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Working Group on Strategies
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Item 3 of the provisional agenda

INTEGRATED ASSESSMENT MODELLING

Progress report by the Chairman of the Task Force

Introduction

1. This report presents scenarios for a multi-pollutant/multi-effect protocol and the data used for modelling. It includes the results of the twenty-second meeting of the Task Force on Integrated Assessment Modelling, held in London from 30 November to 2 December 1998. Experts from Austria, Belgium, the Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Norway, Slovakia, Spain, Sweden, Switzerland, the United Kingdom and the European Community (EC) participated in the meeting. Representatives from the Coordinating Center for Effects (CCE) and the Meteorological Synthesizing Centre-West of EMEP (MSC-W), the European Environment Agency and its Topic Centre for Air Quality, as well as from the International Institute for Applied Systems Analysis (IIASA), the Oil Companies' European Organization for Environmental and Health Protection (CONCAWE) and the World Conservation Union (IUCN), were also present. Mr. Rob MAAS (Netherlands) chaired the meeting.

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2. The first part of this report provides an overview of the data and approaches used by the International Institute for Applied Systems Analysis (IIASA). The modelling results are presented in EB.AIR/WG.5/1998/3/Add.1.

3. The Working Group on Strategies at its twenty-seventh session provided guidance for further integrated assessment modelling and requested the Task Force to examine a number of scenarios (EB.AIR/WG.5/56, paras. 18 and 27). In the light of these requests, IIASA submitted a report to the Task Force, which provides the basis for this document. The work by IIASA was made possible thanks to funding from the Nordic Council of Ministers, the Netherlands and Switzerland. The IIASA reports and complementary information on the Regional Acidification Information and Simulation (RAINS) model used by IIASA can be obtained via the Internet (http://www.iiasa.ac.at/~rains/tfiam22.html). The documents and tables contain, in particular, the maps and scenario results that are not included in this report.

4. A collaborate project coordinated by the Finnish Environment Institute, funded by the EC LIFE Programme and covering Denmark, Finland, Spain and Sweden, has been under way since October 1997. It aims at applying and developing tools at the national level to assess cost-effective emission reductions and impacts with a high spatial and temporal resolution. It helps to check the robustness of integrated assessment models and supports the national work related to the ongoing negotiations. Current work includes the integration of national energy scenarios with EMEP/CORINAIR and RAINS databases, the calculation and comparison of national cost curves, the calculation of critical load exceedances at different spatial resolutions and the assessment of uncertainty of the impacts. A workshop is scheduled to take place jointly with the twenty-fourth meeting of the Task Force in June 1999 to disseminate the findings. The will be coordinated by the Finnish Environment Institute and supported by the EC LIFE programme.

I. INPUT DATA

A. Projected activity levels

5. At the basis of the RAINS model are national energy projections for the year 2010. The model distinguishes the production, conversion and consumption of 22 fuel types in six economic sectors. These energy balances are complemented by additional information relevant to emission projections, such as boiler types (e.g. dry-bottom versus wet bottom-boilers), size distribution of plants, age structures, composition of the vehicle fleet etc.

6. The 'baseline' energy scenario reflects the official business-as-usual forecast, compiled from a variety of national and international sources. For the EC countries, the projection is the pre-Kyoto business-as-usual scenario of the European Commission, DG-XVII, except for those countries that reported alternative business-as-usual energy scenario (Austria, Belgium, Denmark, Finland, Germany, Greece, Ireland, Netherlands, Sweden and the United Kingdom). Italy also submitted a national scenario, but due to inconsistencies, it could not be implemented in the RAINS database. For the non-EC countries, the energy projections are based on data submitted by their Governments to the UN/ECE and published in the UN/ECE energy database. Where necessary, missing forecast data have been calculated by IIASA based on a simple energy projection model. For the Czech Republic, Norway, Poland and

Slovakia the forecasts were modified based on comments obtained from national experts.

7. The energy scenario selected for this report projects, for the EC countries, an increase of total energy consumption of 19% between 1990 and 2010. The demand for coal will decrease by 30%, which will be compensated by a rapid increase in the demand for natural gas (72%) and other fuels, such as nuclear, hydropower, renewable energy (24%). The transport sector is expected to grow further, which - in spite of improvements in fuel economy of new cars and trucks - will result in an increase in the demand for transport fuels by 32%. For the non-EC countries, the scenario projects a 4% drop in total primary energy consumption, due to the sharp decrease in primary energy demand that occurred in the period 1990 to 1995 in the countries of the former Soviet Union and in other countries with economies in transition. Economic restructuring in those countries will allow their economies to grow while keeping the total primary energy demand in 2010 below the 1990 level.

8. Agriculture is a major source of ammonia emissions. Besides specific measures to limit the emissions from livestock farming, the development of the animal stock is an important determinant of future emissions. The projections of agricultural activities for 2010 have been compiled from a variety of national and international studies, including studies for the European Commission (DG-VI). The forecast for the EC countries is based on the assumption that after 2005 the EC will gradually liberalize its agricultural policy. The forecasts presented in this report were reviewed by the Parties in 1997 and include modifications proposed by national experts. The forecast of fertilizer consumption for the EC countries, as well as Switzerland and Norway, is based on a study by the European Fertilizer Manufacturers Association (EFMA). A “moderate grain price” scenario was used. The basic assumptions of this projection are that after the year 2000 a more market-oriented agricultural policy is expected in the EC and that by the year 2005/6 central European countries will have joined the EC. Fertilizer consumption estimates for the rest of Europe were derived from publications of the International Fertilizer Industry Association. Since these forecasts do not always extend up to the year 2010, missing values were calculated based on a trend extrapolation.

9. For Europe as a whole the projections show a stabilisation of the number of poultry and pigs, although the figures for the individual countries are different, and on average decrease of 15% in the number of cows between 1990 and 2010. The use of nitrogen fertilizer is expected to decrease by almost 10%. High densities of livestock and fertilizer use can be found in Belgium, Denmark, Netherlands and parts of France, Germany, Ireland and the United Kingdom.

10. About half the anthropogenic VOC emissions originate from the combustion and distribution of fossil fuels. Hence, projected fuel consumption can be used to estimate future VOC emissions from the relevant sources, i.e. transport, stationary combustion, and extraction and distribution of fuels. The development of the other VOC-emitting sectors is based on information provided by the European Commission and by national experts. The sectoral activity forecasts and population projections are linked to the development of VOC-emitting sectors. Unfortunately, reliable and consistent projections of future activity rates at the process level are scarce. Most economic long-term forecasts restrict themselves to a rather aggregate level of economic

activities. They rarely specify the development of even the major economic sectors. Therefore, the temporal changes in the activity rates are derived from the following four concepts:

(a) The change in the activity rates for processing, distribution and combustion of fossil fuels is linked to changes in fuel consumption provided by the energy scenario;

(b) Some other activity rates (dry-cleaning, use of solvents in households, vehicle treatment, food and drink industry) are linked to economic growth and population development;

(c) The temporal development of a number of industrial activities (e.g. degreasing, paint use, solvent use in chemical industry, printing, other industrial solvent use) is related to changes in the sectoral gross domestic product. As statistics often suggest that these activities grow slower than GDP, sector-specific elasticities derived from statistics have been applied;

(d) Furthermore, comments from national experts on the development of several sectors were taken into account.

In the absence of more information, the activity rates for less important emission sectors are kept constant.

B. <u>Emission estimates</u>

11. Based on activity data obtained as described above, the RAINS model estimates current and future levels of SO2, NOx, VOC and NH3 using emission factors derived from the CORINAIR90 inventory and the EMEP/CORINAIR guidebook, as well as national reports and contacts with national experts. Emissions are estimated on a level of aggregation that is determined by the available details of the energy and agricultural projections and the CORINAIR90 emission inventory.

12. Recent changes to the RAINS emission database included:

- The inclusion of updates of national emission inventories for 1990 received from Austria, Belgium, Croatia, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Norway, Poland, Sweden and the United Kingdom;

- The harmonization of the treatment of emissions from coastal shipping: “Coastal shipping” is now included in the national emissions of the respective countries, and the emissions from international shipping are apportioned to separate categories for the various regional seas.

Contacts between national experts and IIASA made it possible to remove some inconsistencies between the national emission inventories and RAINS estimates. In all cases where national data were well documented, that information was used to improve the RAINS estimate. Compared to the previous Task Force report, the most important changes in the emission database occurred for France, Greece and Sweden, due to the different treatment of the emissions from 'Other mobile sources'.

13. It is also important to mention that, when calculating ozone concentrations, the EMEP model internally determines natural and agricultural

emissions of VOC as a function of temperature, land use, etc. Agricultural emissions are also included in the submitted estimates (sector 10). To avoid double counting of these emissions for ozone calculations, the results presented in this report exclude them from the anthropogenic sources (and the cost curves).

C. The reference scenario

14. As decided by the Working Group on Strategies at its twenty-seventh session (EB.AIR/WG.5/56, para. 18 (c)), the reference scenario (REF) is based on current legislation (CLE) estimates, except for those EC countries that have a lower current reduction plan (CRP), because of the declared preference of EC countries to use such lower CRPs as a starting point (EB.AIR/WG.5/56, para. 19). Tables 1-4 show the CLE estimates by RAINS, modified in the light of comments received by national experts. The tables also show current reduction plans and 1990 emission levels based on protocol obligations or official submissions to the secretariat as of 30 November 1998. Some of these figures were submitted only after IIASA conducted its modelling work and could, therefore, not be taken into account in the modelling results presented here. The abatement costs of the REF scenario are presented in table 5 below. The environmental impacts associated with the reference scenario are discussed in chapter II of the addendum to this report.

15. To construct the CLE scenario, the emission control measures summarized in the latest report on Integrated Assessment Modelling (EB.AIR/1998/1, paras. 7-15) were combined with the activity levels projected for the year 2010 as discussed above. For all of Europe, total SO_2 emissions will be 61% below their 1990 level (-69% for the EC countries). NO_x is projected to decline by 34% (-43% in the EC), and VOC emissions by 35%. Ammonia will be 24% below its 1990 levels (see tables 1-4).

D. Abatement options and their costs

16. Although there is a large variety of options for controlling emissions, an integrated assessment model constructed on a European scale has to restrict itself to a manageable number of abatement options. For each emission source category, the RAINS model identifies a limited number of control options. For each of these measures, the model extrapolates the current operating experience to future years, taking into account the most important country- and sector-specific circumstances affecting the applicability and costs of the techniques.

17. For each of the available emission control options, RAINS estimates the specific costs of the reductions, taking into account investment-related and operating costs. Investments are annualized over the technical lifetime of the pollution control equipment, using a discount factor of 4%. The technical performance as well as investments, maintenance and material consumption are considered to be technology-specific. For a given technology, they will, therefore, be the same throughout Europe. Fuel characteristics, boiler sizes, capacity utilization, labour and material costs (and stable sizes and applicability rates of abatement options for ammonia) are important country-specific factors influencing the actual costs of emission reduction under given conditions.

Table 1: Emissions of NO_x in 1990 and projections for 2010

	1990 submitted	1990 RAINS	2010 submitted	Current legislation (CLE)	Reference (REF)		Maximum Feasible Reductions (MFR)	
					kt	Change[a]	kt	Change[a]
Austria	196	192	154	110	110	-43%	54	-72%
Belarus	285	402	180	316	316	-21%	56	-86%
Belgium	343	351	-	199	199	-43%	81	-77%
Bosnia and Herzegovina	-	80	-	60	60	-25%	11	-86%
Bulgaria	376	355	290	297	297	-16%	61	-83%
Canada	2104	-	2085	-	-	-	-	-
Croatia	83	82	83	91	91	11%	16	-81%
Cyprus	20	-	23	-	-	-	-	-
Czech Republic	742	546	351	296	296	-46%	78	-86%
Denmark	282	274	-	131	131	-52%	49	-82%
Finland	300	276	-	159	159	-42%	56	-80%
France	1585	1867	-	1017	1017	-46%	383	-79%
Germany	2654[b]	2662	1316	1256	1256	-53%	622	-77%
Greece	344	345	-	426	344	0%	127	-63%
Hungary	238	219	196	198	198	10%	50	-77%
Iceland	20	-	19	-	-	-	-	-
Ireland	115	113	105	73	73	-35%	27	-76%
Italy	1938	2037	1436	1166	1166	-43%	396	-81%
Latvia	90	117	-	118	118	1%	23	-81%
Liechtenstein	0.63	-	-	-	-	-	-	-
Lithuania	158	153	110	138	138	-10%	25	-83%
Luxembourg	23	22	-	10	10	-55%	4	-80%
Netherlands	580	542	327	304	304	-44%	127	-77%
Norway	222	220	-	183	183	-17%	49	-78%
Poland	1280	1217	879	879	879	-28%	266	-78%
Portugal	221	208	-	181	181	-13%	51	-76%
Republic of Moldova	39	87	34	66	66	-24%	14	-84%
Romania	546	518	-	458	458	-12%	100	-81%
Russian Federation[c]	2675	3486	-	2798	2798	-20%	527	-85%
Slovakia	225	219	-	132	132	-40%	42	-81%
Slovenia	62	60	31	36	36	-40%	8	-87%
Spain	1177	1162	-	866	866	-25%	263	-77%
Sweden	338	338	200	195	195	-42%	75	-78%
Switzerland	166	163	113	85	85	-48%	41	-75%
The FYR of Macedonia	-	39	-	29	29	-26%	5	-86%
Turkey	497	-	1670	-	-	-	-	-
Ukraine	1097	1888	1094	1433	1433	-24%	325	-83%
United Kingdom	2762	2839	1186	1385	1186	-58%	521	-82%
United States	21584	-	19141	-	-	-	-	-
Yugoslavia	66[d]	211	147	152	152	-28%	27	-87%
European Community	-	13226	-	7478	7197	-46%	2836	-79%
Atlantic	-	911	-	-	-	-	-	-
Baltic	-	80	-	-	-	-	-	-
North Sea	-	639	-	-	-	-	-	-
Total	**-**	**25025**	**-**	**15351**	**15070**	**-36%**	**4580**	**-80%**

a/ Change relative to 1990, using RAINS estimates.
b/ Emissions from international air traffic, marine bunkers and managed forests are not included.
c/ Figures apply to the European part within EMEP.
d/ Emissions from stationary sources only.

Table 2: Emissions of VOC in 1990 and projections for 2010

	1990 submitted	1990 RAINS	2010 submitted	Current legislation (CLE)	Reference (REF)		Maximum Feasible Reductions (MFR)	
					kt	Change[a/]	kt	Change[a/]
Austria	367	352	266	206	206	-41%	97	-72%
Belarus	533	371	321	309	309	-17%	71	-81%
Belgium	358	374	-	195	195	-48%	85	-77%
Bosnia and Herzegovina	-	51	-	48	48	-6%	11	-79%
Bulgaria	217	195	192	190	190	-3%	37	-81%
Canada	2880	-	2927	-	-	-	-	-
Croatia	105	103	100	111	111	8%	25	-76%
Cyprus	-	-	-	-	-	-	-	-
Czech Republic	435	442	-	367	304	-31%	102	-77%
Denmark	178	182	-	86	86	-53%	49	-73%
Finland	207	213	150	111	111	-48%	49	-77%
France	2404	2423	-	1256	1256	-48%	658	-73%
Germany	3181[b/]	3100	1137	1123	1100	-65%	644	-79%
Greece	-	336	-	268	268	-20%	100	-70%
Hungary	205	204	145	174	160	-22%	50	-75%
Iceland	6	-	6	-	-	-	-	-
Ireland	197[c/]	110	138	55	55	-50%	30	-73%
Italy	2213	2055	1440	1166	1166	-43%	617	-70%
Latvia	63	63	-	56	56	-11%	11	-82%
Liechtenstein	1.56	-	-	-	-	-	-	-
Lithuania	111	111	84	105	105	-5%	33	-70%
Luxembourg	20	19	-	7	7	-63%	5	-76%
Netherlands	502	490	247	237	237	-52%	136	-72%
Norway	301	297	-	302	195	-34%	124	-58%
Poland	831	797	954	807	807	1%	284	-64%
Portugal	206	212	-	164	144	-32%	68	-68%
Republic of Moldova	11.1	50	7.0	42	42	-16%	10	-80%
Romania	616	503	-	504	504	0%	126	-75%
Russian Federation[d/]	3566	3542	-	2787	2786	-21%	644	-82%
Slovakia	149	151	-	140	140	-7%	57	-82%
Slovenia	42	55	25	40	40	-27%	12	-78%
Spain	1134	1008	-	699	669	-34%	365	-64%
Sweden	526	492	290	283	283	-42%	128	-74%
Switzerland	292	278	143	145	145	-48%	72	-74%
The FYR of Macedonia	-	19	-	19	19	0%	4	-79%
Turkey	-	-	-	-	-	-	-	-
Ukraine	1369	1161	1369	851	851	-27%	165	-86%
United Kingdom	2552	2667	1351	1638	1351	-49%	841	-68%
United States	19037	-	13418	-	-	-	-	-
Yugoslavia	-	142	-	139	139	-2%	26	-82%
European Community	-	14032	-	7494	7133	-49%	3872	-72%
Atlantic	-	0	-	-	-	-	-	-
Baltic	-	0	-	-	-	-	-	-
North Sea	-	0	-	-	-	-	-	-
Total	**-**	**22641**	**-**	**14719**	**14175**	**-37%**	**5755**	**-75%**

a/ Change relative to 1990, using RAINS estimates.
b/ Emissions from international air traffic, marine bunkers and managed forests are not included.
c/ No information as to whether nature is included.
d/ Figures apply to the European part within EMEP.

Table 3: Emissions of NH_3 in 1990 and projections for 2010

	1990 submitted	1990 RAINS	2010 submitted	Current legislation (CLE)	Reference (REF)		Maximum Feasible Reductions (MFR)	
					kt	Change[a/]	kt	Change[a/]
Austria	77	77	-	67	67	-13%	48	-38%
Belarus	4	219	-	163	163	-26%	103	-53%
Belgium	104	97	-	96	96	-1%	57	-42%
Bosnia and Herzegovina	-	31	-	23	23	-26%	17	-45%
Bulgaria	144	141	126	126	126	-11%	86	-39%
Canada	-	-	-	-	-	-	-	-
Croatia	37	40	33	37	37	-8%	22	-46%
Cyprus	-	-	-	-	-	-	-	-
Czech Republic	156	107	-	108	108	1%	72	-33%
Denmark	122	77	-	72	72	-6%	40	-47%
Finland	35	40	34	31	31	-23%	23	-43%
France	700	805	-	798	798	-1%	541	-33%
Germany	769[b/]	757	572	571	571	-25%	353	-53%
Greece	-	80	-	74	74	-8%	59	-26%
Hungary	164[c/]	120	150	137	137	-14%	73	-40%
Iceland	-	-	-	-	-	-	-	-
Ireland	126[c/]	127	126	130	126	-1%	111	-13%
Italy	466	462	449	432	416	-10%	282	-39%
Latvia	44	43	-	35	35	-19%	19	-56%
Liechtenstein	0.15	-	-	-	-	-	-	-
Lithuania	84	80	84	81	81	1%	49	-38%
Luxembourg	7	7	-	9	7	0%	7	-4%
Netherlands	226	233	136	196	136	-42%	105	-55%
Norway	23	23	-	21	21	-9%	17	-27%
Poland	508	505	-	541	541	7%	367	-27%
Portugal	93	71	-	67	67	-6%	46	-36%
Republic of Moldova	-	47	0.15	48	48	2%	29	-39%
Romania	300	292	-	304	304	4%	206	-30%
Russian Federation[d/]	1191	1282	-	894	894	-30%	571	-55%
Slovakia	62	60	-	47	47	-22%	30	-50%
Slovenia	24	23	27	21	21	-9%	12	-49%
Spain	353	352	-	383	353	0%	225	-36%
Sweden	51	61	48	61	48	-21%	44	-28%
Switzerland	72	72	68	66	66	-8%	54	-25%
The FYR of Macedonia	-	17	-	16	16	-6%	11	-34%
Turkey	-	-	-	-	-	-	-	-
Ukraine	-	729	-	649	649	-11%	406	-44%
United Kingdom	333	329	-	297	297	-10%	218	-34%
United States	4731[c/]	-	-	-	-	-	-	-
Yugoslavia	-	90	-	82	82	-9%	54	-40%
European Community	-	3576	-	3283	3159	-12%	2156	-40%
Atlantic	-	0	-	-	-	-	-	-
Baltic	-	0	-	-	-	-	-	-
North Sea	-	0	-	-	-	-	-	-
Total	**-**	**7556**	**-**	**6745**	**6621**	**-12%**	**4394**	**-42%**

a/ Change relative to 1990, using RAINS estimates.
b/ Emissions from international air traffic, marine bunkers and managed forests are not included.
c/ No information as to whether nature is included.
d/ Figures apply to the European part within EMEP.

Table 4: Emissions of SO_2 in 1990 and projections for 2010

	1990 submitted	1990 RAINS	2010 submitted	Current legislation (CLE)	Reference (REF) kt	Reference (REF) Change[a/]	Maximum Feasible Reductions (MFR) kt	Maximum Feasible Reductions (MFR) Change[a/]
Austria	93	93	-	42	42	-55%	30	-68%
Belarus	637	843	480	494	494	-41%	49	-94%
Belgium	322	336	215	208	208	-38%	60	-82%
Bosnia and Herzegovina	480	487	-	415	415	-15%	23	-95%
Bulgaria	2020	1842	1127	846	846	-54%	130	-93%
Canada	3236	-	2914	-	-	-	-	-
Croatia	180	180	117	70	70	-61%	17	-91%
Cyprus	55	-	62	-	-	-	-	-
Czech Republic	1876	1873	376	366	366	-80%	100	-95%
Denmark	182	182	-	97	90	-51%	19	-90%
Finland	260	232	-	124	116	-50%	67	-71%
France	1298	1250	737[b/]	489	489	-61%	165	-87%
Germany	5263[c/]	5280	609[c/]	661	660	-88%	311	-94%
Greece	503	504	570	562	562	12%	87	-83%
Hungary	1010	913	653	546	546	-40%	286	-69%
Iceland	24	-	23	-	-	-	-	-
Ireland	178	178	155	70	70	-61%	21	-88%
Italy	1651	1679	842	593	593	-65%	194	-88%
Latvia	57	121	-	104	104	-14%	18	-85%
Liechtenstein	0.15	-	-	-	-	-	-	-
Lithuania	222	213	145	107	107	-50%	22	-90%
Luxembourg	15	14	-	9	4	-71%	2	-84%
Netherlands	202	201	98	74	74	-63%	47	-76%
Norway	53	52	-	33	33	-37%	17	-68%
Poland	3210	3001	-	1525	1525	-49%	367	-88%
Portugal	283	284	-	146	146	-49%	29	-90%
Republic of Moldova	231	197	130	117	117	-41%	19	-90%
Romania	1311	1331	-	594	594	-55%	93	-93%
Russian Federation [d/]	4460[e/]	5012	4297[e/]	2344	2344	-53%	539	-89%
Slovakia	543	548	240	137	137	-75%	68	-88%
Slovenia	194	200	37	76	76	-62%	10	-95%
Spain	2266	2189	-	793	793	-64%	166	-92%
Sweden	119	119	67	69	67	-44%	52	-56%
Switzerland	43	43	27	36	36	-16%	12	-72%
The FYR of Macedonia	-	107	-	81	81	-24%	5	-95%
Turkey	-	-	-	-	-	-	-	-
Ukraine	2782	3706	2310	1488	1488	-60%	368	-90%
United Kingdom	3764	3805	980	1099	980	-74%	286	-92%
United States	20989	-	16235	-	-	-	-	-
Yugoslavia	508[e/]	585	1135[e/]	269	269	-54%	29	-95%
European Community	-	16345	-	5035	4894	-70%	1535	-91%
Atlantic	-	641	-	-	-	-	-	-
Baltic	-	72	-	-	-	-	-	-
North Sea	-	439	-	-	-	-	-	-
Total	**-**	**39096**	**-**	**14912**	**14771**	**-61%**	**3728**	**-90%**

a/ Change relative to 1990, using RAINS estimates.
b/ Drawn from the 1994 Sulphur Protocol.
c/ Emissions from international air traffic, marine bunkers and managed forests are not included.
d/ Figures apply to the European part within EMEP.
e/ Emissions from stationary sources only.

18. The databases on emission control costs have been based on the actual operating experience of various emission control options documented in a number of national and international studies. Their main sources of information include the proceedings of the UN/ECE Seminars on Emission Control

Technology for Emissions from Stationary Sources (EB.AIR/SEM.3/3) and the technical annexes to the Oslo Protocol and other documentation. Data on mobile sources are based on the material developed within the EC Auto-Oil Programme. Country-specific information has been extracted from relevant national and international statistics and was provided by national experts. The list of control options for SO_2, NO_x, NH_3 and VOC and the country-specific data used for the cost calculations were presented to the Parties for review. All costs are expressed in constant 1990 ECU.

19. For a given energy scenario, reduction options for SO_2 emissions are the use of low-sulphur fuel, fuel desulphurization, combustion modification (e.g. limestone injection processes and fluidized bed combustion) and flue gas desulphurization (e.g. wet limestone scrubbing processes). The boxes below show the available control options for the major source categories and the data applied for the analysis. The data have recently been updated to take the latest operating experience into account. The most important updates are:

- The reduction efficiency of limestone injection has been increased from 50 to 60%. Such reduction efficiencies are achieved in German plants equipped with this technology;

- Following the comments made by CONCAWE, the price differential for low-sulphur heavy fuel oil was corrected to reflect modified assumptions about the capacity utilization of desulphurization plants.

Emission control options for SO_2 in the power plant and industrial sector

Sector/control option	**Costs** [a/]		
	Removal efficiency (%)	**Investment (1000 ECU/MW_{th})**	**Operating and maintenance (% year)** [b/]
<u>Retrofit of existing boilers (power plants)</u>			
Limestone injection	60	30	4
Wet flue gas desulphurization (FGD) - boilers already retrofitted in the base year	90	69	4
Wet flue gas desulphurization- boilers not yet retrofitted	95	69	4
Regenerative FGD	98	165	4
<u>New boilers (power plants)</u>			
Limestone injection	60	22	4
Wet flue gas desulphurization	95	49	4
Regeneration FGD	98	119	4
<u>Industrial boilers and furnaces</u>			
Limestone injection	60	35	4
Wet flue gas desulphurization	85	72	4

a/ Values are for typical hard coal fired boilers for each source category.
b/ Per cent of investments per year.

Options for low-sulphur fuels		
Fuel type	**Price difference (ECU/GJ/%S)**[a]	**Costs ($ECU/t\ SO_2$)**[b]
Hard coal and coke, 0.6% S	0.28	397
Heavy fuel oil, 0.6% S	0.20	463
Gas oil, reduction to 0.2% S	0.68	1440
Gas oil, reduction from 0.2% to 0.045% S	2.04	4330
Gas oil, reduction from 0.045% to 0.003% S[c]	6.69	14200

a/ Per cent of sulphur reduced compared to original fuel.

b/ Per ton of SO_2 removed. Since the costs depend on the heating value of the fuel, values given in the table are indicative.

c/ Only available for transport.

Emission control options for industrial process emissions of SO_s		
Control option	Removal efficiency (%)	Costs (ECU / t SO_2)
Stage 1	50	350
Stage 2	70	407
Stage 3	80	513

20. Options for reducing NO_x emissions from stationary sources and their costs are presented in the following boxes. Depending on the source category, the following main control options are used:

- Primary measures (low-NO_x burners, re-burning, staged combustion). In the power plant sector this option is considered as a retrofit measure. For new installations, the use of primary measures is assumed by default at no extra cost;
- Selective catalytic (SCR) and non-catalytic (SNCR) reduction (always in combination with primary measures).

Control options for NO_x emissions for the power plant sector			
Sector/control option	**Removal efficiency (%)**	**Costs**[a]	
		Investment ($kECU/MW_{th}$)	**Operating and maintenance (%/year)**
Retrofits of existing boilers:			
Combustion modification and primary measures (CM) [b]			
Brown coal and lignite	65	6.8	-
Hard coal	50	3.9	-
Heavy fuel oil	65	4.7	-
Gas	65	5.0	-
CM + SCR			
Brown coal and lignite	80	28.9	6
Hard coal	80	23.0	6
Heavy fuel oil	80	22.9	6
Gas	80	24.7	6
New boilers:[c]			
SCR			
Brown coal and lignite	80	14.1	6
Hard coal	80	12.2	6
Heavy fuel oil	80	9.8	6
GAS	80	12.9	6

a/ Values are for typical boilers in each source category.
b/ Combination of various measures.
c/ Low-NO_x burners are assumed by default; thus, new boilers have lower emission factors than existing ones.

Control options for NO_x emissions from the residential and commercial sector			
Sector/Control option	Removal efficiency (%)	Costs	
		Investment (kECU/MW_{th})	Operating and maintenance
Residential and commercial sector[a]			
Combustion modification, low-NO_x burners			
Heavy fuel oil	50	5.6	-
Medium distillates	30	12	-
Natural gas	30	16.3	-

a/ Weighted average for the residential and commercial sector. Unit control costs for gas and gas oil fired boilers in the commercial sector are 40-50% lower.

Control options for NO_x emissions from industrial boilers			
Sector/control option	Removal efficiency (%)	Costs[a]	
		Investment (kECU/MW_{th})	Operating and maintenance (%/year)[b]
Combustion modification and primary measures (CM)			
Brown coal and lignite	50	5.6	-
Hard coal	50	5.6	-
Heavy fuel oil	50	5.0	-
Medium distillates and gas	50	5.7	-
CM + selective non-catalytic			
Brown coal and lignite	70	11.0	6
Hard coal	70	11.0	6
Heavy fuel oil	70	9.1	6
Gas	70	10.6	6
CM + select. cat. reduction			
Brown coal and lignite	80	26.0	6
Hard coal	80	25.3	6
Heavy fuel oil	80	18.5	6
Gas	80	21.4	6

a/ Values are for typical boilers for each source category.
b/ Per cent of investment cost per year.

Control options for NO_x emissions from industrial processes		
Control option	Removal efficiency (%)	Costs (ECU/t NO_x)
Stage 1	40	1000
Stage 2	60	3000
Stage 3	80	5000

21. Options for reducing VOC emissions from stationary sources and their costs are described in the box below. The box also includes carbon canisters and oxidation catalysts for two-stroke petrol engines, which relate to mobile

sources. Common methods for reducing VOC emissions from stationary sources include modifying the production process or storage tanks, improving management practices (e.g. good housekeeping, leak monitoring and repair programmes), solvent substitution and, finally, add-on technologies, such as thermal or catalytic incineration, adsorption, absorption, condensation/refrigeration and bio-oxidation. The efficiencies presented below refer to the option's assumed technical efficiency. In reality, the most efficient options often have only limited applicability.

Major categories of VOC abatement measures

Sector	Technology	Efficiency (%)	Cost range (ECU/t)
Solvent use			
Dry Cleaning	Good housekeeping and adsorption	60	~600
	Closed circuit conventional or new machines	76/92	550/1200-4500
Metal degreasing	Basic emission management techniques	20	< 200
	Carbon adsorption	80	1300-2000
	Low-temperature plasma process	98	1700-2300
	Conveyored degreaser with integrated adsorption	95	1700-2200
	Water-based systems	99	2500-4000
Domestic solvent use	Substitution	~25	< 4300
Non-industrial paint use	Water based paints	70-80	400-800
	High solids	40-60	1200-3000
Industrial paint use (car manufacturing)	Good housekeeping, application technique modification	20-45	< 100
	Process modification and substitution	55-70	600-800/2000-4000
	Adsorption, incineration	95	1500-1800/ 3000-7000
Vehicle refinishing	Good housekeeping, application technique modification	15-30	< 0
Products incorporating solvents	Housekeeping, application technique, substitution	72	300-800
	Substitution	50	< 50
Products not in-corporating solvents	Basic emission management and end-of-pipe	95	600-900
	Solvent management plan and substitution	50	~200
Printing	Basic emission management and end-of-pipe	60	1200-2500
	Low-solvent inks and enclosure	50-75	< 30
	Water-based inks	75-95	30-600
	Adsorption	75	150-1000
	Incineration	75	1000-10000
Glues and adhesives in industry	Good housekeeping	15	< 50
	Substitution	85	350
	Incineration	80	~600
Preservation of wood	Double vacuum impregnation & dryer enclosure	40	~2800
	As above plus end-of-pipe	75	4300-7500
Other industrial use of solvents	Process modification and biofiltration	75	~600
	Water-based coating (leather tanning)	-60	~350
	New agrochemical products	~40	~0

Chemical industry			
Organic chemical industry, processing and storage	Quarterly, monthly inspection and maintenance programmes	60/70	~1600/-6000
	Flaring	85	~350
	Incineration	96	~800
	Internal floating covers and secondary seals	90	~2800
	Vapour recovery units	95-99	5600-6200
Pharmaceutical ind.	Good housekeeping and end-of-pipe	85-90	2500-6000
Refineries	Quarterly, monthly inspection and maintenance programme	60/70	<50/300-1000
	Covers on oil/water separators	90	~200
	Flaring / Incineration	98/99	200-300
	Internal floating covers and secondary seals	85	<100

Major categories of VOC abatement measures			
Sector	**Technology**	**Efficiency (%)**	**Cost range (ECU/t)**
	Vapor recovery units (Stage IA)	95-99	500-2500
Liquid fuel extraction and distribution			
Fuel extraction, loading and transport	Venting alternatives and increased recovery	90	1800-2200
	Improved ignition system on flares	62	4500-5500
	Vapour balancing on tankers and loading facilities	78	50-200
Fuel distribution	Internal floating covers and secondary seals	85	<100
	Vapour recovery units (Stage IA)	95-99	500-2500
	Stage II	85	1500-3000
	Stage IB	95	200-800
Petrol evaporat.	Small carbon canister	85	50-500
2-stroke engines	Oxidation catalyst	80	900
Residential combustion	New boilers Catalyst	80 50	100-500 1000-7000
Miscellaneous			
Food and drinks industry	End-of-pipe	90	10 000
Agriculture	Ban on burning waste	100	60
Other industrial	Good housekeeping	20-60	<100
	Bitumen substitution (asphalt)	92	<50
Waste disposal	Improved landfills	20	400

22. There is a wide variety of fuel- and vehicle-related measures for reducing emissions from mobile sources. To keep the analysis manageable, RAINS aggregates individual measures into packages, following as far as possible the legislative proposals for emission standards discussed within the EC. The boxes below present the packages for controlling NO_x and VOC emissions from mobile sources. Data on mobile sources have been derived from various reports developed within the EC Auto/Oil Programme and from other national and international sources. The costs and control efficiencies of technologies used for the calculations presented in this report include the decisions of the European Council of October 1997 regarding the common positions on the quality of petrol and diesel fuels as well as on pollution control measures for motor vehicles. In particular, the following measures have been included in addition to the original Auto/Oil proposal:

- Change in petrol characteristics. For the year 2000, a reduction in the sulphur content to 150 ppm, in benzene to 1% and in aromatics to 42%. For 2005, further reductions to 50 ppm for sulphur and 35% for aromatics;

- Reduction of the maximum sulphur content in diesel oil to 50 ppm. It has been assumed that this low-sulphur diesel fuel will be phased in between 2005 and 2015. Its additional costs are allocated to SO_2 control;

- For petrol cars and light commercial vehicles, Stage 3 controls from the year 2000 and Stage 4 controls after 2005, taking into account the costs of the cold start test;

- Stage 4 controls for diesel cars and light commercial vehicles, including the requirement for on-board diagnostic systems;

It is important to note that the EC Auto/Oil Programme used the net present value costing methodology, whereas RAINS expresses costs in terms of total annual costs, based on annualized investments over the entire technical lifetime of the equipment and the fixed and variable operating costs. In addition, EC Auto/Oil costs are in 1995 prices, while RAINS uses constant prices from 1990 as the basis for its calculations.

Control options for NO_x and VOC emissions from mobile sources			
Fuel/vehicle type/control technology	Removal efficiency NO_x/VOC (%)	Costs	
		Investments (ECU/vehicle)	Operating & maintenance (%/year)[a]
Petrol 4-stroke passenger cars and LDV[b]			
3-way catalytic converter - 1992 standards	75/75	250	30
3-way catalytic converter - 1996 standards	87/87	300	25
Advanced converter with maintenance schemes - EU 2000 standard	93/93	709	11
Advanced converter with maintenance schemes – EU post-2005 standard (**)	97/97	884	8
Diesel passenger cars and LDV			
Combustion modification - 1992 standards	31/31	150	34
Combustion modification - 1996 standards	50/50	275	19
Advanced combustion modification with maintenance schemes - EU 2000 standards	60/60	780	7
NO_x converter(**)	80/80	1 027	5
Heavy-duty vehicles - diesel			
Euro I - 1993 standards	33/36	600	42
Euro II - 1996 standards	43/47	1 800	14
Euro III - EU 2000 standards with maintenance schemes	60/66	4 047	6
Euro IV (NO_x converter) (**)	85/93	8 047	3
Heavy-duty vehicles – petrol			
Catalytic converter	85/85	2 750	7
Seagoing ships			
Combustion modifications – medium vessels[c]	40/0	115 000	4
Combustion modifications – large vessels[d]	40/0	165 000	4
SCR – large vessels	90/0	526 000	4

(**) - Not yet commercially available.
a/ Per cent of investment cost per year.
b/ LDV - light-duty vehicles.
c/ About 300 kW thermal.
d/ About 2500 kW thermal.

23. Ammonia emissions from livestock occur at four stages: in the animal house, during the storage and application of manure, and during the grazing period. At every stage emissions can be controlled by applying various techniques. RAINS cannot distinguish all of the several hundred available

control options, but considers groups of techniques with similar technical and economic characteristics. The major categories considered are:

- Low-nitrogen feed (dietary changes), e.g. multi-phase feeding for pigs and poultry, use of synthetic amino acids (pigs and poultry), and the replacement of grass and grass silage by maize for dairy cattle;

- Biofiltration (air purification), e.g. by treatment of ventilated air using biological scrubbers to convert the ammonia into nitrate or biological beds where ammonia is absorbed by organic matter. This option is applicable mainly for pigs and poultry;

- Animal house adaptation by improving the design and construction of the floor (applicable for cattle, pigs and poultry), flushing the floor, climate control (for pigs and poultry), or wet and dry manure systems for poultry;

- Covered outdoor storage of manure (low-efficiency options with floating foils or polystyrene and high-efficiency options using tension caps, concrete, corrugated iron or polyester);

- Low-ammonia application techniques, distinguishing high-efficiency (immediate incorporation, deep and shallow injection of manure) and medium- to low-efficiency techniques, including slit injection, trailing shoe, slurry dilution, band spreading, sprinkling (spray boom system);

- Replacement of urea by ammonium nitrate for fertilizer application;

- Stripping and absorption techniques in the chemical industry (e.g. during fertilizer production).

24. The removal efficiencies and costs of the control options are presented below. The cost estimates for ammonia abatement techniques are less certain than those for SO_2 and NO_x control options, mainly due to the lack of practical operating experience with many of the techniques in most European countries. An overview of national experience is available in the proceedings of the Workshop on the Potential for Abatement of Ammonia Emissions from Agriculture and the Associated Costs (Culham, United Kingdom, October 1994).

Emission control options for NH_3 and their assumed removal efficiencies

Abatement option	Application area	Removal efficiency (%)				Investments (ECU/animal-place)		Total costs * (ECU/animal place/year)	
						Stable size**			
		Stables	Storage	Application	Meadow	Small	Typical	Small	Typical
Low-nitrogen feed	Dairy cows	15	15	15	20	n.a.		45	
	Pigs	20	20	20	n.a.	2.7		8	
	Laying hens	20	20	20	n.a.	n.a.		0.1	
	Other poultry	10	10	15	n.a.	n.a.		0.12	
Bio-filtration[a/] and bio-scrubbers	Pigs, poultry	80	-	n.a.	n.a.	200-300	170	40-60	35-38
	Laying hens	-	-	-	-	4.7		1.3-2.0	
	Other poultry	-	-	-	-	4.7		1.5-2.5	
Animal house adaptation	Dairy cows, other cattle	45	60	n.a.	n.a.	450-550	400	90-110	75-90
	Pigs	50	60	n.a.	n.a.	90-94	89	18-20	
	Laying hens	70	70	n.a.	n.a.	0.8		0.2-0.25	
	Other poultry	80	70	n.a.	n.a.	1.8		0.28	
Covered storage high-efficiency	Dairy cows	n.a.	50/80	n.a.	n.a.	150-350	100-220	20-50	10-20
	Other cattle					80-200	70-150	20-35	9-15
	Pigs					25-80	15-20	6-15	2-4
	Laying hens					0.4		0.05	
Covered storage low-efficiency	Dairy cows					50-100	30-60	10-20	5-7
	Other cattle					40-100	30-40	10-15	4-5
	Pigs					10-40	7-8	3-7	1-2
	Laying hens					0.2		0.03	
Low NH_3 appli-cation (LNA-low/high)	Dairy cows	n.a.	n.a.	40/80	n.a.	n.a.		40-70	
	Other cattle					n.a.		10-40	
	Pigs					n.a.		4-12	
	Laying hens					n.a.		0.1-015	
	Other poultry					n.a.		0.02-0.06	
	Sheep					n.a.		2-4	
Urea sub-stitution	Fertilizer	80 - 93				ECU 350-950/t NH_3 removed			
Stripping/ adsorption	Industry	50				ECU 7000/t NH_3 removed			

a/ Although some Parties indicated during the review of cost data that this option was also available for cattle (because many animal houses are equipped with mechanical ventilators), it has not yet been implemented in RAINS.

n.a.: not applicable.

* Taking into account fixed and variable operating costs.

** The following stable sizes are assumed:
Pigs - small (<50 animals/stable), typical (~170)
Dairy cows - small (<20 animals/stable), typical (~35)
Other cattle - small (<30 animals/stable), typical (~40).

E. Maximum feasible emission reductions

25. The maximum feasible reduction (MFR) scenario has been constructed to illustrate the potential of the full application of current control technologies. Based on the baseline energy scenario, the MFR scenario simulates the hypothetical case of a complete implementation of the currently available most efficient emission control technologies to all emission sources. In contrast to the assumptions made previously, constraints imposed by current legislation and historically observed turnover rates of the capital stock are ignored in this 'ultimate' MFR scenario. However, changes to the structure and the levels of economic activity and energy consumption, for instance as a reaction to abatement policies imposed, are excluded. This hypothetical scenario assumes a complete penetration of the presently best available emission control techniques, also implying that already installed equipment with lower reduction efficiencies will be replaced by more efficient measures, and that such replacement might occur before the end of its normal technical lifetime.

26. In reality, the limited turnover of capital stock will be an important factor determining the achievable emission reductions. The methodology for deriving the cost curves, described above, takes full account of these limitations and distinguishes different emission control efficiencies for the several vintages of emission control equipment. Furthermore, the cost curves exclude the early retirement of already existing equipment. Consequently, these cost curves, which were those used for the optimization runs, do not reflect the full theoretical potential for reducing emissions.

27. The analysis presented below, includes for the first time also the potential for further emission reductions from mobile sources beyond measures agreed upon in the EC Auto/Oil 1 Programme (in particular, for off-road and heavy-duty vehicles).

28. The abatement costs for the hypothetical MFR scenario are presented in table 5. The environmental impacts associated with this scenario are discussed in chapter II of the addendum to this report.

F. Atmospheric source-receptor relationships

29. The RAINS model calculates the contributions of national emissions to the deposition of acidifying and eutrophying compounds and to ozone formation on the basis of source-receptor matrices derived from the Lagrangian models of long-range transport of air pollutants in Europe developed by EMEP. The EMEP Lagrangian models are receptor-oriented one-layer trajectory models in which air parcels follow the air motion within the atmospheric boundary layer. During transport, air parcels receive emissions from the underlying grid of 150x150 km^2, experience chemical transformations and removal to the ground surface by dry and wet deposition. Transboundary air pollution exchange budgets are calculated every year based on six-hourly input data of the actual meteorological conditions and officially reported emissions for the specific years.

Table 5. Cost of abatement for Reference and MFR scenarios (million ECU)

	Cost of REF				Costs ult. MFR			
	NO_x &VOC	SO_2	NH_3	Total	NO_x &VOC	SO_2	NH_3	Total
Albania	0	0	0	0	165	44	60	269
Austria	887	174	0	1 061	1 496	207	362	2 065
Belarus	0	0	0	0	1 071	288	433	1 792
Belgium	1 254	341	0	1 595	2 101	627	496	3 224
Bosnia and Herzegovina	1	0	0	1	222	143	78	443
Bulgaria	4	153	0	157	1 100	365	295	1 760
Croatia	1	52	0	53	416	102	119	637
Czech Republic	569	410	0	979	1 821	582	411	2 814
Denmark	477	115	0	592	808	268	693	1 769
Estonia	0	0	0	0	269	114	88	471
Finland	627	205	0	832	1 026	393	143	1 562
France	7 273	1 005	0	8 278	11 734	1 605	2 217	15 556
Germany	10 109	2 813	0	12 922	15 258	3 719	1816	20 793
Greece	1 025	346	0	1 371	2 220	809	222	3 251
Hungary	420	166	0	586	1 436	331	493	2 260
Ireland	465	108	9	582	716	191	464	1 371
Italy	7 801	1 578	12	9 391	12 482	2 067	683	15 232
Latvia	0	0	0	0	346	80	113	539
Lithuania	0	0	0	0	505	84	246	835
Luxembourg	70	9	15	94	110	15	15	140
Netherlands	1 677	306	237	2 220	2 735	343	1 072	4 150
Norway	542	44	0	586	1 063	67	108	1 238
Poland	2 487	812	0	3 299	6 974	2 096	1 527	10 597
Portugal	1 318	152	0	1 470	2 226	285	374	2 885
Republic of Moldova	0	0	0	0	215	69	127	411
Romania	2	155	0	157	1 826	420	834	3080
Russian Federation	0	694	0	694	10 431	1 888	2 943	15 262
Slovakia	332	91	0	423	1 011	147	173	1 331
Slovenia	93	32	0	125	285	79	64	428
Spain	5 613	678	28	6 319	8 798	1 251	2 043	12 092
Sweden	1 111	299	113	1 523	1 899	423	230	2 552
Switzerland	813	67	0	880	1 270	151	187	1 608
The FYR Macedonia	1	0	0	1	102	71	43	216
Ukraine	0	328	0	328	4 587	1 035	2 126	7 748
United Kingdom	6 494	1 148	0	7 642	11 063	2 647	770	14 480
Yugoslavia	3	89	0	92	600	387	346	1 333
European Community	46 201	9 278	413	55 892	74 672	14 850	11 600	101 12
Total	**51 467**	**12 372**	**413**	**64 252**	**110 387**	**23 394**	**22 413**	**15 619**

30. There are two different models: the Acid Deposition EMEP Lagrangian model and the Photo-oxidant EMEP Lagrangian model. The Acid Deposition model considers the dispersion of sulphur and nitrogen compounds in the atmosphere. A recent description of the model and extensive validation of its results can

be found in EMEP/MSC-W Report 1/98, Parts I and II ("Transboundary Acidifying Air Pollution in Europe"). The most recent transboundary budgets and source-receptor matrices are to be found in EB.AIR/GE.1/1998/2. These annual source-receptor budgets have been averaged over 11 years to account for inter-annual meteorological variability and have been re-scaled to provide the spatial distribution of unit emissions. The resulting atmospheric transfer matrices have been used as input for the RAINS model.

31. The Photo-oxidant EMEP Lagrangian model describes the long-range transport and formation of tropospheric ozone. Its results provide a reference for the source-receptor relationships used in integrated assessment. Source-receptor matrices from the EMEP Photo-oxidant model averaged over five years are presented in EMEP/MSC-W Report 3/97. A recent description and evaluation of the chemical scheme used in the EMEP Photo-oxidant model can be found in EMEP/MSC-W Note 1/97 and an extensive validation of its results is reported in EMEP/MSC-W Report 2/98 ("Transboundary Photo-oxidant Air Pollution in Europe").

G. Critical loads and levels

32. An ecosystem's critical load is defined as the deposition "below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (EB.AIR/WG.5/R.24/Rev.1). Over the past years methodologies for computing critical loads have been worked out for acidification and eutrophication and compiled by the Mapping Programme under the Working Group on Effects.

33. Acidification is caused by the deposition of both sulphur and nitrogen, and both compounds "compete" for the counteracting (neutralizing) base cations, which are mostly provided by deposition and weathering. In contrast to sulphur, for nitrogen there are additional natural (sources and) sinks such as uptake by vegetation, immobilization and denitrification. Consequently, it is not possible to define a single critical load for acidity, as was the case when looking at sulphur alone. A (simple) function, called critical load function, has to be used. This function defines pairs of sulphur and nitrogen deposition for which there is no risk of damage to the ecosystem under consideration, thus replacing the single critical load value used earlier. The critical load function for each ecosystem has a trapezoidal shape and is defined by three quantities: critical load of acidity (as defined earlier), the net nitrogen sinks and the maximum deposition of nitrogen (in case of zero sulphur deposition). In addition to acidification, nitrogen deposition also acts as a nutrient for ecosystems. So to avoid eutrophication, critical loads for nutrient nitrogen have been defined and calculated for various ecosystems.

34. Critical loads data are compiled on a national level. For the modelling reported on below, 24 countries submitted data. National focal centres selected a variety of ecosystem types as receptors for calculating and mapping critical loads. For most ecosystem types (e.g. forests), critical loads are calculated for both acidity and eutrophication. Other receptor types, such as streams and lakes, have only critical loads for acidity, on the assumption that eutrophication does not occur in these ecosystems. For some receptors, like most semi-natural vegetation, only critical loads for nutrient nitrogen are computed, since the sensitivity to acidifying effects is lower than the eutrophication effects. For those countries that did not provide their national estimates, the European background database of CCE is used. The European background database is based on internationally published

information, such as the 1994 digital soil map of the Food and Agriculture Organization of the United Nations (FAO) and the RIVM European land-use maps. Updated maps of critical loads and of sulphur and nitrogen were presented in EB.AIR/WG.1/1997/4 and EB.AIR/WG.1/1998/5.

35. Most recently, a new measure for evaluating ecosystem protection has been developed to facilitate integrated assessment modelling (EB.AIR/WG.5/R.96, paras. 18-19). This new measure reflects the total excess deposition (above the critical loads) accumulated for all ecosystems in a grid cell (in acid equivalents per year). Starting from a given deposition, this 'accumulated exceedance' (AE) is calculated by adding up (for each ecosystem) the sulphur and nitrogen reduction needed to achieve non-exceedance by taking the shortest path to the critical load function.

36. The Working Group on Effects adopted two long-term related critical levels for ozone effects on vegetation (EB.AIR/WG.1/26, para. 49(a) with reference to: Critical Levels for Ozone in Europe: Testing and Finalizing the Concepts; UN/ECE Workshop report, Kuopio, Finland, 15-17 April 1996):

(a) For agricultural crops and herbaceous plant communities (natural vegetation), the critical level is set at an AOT40 of 3 ppm.hours for the growing season and daylight hours, over a five-year period;

(b) For forest trees, a critical level of 10 ppm.hours for daylight hours, accumulated over a six-month growing season, is proposed.

The AOT40 is calculated as the sum of the differences between the hourly ozone concentrations in ppb and 40 ppb for each hour when the concentration exceeds 40 ppb, using daylight hours only. For the currently prevailing ozone regimes in Europe, the critical level for crops and natural vegetation is stricter than the critical level for forest trees. This means that, while the critical levels for forest trees are usually met when the critical level for crops and vegetation is achieved, the opposite does not hold. Therefore, the scenario analysis presented below is restricted to the critical levels for crops and natural vegetation.

37. Ozone effects on human health are covered on the basis of the revised WHO Air Quality Guidelines for Europe, which propose a maximum eight-hour average concentration of 60 ppb (120 µg). The ultimate goal is to eliminate all excess of this criterion. To simplify the modelling task, the target of non-exceedance of the WHO criterion (60 ppb as maximum eight-hour mean concentration) was converted into an AOT index, which could be handled in a similar way to the AOT40 for vegetation. As a result, an AOT60 (i.e. the cumulative excess exposure over 60 ppb, for practical reasons over a six-month period) of zero is considered as equivalent to the full achievement of the WHO criterion. Any violation of this WHO guideline will consequently result in an AOT60 above zero. This AOT60 surrogate indicator has been introduced purely for practical modelling reasons. Given the current knowledge on health effects, it is not possible to link any AOT60 value above zero to a certain risk to human health.

1. Binding receptor areas

38. Following an initiative by the Chairman of the Task Force on Integrated Assessment Modelling, CCE requested national focal centres from 18 Parties to provide some more detailed information about 24 grid cells that had proven to be of importance in integrated assessment modelling, because they turned out to dominate the results of some of the scenarios (binding grids). CCE had received responses from ten Parties at the time of the meeting. All except one confirmed the previously submitted critical load data for the grid cells in question. In some cases detailed information about the ecosystems to be protected by bringing deposition below critical loads was provided and it was stressed that the grid cells should not be excluded from the analysis. The critical loads in these grid cells may even have to be further reduced in the light of further analysis. Only Slovakia informed CCE of a need to correct the critical load data. While the ecosystems had been studied at a very fine resolution (250m by 250m), some parameter had to be revised in the calculations.

39. CCE also presented a simple programme to extract information about nature reserves above 100 ha (like national parks) from the EMEP grid cells. The information is based on the World Conservation Monitoring Centre’s database of legally protected areas and shows that there are some 1800 protected sites in Europe. A large number of them are also protected under international law. Some of the nature reserves in this database are, however, protected because of ecosystems other than those used for calculating the critical loads.

2. Target-setting for receptor areas where European targets are difficult to attain

40. A study carried out at IIASA by experts from Norway examined ways of treating receptor areas where some of the environmental targets could not be reached using even the most advanced abatement techniques presently known. The study pointed out that the importance of such unfeasible targets should not be overemphasized, as the models did not provide a possibility for structural change or for technological progress and was to be considered only as a tool to support the policy process. Certain policies could, however, initiate structural or technological developments that would make even stringent targets feasible.

41. The option of removing difficult receptor areas from the analysis altogether is not satisfactory, as such a step ignores some potentially important problems. A theoretically appealing solution would be to introduce a penalty term into the model to reduce the influences of difficult receptors from a certain threshold. The problem with this solution is, however, that there is no basis, in particular no damage function, for defining the penalty. An alternative would be to differentiate targets for receptor areas, but this would imply a loss of the equity aspect of the gap closure approach. The compensation mechanism used in target setting also helps to deal with difficult receptor areas. Restricting the possibility to compensate for the achievement of targets within a country in relative terms, as is done in the RAINS model, also reduces the inequality this mechanism introduces between small and large countries.

42. To deal with the two difficult receptor areas in southern Norway (grid cells 17/20 and 17/21), the study proposed a reduction in the gap closure

target just for these receptors. In a 95% gap closure scenario for acidification, only a 92% gap closure was feasible for the two Norwegian grid cells, while setting the gap closure target there below 72% would completely remove them from the analysis. Some relaxed gap closure percentage (between 72 and 92% in this case) would lead to some measures being taken to protect ecosystems in those grid cells, without leading to excessive abatement costs for other countries.

43. The Task Force supported this approach also in view of the extensive documentation on the ecosystems in the area in question that provides a firm basis for the critical loads for this area.