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External costs of aviation

Background report

Delft / Amsterdam

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Foreword

Besides numerous benefits to citizens and companies, air transport also brings undesired side-effects such as emissions and noise nuisance. Most of these negative 'external' effects, as they are called, are currently not priced or only to a limited degree. Consequently, the market place creates insufficient incentives to reduce these external effects.

The study 'External costs of aviation', commissioned by the German Umweltbundesamt, aims to contribute to the ongoing international process to create market-based incentives to the aviation industry to reduce the environmental impact of aviation. It does to by assessing, within margins as small as possible, external costs of aviation.

The report at hand is a background report to the study 'External costs of aviation'. It contains four technical annexes.

The first annex, written by CE, contains an overview of the international literature on the valuation of greenhouse gas emissions.

The second annex, written Mr Fransen, describes the dependence of climatic impact of aviation on the occurrence of contrails, and the dependence of contrail formation on operational circumstances.

The third annex, written by CE, contains an assessment of international literature o the valuation of non-greenhouse gas emissions, such as NO_X and SO_2.

The fourth annex, written by CE, contains a short description of the methodology by which emissions and noise are allocated to passenger and freight transport in this study.

We gratefully acknowledge the support of the German Umweltbundesamt, and in particular Mr Friedrich, Mr Huckestein, Mr Heinen and Mrs Mäder for their always constructive comments and flexible and respectful attitude. Needless to say, responsibility for the content of this report rests fully with the authors.

Contents

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External costs of aviation

Annex I: External costs of greenhouse gas emission

Delft, February 2002

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Contents

1 External costs of greenhouse gas emission

1.1 Methods for the valuation of CO_2

The methods for determining the price of CO_2 (per kilogram), are the prevention cost method and the damage cost method.

Below we will briefly describe these two methods and the most important determinants of the differences between these methods. This knowledge is useful when analysing the literature. After that we will judge both methods.

Prevention cost method
The prevention cost method is based on the costs that must be made to reach a predetermined goal. We distinguish two variants:
- one at which a emission reduction goal is enforced to the aviation sector ('closed system');
- in a second possible variant the aviation sector will be included in the Kyoto Protocol; in this variant the sector will have an own goals just like the other Annex 1 Parties, but it will be free to trade emissions according to the mechanisms of the Kyoto Protocol.

In the prevention cost method, the most important variables determining the final shadow price are:
1 The reduction goal to be achieved.
2 The degrees of freedom in trade: is trade possible between Annex 1 countries or even world-wide?
3 The degrees of freedom in the use of 'flexible mechanisms' like emission trade, the Clean Development Mechanism and Joint Implementation.

Damage cost method
Besides the prevention cost method, the literature also pays much attention to the damage cost method. In this method it is tried to establish the regional consequences of climate change, mainly higher water levels and shifts in climatic zones. These changes in the ecosystem damage the economy.
The differences in literature sources that use this approach are mainly dependent on differences in dose-response relationships. Also discount rates play a large role, as damages will most occur in the future. Recalculating damages to net present values implies use of an interest rate reflecting societal preferences of time. This is illustrated in Table 1.

Table 1 Sensitivity of damage costs estimates of CO_2 for interests rates (IPCC 1996)

discount rate	CO_2 shadow price (in € 1999 per tonne)	
	low	high
2%	14	33
5%	1.4	3.3

Some other studies that use the damage costs method to value the damage of CO_2 emissions Nordhaus (1991, 1993) and Fankhauser (1994). Nordhaus calculates in his studies costs of about € 2.7/tonne CO_2, Fankhauser arrives at € 7 - 9/tonne CO_2.

In this study we will only use the prevention cost method to establish a CO_2 price, and we will base our estimates on the Kyoto shadow price, for reasons that have been explained in the main text.

Conversion rates used
In many cases we didn't copy the exact results from the respective sources for the following two reasons:
1. In some cases the results are given in the reduction of one tonne C and in other cases in the reduction of one tonne CO_2; we have decided to present all numbers in prices per avoided tonnes of CO_2. We have multiplied the prices of C with 12/44 where necessary, for the reduction of one tonne C equals the reduction of 44/12 tonne of CO_2.
2. In some cases the results are given in € and in some cases in US $. The basic year for the different data also varies. We've decided to convert all values to €1999. We have used the following conversion table.

Table 2 Conversion rates from $ to €

year	CPI (US, 1989 = 100)	Exchange rates (1 € = .. US$)
1990	105.4	1.40
1991	109.8	1.30
1992	113.1	1.44
1993	116.5	1.19
1994	119.5	1.25
1995	122.9	1.32
1996	126.5	1.28
1997	129.4	1.11
1998	131.4	1.19
1999	134.3	1.07

1.2 Summary of results from prevention cost method

This paragraph presents the CO_2-emission reduction costs found in the literature. A complete review follows later on in this annex.

The ranges of values we've found are presented into four variants:
1. First the variants where the different regions must reach their goal in their own region without trade between the regions.
2. Then the variants where international emission-trading is permitted between Annex I countries.
3. Next a variants where global emission trading is permitted, in other words the maximal variant of CDM.
4. We'll finish with a few examples of values where sinks are permitted, other greenhouse gasses can be reduced or explicitly not, agreement on double-bubble, etc.

1.2.1 Every region it's own

At first we'll give the ranges for the different regions distinguished in the models. Hereby we present the range in the case where the extreme values are being ignored and, between brackets, the whole range.

It further concerns the costs involved for reaching the Kyoto-goals for every region when all reductions must be made in own country.

Table 3 Every region on it's own

Region	Marginal reduction cost (in € 1999 per tonne CO_2)
US	25 – 78 (17 – 105)
EU	40 – 83 (29 – 216)
Japan	29 – 177 (22 – 209)

Sources:

- for the US: 9 literature sources;
- for the EU: 8 literature sources;
- for Japan: 8 literature sources.

This table shows that in all probability the US can reach their goal in their own country in the cheapest way. This is because of the relatively energy-inefficient structure of the American economy, where with the help of energy-savings and 'good-housekeeping' a lot of win-win measures can be taken. Europe is already in a further stage of efficiency-increasing measures, which makes it more expensive to take further measures.

1.2.2 Emission trade between Annex-I countries

When we study the price per avoided tonne CO_2 when emission trading between Annex I countries is permitted, we find the following range of values:

€ 15 – 35 (10 – 49)

This range is based on the results of 10 literature sources.

In this scenario Joint Implementation is permitted, but the Clean Development Mechanism is prohibited.

1.2.3 Global emission trading

In the variant where global emission trading takes place to minimise the total costs to reach the Kyoto-goals, more cheap measurements come available resulting in a lower price.

In this situation there has been assumed that in all models the countries not belonging to Annex I will have emission rights for the forecasted emissions of that country in 2010. This results in an emission ceiling leading to a real market. This variant can be seen as a upper-limit of the opportunities of the CMG-model.

The ranges of values found are (between bracelets is the range without extreme values:

€ 6 – 8 (4.8 – 17)

There were only 4 sources of literature presenting these results.

1.2.4 Some other variants

In the literature analysed we encountered sources which have assessed some extra variants. Below in brief the characteristics with corresponding values:

Table 4 Results sensitive for assumptions

Characteristics	Development shadow price	Reference
Annex I trade + counting all the sinks	22 -> 7	Annex I trade
Annex I trade + counting halve of the sinks	22 -> 14	Annex I trade
Annex I trade + infinite high costs for reduction CO_2 gasses	22 -> 29	Annex I trade
Double-bubble	17 -> 9 (US, Jap. en Austr.) 17 -> 74 (rest OECD)	Annex I trade

Each of these variants was presented by only one source of literature.

Next to these variants model calculations have been made at which the goals of Kyoto have been extrapolated to 2020. We've presented the differences in the prices per avoided tonne CO_2 in Table 5.

Table 5 Kyoto targets also apply to 2020

Source	Prices in 2010 en 2020	Characteristic
McKibben et al. (1999)	17 -> 31	Annex I trade
McKibben et al. (1999)	6 -> 10	Global emission trade
MacCracken et al. (1999)	22 -> 36	Annex I trade

The last two tables show that:
- fully counting of sinks lowers the price of CO_2 with two thirds;
- counting halve the sinks lowers the price of CO_2 with one third;
- infinite high costs for not-CO_2 gasses raise the price of greenhouse gasses with almost one third;
- the effect in implementation of double-bubble differs greatly between the 'bubbles';
- the extrapolation of the Kyoto-goals to 2020 causes higher reduction costs, approximately 60% per tonne avoided.

1.3 Literature studied

The separate sources of literature that are found and analysed are presented below.

Capros, P., en L. Mantzos, 2000, The economic effects of EU-wide industry-level emission trading to reduce greenhouse gasses: results from PRIMES energy systems model, National Technical University of Athens

This study describes the results of model exercises with the PRIMES-model, a partial balance model aimed at the energy markets within the European Union.

Five scenario's to reach the Kyoto-goals within the European Union are being dealt with. This study shows clearly the cost advantages of trading that can be reached.
The five scenario's are:
- every member state reaches his own goal, without trading;
- every sector within a Member State reaches its reduction as is determined for every member state;

- ever member state reaches his own goal where trading between energy producers is permitted;
- ever member state reaches his own goal where trading between energy producers and the energy intensive industries is permitted;
- the European Union reaches the goal, where trading between all sectors in all members states is permitted.

The costs to reach the goals of the EU vary greatly between the different scenario's. Table 6 shows a overview of the scenario's and the marginal reduction costs of the last tonne CO_2 needed to reach the goal.

Table 6 Estimated price per avoided tonne CO_2

Scenario	Marginal reduction cost (in $ 1995 per tonne CO_2)
(I) Every sector within the member state same target as member state	108
(ii) Every member state has a target.	46
(iii) Trade between energy producers	39
(iv) Trade between energy producers and energy intensive sectors.	37
(v) Free trade within the EU	28

This shows that the Kyoto goal of the EU can be reached at relatively low costs if a EU internal emission trading will be set up.

An important assumption in this modelling is that the transaction costs of a emission trading system are set to zero.

CPB/RIVM, 2000, De economische gevolgen van het Kyoto-protocol voor sectoren en wereldregio's (Economic consequences of the Kyoto protocol for setors and world regions), no. 00/31, Den Haag

In this paper the investigators have performed model calculations with the model WorldScan. Goal of this paper was to map especially the economic consequences of the Kyoto protocol, focused especially on the consequences for energy exporting countries and developing countries.
WorldScan is a global general balance model, primarily to describe long term developments. The quotes about the developments in the period 2008-2012 must therefor be carefully interpreted.

The simulations are confined only to CO_2 greenhouse gas and the basic variant is given by the individual reaching of the different goals through the different countries.

The possible cost lowering mechanisms as Clean Development Mechanism, Joint Implementation and the usage of sinks can't be simulated in WorldScan.

Emission trading (between Annex I countries) can be simulated and serves as an alternative variant. In this paper there are no trading limitation simulated though, so in the alternative variant the emission reduction goal can be reached fully by trade between other Annex I countries.

The results of the (two) simulated situations are summarised as follows.

Table 7 Results of the (two) simulated situations

	Marginal reduction costs (in € 1999 per tonne CO_2)	
Region	**Without emission trade**	**With emission trade**
VS	40	15
Japan	29	15
Pacific OECD	32	15
EU	52	15
Eastern Europe	3	15
Former Soviet Union	0	15

ECN/RIVM, 1998, Optiedocument voor emissiereductie van broeikasgassen: inventarisatie in het kader van de Uitvoeringsnota Klimaatbeleid. (option document for GHG emission reduction; inventory in the framework of the Climate Change Execution Paper)

In this publication a overview is presented of the possibilities to reach the emission reduction goal of the Netherlands domestically. An analysis of the results shows that the measures that can and should be taken in the Netherlands (the so-called "basic package") are not the cheapest measures.

A similar analysis is performed by Dings et al. (1999) and this shows that the most expensive measure in the basic package is unequal to the cheapest measure in the extra package. Nevertheless we choose to consider the most expensive measure of the basic package as the marginal costs of the last measure needed in the Netherlands to reach the Kyoto goal.

The costs are roughly € 70 per tonne CO_2. However, this price concerns only the domestic measures and can't be used as a international price to reduce one tonne CO_2. It gives a good view of the possibilities to reach the Kyoto goals domestically.

ECN/AED/SEI, 1999, Potential and cost of Clean Development Mechanism options in the energy sector: inventory of options in non-Annex I countries to reduce GHG emissions

This publication gives a estimation of the possibilities to reach cost savings by the CDM. The table below presents the outcomes of a simple simulation, where a perfect competition market is assumed.

This publication describes a trading system within the OECD, a system where trading between Annex I countries is permitted and a global trading system. This variant can be seen as the extreme variant of CDM.

This resulted in the following outcomes.

Table 8 Results of the simulation

Trade within	Marginal reduction costs (in € 1999 per tonne CO_2)
OECD	68
Annex I	21 – 35
Global	4.8 – 18

It has to be noticed that the lower prices in the range will approach the reality the closest. The lower prices will be the result if the so-called 'no regret' measures will count for reaching the Kyoto goals. The 'no regret' measures are the measure which will be economic profitable even without strict climate policy.
This separation, between profitable and not-profitable, has been made explicit in this publication.

McCracken, C.N., J.A. Edmonds, S.H. Kim and R.D. Sands, 1999, The economics of the Kyoto-protocol, in: The Energy Journal: special issue, May 1999, p. 25 – 72

With the so-called 'Second Generation Model" the authors estimated the marginal costs needed to reach the Kyoto goals. These marginal costs represent the costs per tonne CO_2 of the last measure needed to reach the goals. It has been done for 5 scenario's:

1 All region comply with their Kyoto-goal, no trading.
2 Trading is permitted between Annex I countries.
3 Trading is permitted between Annex I countries and CDM is permitted.
4 Not-CO_2 greenhouse gasses are taken into account.
5 'Sinks" are permitted in some degree.

Below the resulting prices per avoided tonne of CO_2 for 2010. Between brackets are the values resulting form the model for the year 2020, with the assumption that the Kyoto goals in 2020 are still effective.

Table 9 Resulting prices per avoided tonne CO_2 for 2010

		Marginal reduction costs (in € 1999 per tonne CO_2)				
region	**scenario**	**(i)**	**(ii)[b]**	**(iii)[c]**	**(iv)[d]**	**(v)[e]**
Australia		36 (43)	22 (36)	8 (-)	29 (-)	7 (-)
Europe		40 (63)				
US		51 (60)				
Canada		106 (117)				
Japan		139 (130)				

a When there's no expansion of the nuclear power capacity the marginal reduction costs in Europe can reach up to € 44.
b If Eastern Europe will behave as a monopolist on the market of tradable emission rights, the trading price for this scenario will be higher, namely € 32.
c This price was achieved by allocating non-Annex 1 countries emissions in the reference scenario and subsequently apply global trade. A fictitious market is created, in which indeed scarcity of emission reduction is achieved.
d This price is based on the assumption that the not-CO_2 gases only can be driven back against infinite high costs; when these gasses can be driven back for free, every region can reach their Kyoto goal without costs and the resulting market price for CO_2 will be zero. The price in the second scenario is based on the assumption that the not-CO_2 gasses can be driven back against the same proportional costs as CO_2 can be driven back.
e This price is based on the assumption that all sinks count for reaching the Kyoto-targets, while further trading between Annex I countries is permitted. When only halve of the sinks are counted, the trading price to $ 14.

Table 9 shows that the different assumptions of the filling-in of the Kyoto protocol and its mechanisms have an important influence on the costs the different regions have to make.

Trade between all countries to reach Kyoto targets gives *ceteris paribus* the lowest costs for reaching the goals, namely € 8 per tonne CO_2.

McKibbin,W., M. Ross, R. Shackleton and P. Wilcoxen, 1999, Emissions trading, capital flows and the Kyoto-protocol, in: The Energy Journal: special issue, May 1999, p. 287 – 334

This publication describes the estimation of the costs for reaching the Kyoto targets with the help of the so-called G-Cubed model. This model describes measures and adjustments in several regions and sector in an inter-temporal equilibrium model.

In this study five scenarios are calculated:
1 Only the US fulfil the Kyoto goals.
2 All Annex I countries fulfil their Kyoto goals, trade is not permitted.
3 All Annex I countries fulfil their Kyoto goals, trade is permitted between Annex I countries.
4 All Annex I countries reach their Kyoto goals, trade is permitted within two trading blocks 'other OECD' and "other Annex I', while there's no trade permitted between trading blocks.
5 Global trade is permitted where the developing countries not appearing in the Kyoto protocol get their reference emissions assigned.

The model is not capable to consider the reduction of not-CO_2 emissions as well. This approach counts for more models treated in this annex and ignores the relatively cheap reduction measures of other greenhouse gasses.

This model proclaims a strict climate policy in 2000, so the economic actors have 10 years to anticipate on the policy and take action.
We present the resulting prices per avoided tonne CO_2 in Table 10 for 2010 and 2020 (in € 1999).

Table 10 Resulting prices per tonne of CO_2 avoided

<table>
<tr><th colspan="2"></th><th colspan="5">Marginal reduction cost per tonne CO_2 (in € 1999)</th></tr>
<tr><th>region</th><th>Scenario</th><th>(i)</th><th>(ii)</th><th>(iii)</th><th>(iv)</th><th>(v)</th></tr>
<tr><td colspan="2">Australia</td><td>-</td><td>50 (64)</td><td rowspan="4">17 (31)</td><td rowspan="3">9 (19)</td><td rowspan="4">6 (10)</td></tr>
<tr><td colspan="2">US</td><td>22 (27)</td><td>25[a] (29)</td></tr>
<tr><td colspan="2">Japan</td><td>-</td><td>32 (45)</td></tr>
<tr><td colspan="2">rest of OECD</td><td>-</td><td>73 (88)</td><td>74 (89)</td></tr>
</table>

a The difference between this price ($ 25) and the price of 23 in case of unilateral action by the US (scenario 1) can be explained as follows: when all countries have to reduce their CO_2 emissions demand for oil and thus its price will decrease. It will be harder then to achieve the US reduction targets;

b The difference between this price ($25) and the price of $23 in case of one-sided action by the US (scenario 1) can be explained as follows: If all countries must push back.

De price that will result from global trade is about 6 €/ton CO_2 in 2010.

Manne, A.S. and R. Richels, 1999, The Kyoto-protocol: a cost-effective strategy for meeting environmental objectives? in: The Energy Journal: special issue, May 1999, p. 1 – 24

From this article it is hard to judge the assumptions made for modelling climate policy and the resulting costs.

Next prices are mentioned as marginal reduction costs in € 1999 per tonne CO_2:

1 € 78 in case of US unilateral domestic action.
2 € 33 in case of trade between Annex 1 countries and application of CDM.
3 € 22 in case of completely global trade.

The difference between variants (ii) and (iii) the CDM potential assumed; in variant (ii) the authors assume only 15% of total CDM potential can be exploited in practice. This reflects the complexity of CDM. In case of global trade, the full potential of CDM can be exploited.

PEW Center on Global Climate Change, 1999, International emissions trading and global climate change, Arlington, USA

This report gives an overview of advantages of international emission trade for reducing GHG emissions. The researchers assess differences between various models used to assess the effects of GHG emission reduction.

Table 11 below offers an overview of marginal reduction costs as calculated by various models. Reduction costs birth in case of regional and Annex 1 trade are calculated.

Table 11 Differences between models

	Marginal reduction costs per ton CO_2 (in € 1999)									
	SGM		EPPA		GTEM		G-Cubed		OECD Green	
region	no trade	Annex I trade	no trade	Annex I trade	no trade	Annex I trade	no trade	Annex I trade	no trade	Annex I trade
VS	51	22	56	49	105	35	17	10	44	19
Japan	139	22	177	49	209	35	71	10	22	19
Western Europe	44	22	83	49	216	35	47	10	58	19
former Soviet Union	0	22	0	49	0	35	0	10	0	19

Differences are caused by factors as previously described in this annex.

PNNL, 1997, Return to 1990: The cost of mitigating United States carbon emissions in de post-2000 period (no. PNNL-11819)

This publication gives a brief overview of possibilities to reduce costs to achieve reduction targets. For fictive US targets are used instead of the Kyoto targets. We will not discuss the results in detail, also because the results from the Second Generation model used have already been described under MacCracken et al. (1999).

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External costs of aviation

Annex II: The contribution of contrail occurrence to climatic change induced by air traffic

Delft, February 2002

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