLICIES:

N.B. : NOT IN SCENARIO "ER0" !
Technical measures:

Variable	Change in 2015 (50% penetration assumed *)
SFC:	-20 %
EF-NOx:	-42.5 %
EF-SO2 **:	-37.5 %
EF-CO/VOC:	-25 %
EF-N2O ***:	-0 %

Operational measures:
Load Factor +6 % (to 75% total in 2015)
(-9 % fuel consumption)

* In 2003 13/25 x 50% = 26% penetration was assumed. Put another way: change is about half of the figures mentioned here for 2015.

AGGREGATIONS:

Results of DTI runs are compressed to LULU regions/types-ranges:

LULU region/link codes:
R1 = NA (North America: USA and Canada, excluding traffic to Western Europe)
L1 = NA->WEU (North America to Western Europe)
R2 = WEU (Western Europe, excluding traffic to North America)
L2 = WEU->NA (Western Europe to North America)
R3 = FE (Far East: Japan, China, Indian subcontinent, Asia)
R4 = OTH (Others: Latin America, Africa, Middle East, Oceania [= Australia & NZ])
R5 = CPE (former Centrally Planned Europe: Eastern Europe and CIS [= former USSR])

For each of these regions/links for 6 type/range combinations individual growth factors are applied (see ANNEX D to F). In EDGAR-LULU the separate activity levels are multiplied by these growth factors, and then aggregated to the requested aggregation level of global emissions:

= Altitude bands:
0-1 km, 1-2 km .., 7-8 km; 8-8.5 km, 8.5-9 km .., 11.5-12 km.
and
= Region/link codes for temporal distribution of global emissions:
LI - Links (Western Europe -> North America, N.A. -> Western Europe)
WE - Western Europe (includes only type/range T1A, T2S, T3S, T4A; not T2L and T3L)
OT - All Other regions/links not in WE or LI
AL - Summation of the three region groups

For more details we refer to research note to DGM (ref. 94.049 d.d. 8 June 1994).

DATA SOURCES
============
WSL data: files on NOx, CO and fuel consumption generated by WSL (Walker, 1993)
Scenario definition: regional economic growth by CPB;
price developments and load factors by DTI;
growth of seat-km by region, type/range calculated by DTI;
SFC and emission factors by RIVM and NLR
Conversions: from DTI regions/types to WSL regions/type by RIVM;
from WSL regons/types to aggregated LULU regions/types by RIVM
Integrated emissions scenario: EDGAR
Doc-file: Jos Olivier/Rob paar RIVM/LAE
Name: a_90_15.doc
Date: 94.06.17

REMARKS/DIFFERENCES WITH FILES OF FEBRUARY 1994
==
1. Data are now split over 3 regions/links to allow application of different monthly time profiles.
2. Data for 1990 and 2015 now include the scaling up to the UN figure for total jetfuel consumption in 1990 (multiplication factor of 1.863).
3. Global total NOx emissons for 1990 are, by altitude, equal to the previous dataset (besides the scaling).
4. Global total CO emissons for 1990 are slightly different from the previous dataset (besides the scaling):
   global total is now 358.4 instead of 365.2 Gg and differences mainly occur in band 0-1 km, 10-10.5 km, 11-11.5 km.
   After a double check of the data it was concluded that the current data are correct and that the data of februar include a minor error, notably for these altitude bands.
5. CO emissions for the aircraft type 4A (WSL types 7 to 10) are missing, because no emission factor for this inhomogenous group was available. However, since the fuel consumption pattern for this group indicate flight levels alwayes below 6 km, this was not onsidered a problem for the field of application for LULU. Compared to other Surface sources - as well as other aircraft? - this category can probably be neglected.
6. Since about 50% of fuel consumption by aircraft is missing in the WSL database, all data are uniformly scaled up. In practice however, activities in notably the former USSR and in China are heavily undervalued. A more realistic adjustment would have been scaling up for these regions differently. However, since data/estimates are lacking this was not feasible. This underlines the relative unprecision of the spatial distribution of aircraft emissions based upon the WSL database. For our purposes, howver, no better one was available.
7. Slight differences of aggregated total figures with figures presented in the note to DGM (ref. 94.049 d.d. 8 June 1994) are caused by a more detailed calculation of activity growth within regions/links, than was done for the summary assessment as presented in that note. (Aircraft with higher/lower emission factors may growth faster/slower than the regional average, according to the results of the DTI scenario run).

APPENDIX K: Documentation provided with the EDGAR/LULU surface sources results for the ER0 scenario (1990, 2003 and 2015).

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```
EMISSIONS OF NOX, CO AND CH4 FROM SURFACE SOURCES (EXCLUDING AIRCRAFT).
=====================================================================
Emissions data from J.-P. Muller: monthly data on 5x5 degree grid.
Original data were on 5x5 grid cells centred on 0E,85 N; 5E,85N; etc.
All data were converted to 5x5 grid cells with lower left corner at 0E,85N;
5E,85N; etc. (by dividing original data in 2.5x2.5 degree cells, and summing
according to new convention).
Scenarios on grid are constructed by globally scaling up of emissions per
source category with an index based on growth patterns of similar IPCC
scenarios.

FILES
=====
name:            contents:
----             --------
pkunzip.exe      programme to unpack the *.zip files
s_90_15.doc      information on files, format, units, scenarios and data sources
sur90er0.zip     NOX, CO, CH4, SO2 emissions per month in 1990
sur03er0.zip     NOX, CO, CH4 emissions per month in 2003
sur15er0.zip     NOX, CO, CH4 emissions per month in 2015
sou90er0.zip     CH4 emissions by source in 1990
sou03er0.zip     CH4 emissions by source in 2003
sou15er0.zip     CH4 emissions by source in 2015
s_timepr.ch4     seasonality of CH4 sources

contents of ZIP-files:
---------------------
SUR90ER0.ZIP (NOX, CO, CH4, SO2 emissions per month in 1990)
 MUL90SO2.01..MUL15SO2.12
 MUL90NOX.01..MUL15NOX.12
 MUL90CO.01..MUL90CO.12
 MUL90CH4.02..MUL90CH4.12

SUR03ER0.ZIP (NOX, CO, CH4 emissions per month in 2003)
 MUL03NOX.01..MUL03NOX.12
 MUL03CO.01..MUL03CO.12
 MUL03CH4.02..MUL03CH4.12

SUR15ER0.ZIP ( NOX, CO, CH4 emissions per month in 2015)
 MUL15NOX.01..MUL15NOX.12
 MUL15CO.01..MUL15CO.12
 MUL15CH4.01..MUL15CH4.12

SOU90ER0.ZIP  (CH4 emissions by source in 1990)
 ANT90CH4.01..ANT90CH4.12
 BIO90CH4.01..BIO90CH4.12
 CAT90CH4.01..CAT90CH4.12
 RIC90CH4.01..RIC90CH4.12

SOU03ER0.ZIP (CH4 emissions by sources per month in 2003)
 ANT03CH4.01..ANT03CH4.12
 BIO03CH4.01..BIO03CH4.12
 CAT03CH4.01..CAT03CH4.12
 RIC03CH4.01..RIC03CH4.12

SOU15ER0.ZIP  (CH4 emissions by source in 2015)
 ANT15CH4.01..ANT15CH4.12
 BIO15CH4.01..BIO15CH4.12
 CAT15CH4.01..CAT15CH4.12
 RIC15CH4.01..RIC15CH4.12

FILE CODES, FORMATS AND UNITS
===========================
File names "nnnyysss" of ZIP files correspond with:
         nnn = source name (sur = all surface sources; sou = CH4 sources only)
         yy  = year, last 2 digits only (90=1990, 03=2003, 15=2015)
         sss = scenario (er0 = European Renaissance)
Data files are labeled "sssyyccc.##" in which:
         sss = source category (mul = all surface sources *)
         yy  = year, last 2 digits only (90=1990, 03=2003, 15=2015)
```

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```
        ccc = compound
        ##  = number of month (e.g. 01 = January)
* For specific sources of methane see par. on scenario definition

Units on files: Tg of CH4, NO2, CO and SO2/cell/month

Data are write in a block in the following order:
-180,85      -175,85 ....
-180,80      -175,80 ....
(longitude,latitude of lower left corner of 5x5 cell)

TIME PROFILES
=============
For all source categories emission estimates are included for 12 months;
one month being defined as 1/12 of a year. Aggregated data for ch4 are
presented in file s_timepr.ch4. For future years we assumed the same time
profile as for 1990.
For more information we refer to the paper of J.-F. Muller (1992).


DEFINITION SCENARIO ER0
======================

CH4 Sources     Index
-----------     1990     2003     2015

       ANT *    1.00     1.19     1.37
       BIO *    1.00     1.07     1.13
       CAT *    1.00     1.25     1.48
       RIC *    1.00     1.15     1.30

NOx Sources
-----------
       ANT      1.00     1.31     1.60
       BIO      1.00     1.08     1.16
       SOIL     1.00     1.00     1.00

CO Sources
----------
       ANT      1.00     1.14     1.26
       BIO      1.00     1.07     1.13
       SOIL     1.00     1.00     1.00
       SEA      1.00     1.00     1.00

Notes: * ANT = Sum of energy and landfills
         BIO = Sum of animal waste, biomass burning, sewage, and natural sources.
               (for each of these an individual index has been constructed)
         CAT = Ruminants
         RIC = Rice cultivation

For details we refer to the research note to DGM (ref. 94.049 d.d. 8 June 1994).

DATA SOURCES
============
Muller data: files through FTP
Scenario definition: regional economic growth by CPB;
                     emission development by category by IPCC (Pepper, 1992)
Grid conversions: EDGAR
Emissions scenario: EDGAR
Doc-file: Jos Olivier/Rob paar RIVM/LAE
Name: s_90_15.doc
Date: 94.06.17

REMARKS/DIFFERENCES WITH FILES OF FEBRUARY 1994/DIFFERENCES WITH IPCC ESTIMATE FOR 1990
=======================================================================================
1. In the previous dataset for 1990 constructed in February 1994, emissions by ruminants
   of CH4 contained an error. Now global total emissions in 1990 are 391.21 Tg (instead
   of 412.11). Ruminant (catlle) emssions now total 78.52 Tg (instead of 99.48).
2. For NOx and CO the data for 1990 are identical.
3. In addition to total monthly CH4 emission files, we include files for the 4 categories
   to allow for adjusting sectoral data, if required by atmosheric models.
```

APPENDIX K: Continued

4. For aggregated monthly time profiles of the 4 sources of CH4 see Annex C.
5. Estimations for 2015 in cae of the ER0 scenario are now included.

ANNEXES
=======

A. AGGREGATED EMISSIONS OF NOX, CO, AND CH4 BY MONTH FOR BASE YEAR 1990

Surface Sources
Year: 1990

Compound:		NOx	CO	CH4
Unit:		ton NO2	ton CO	ton CH4
January	1	8.45	119.83	28.41
February	2	8.71	124.12	28.35
March	3	8.52	119.03	29.89
April	4	8.09	108.85	31.51
May	5	7.65	101.85	33.73
June	6	7.91	112.68	36.49
July	7	8.74	135.52	37.87
August	8	9.38	152.46	37.83
September	9	9.27	149.73	36.83
October	10	8.48	127.67	33.68
November	11	7.91	110.74	28.91
December	12	8.08	111.46	27.72
SUM		101.19	1473.94	391.21

B. AGGREGATED EMISSIONS OF NOX, CO, AND CH4 BY MONTH FOR SCENARIO ER0 IN 2003

Surface Sources
Scenario: European Renaissance (ER0)
Year: 2003

Compound:		NOx	CO	CH4
Unit:		ton NO2	ton CO	ton CH4
Mult factor: 1				
January	1	10.46	128.75	33.25
February	2	10.73	133.32	33.18
March	3	10.49	127.75	34.88
April	4	10.01	116.79	36.67
May	5	9.50	109.23	39.15
June	6	9.72	120.75	42.27
July	7	10.57	145.00	43.78
August	8	11.25	163.08	43.73
September	9	11.16	160.19	42.66
October	10	10.39	136.68	39.13
November	11	9.84	118.76	33.77
December	12	10.05	119.73	32.45
SUM		124.17	1580.03	454.92

C. AGGREGATED EMISSIONS OF NOX, CO, AND CH4 BY MONTH FOR SCENARIO ER0 IN 2015

Surface Sources

Scenario: European Renaissance (ER0)
Year: 2015

Compound:		NOx	CO	CH4
Unit:		ton NO2	ton CO	ton CH4
Mult factor: 1				
January	1	12.35	136.39	37.78
February	2	12.62	141.21	37.69
March	3	12.35	135.23	39.55
April	4	11.80	123.59	41.51
May	5	11.24	115.56	44.26
June	6	11.43	127.68	47.73
July	7	12.30	153.13	49.36
August	8	13.00	172.18	49.31
September	9	12.94	169.16	48.17
October	10	12.17	144.41	44.28
November	11	11.64	125.65	38.32
December	12	11.91	126.82	36.87
SUM		145.74	1671.00	514.82

D. AGGREGATED EMISSION OF CH4 SOURCES BY MONTH FOR BASE YEAR 1990

Surface Sources of Methane
Year: 1990

Compound:		CH4 Anthr.	CH4 Cat	CH4 Rice	CH4 Bio
Unit:		ton CH4	ton CH4	ton CH4	ton CH4
January	1	11.75	6.543	3.319	6.796
February	2	11.691	6.543	3.299	6.818
March	3	11.309	6.543	4.544	7.494
April	4	10.71	6.543	6.161	8.091
May	5	10.051	6.543	8.485	8.651
June	6	9.511	6.543	11.314	9.12
July	7	9.233	6.543	12.105	9.992
August	8	9.293	6.543	12.02	9.976
September	9	9.674	6.543	11.46	9.149
October	10	10.273	6.543	8.607	8.255
November	11	10.932	6.543	4.314	7.124
December	12	11.472	6.543	2.933	6.77
SUM		125.90	78.52	88.56	98.24

APPENDIX L: Fuel consumption by air traffic in USA in EIA scenario.

Table L.1: Fuel consumption by aircraft in USA 1990-2015 in reference scenario of EIA.

Fuel consumption: in 10^12 Btu				
Type	**1990**	**2000**	**2005**	**2010**
Commercial - Jet fuel	2334.5	3147.5	3509.5	3856.3
Commercial - Avgas	45.4	42.6	43.3	42.1
Military - jet fuel	795.0	570.1	573.7	582.5
Total	**3174.9**	**3760.2**	**4126.5**	**4480.9**
Fuel consumption: index (1990 = 1)				
Type	**1990**	**2000**	**2005**	**2010**
Commercial - Jet fuel	1.00	1.35	1.50	1.65
Commercial - Avgas	1.00	0.94	0.95	0.93
Military - jet fuel	1.00	0.72	0.72	0.73
Total	**1.00**	**1.18**	**1.30**	**1.41**

Source: EIA, 1994a,b.

It shows that total US jet fuel use by aircraft will grow by about 41% in 20 years.
This is a composite of 65% growth in civil air traffic and a 27% decrease in military air traffic, shifting the share of civil US air traffic from 75% in 1990 to 87% in 2010.

APPENDIX M: Global jet fuel consumption: regional distribution and annual growth.

Table M.1: Global consumption of jet fuel for transportation in 1990.

	EDGAR Region	PJ	Mton	%	Index 1990 (1971 = 1)
E1	Canada	179	4.0	2	1.8
E2	USA	3,162	70.9	42	1.6
E5	OECD EUROPE	1,289	28.9	17	1.9
	- of which: EU-12 *	1,135	25.4	14.9	1.9
	- of which: Netherlands	70	1.6	0.9	2.0
E6	EASTERN EUROPE	59	1.3	1	1.7
E7	Former USSR (CIS)	945	21.2	12	1.0
E3	LATIN AMERICA	339	7.6	4	2.2
E4	AFRICA	195	4.4	3	2.3
E8	MIDDLE EAST	398	8.9	5	4.5
E9	INDIA REGION	107	2.4	1	1.9
E10	CHINA REGION	178	4.0	2	1.6
E11	EAST ASIA	311	7.0	4	4.7
E12	OCEANIA	137	3.1	2	2.2
E13	Japan	315	7.1	4	2.9
	Global total:	**7,613**	**170.7**	**100**	**1.7**

Source: EDGAR, 1995; based on IEA country statistics (IEA, 1994).
* Including former DDR

Table M.2: Consumption within the European Union of jet fuel for transportation in 1990.

ISO	EU Country	PJ	Mton	%	Index 1990 (1971= 1)
BEL	Belgium	41	0.9	4	2.4
DNK	Denmark	31	0.7	3	1.1
DEU	Germany *	236	5.3	21	2.3
FRA	France	167	3.7	15	2.5
GRC	Greece	55	1.2	5	2.0
IRL	Ireland	16	0.4	1	1.0
ITA	Italy	88	2.0	8	1.1
LUX	Luxembourg	6	0.1	1	3.6
NLD	Netherlands	70	1.6	6	2.0
PRT	Portugal	25	0.6	2	1.3
ESP	Spain	107	2.4	9	2.1
GBR	United Kingdom	294	6.6	26	1.8
	EU-12 *	**1,126**	**25.3**	**100**	**1.8**

Source: EDGAR, 1995; based on IEA country statistics (IEA, 1994).
* Including former DDR

Table M.3: Annual global jet fuel consumption for transportation 1989-1992.

Year	Consumption (EJ)	(Mton)	Annual growth (%)
1989	7579.7	170.0	-
1990	7606.6	170.6	0.4
1991	7382.2	165.6	-3.0
1992	7426.1	166.5	0.6

Source: EDGAR, 1995; based on IEA country statistics (IEA, 1994).