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Climate externalities of aviation –
Particularities, economic evaluation methods and emissions trading as internalisation strategy

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Abstract

Aviation emissions contribute to climate change by causing environmental damages which in general are not or not adequately reflected in the air transport prices. As long as third parties are affected they represent climate externalities. Non-optimal allocation of resources leading to welfare losses of society may occur unless policy intervention is undertaken.

To design effective climate policies in aviation, policy makers should assess the full impact of candidate policies, while also accounting for potential interdependencies with other externalities. There is a variety of potentially important impacts and trade-offs with regard to aviation and climate change, for example the trade-offs between short-lived and long-lived climate effects like carbon dioxide, nitrogen oxides and aviation-induced cloud formation. Therefore the identification, quantification and economic evaluation of aviation-induced climate externalities and their interdependencies seem to be a valuable basis for evaluating climate policies in aviation.

In 2006, the EU Commission adopted a proposal for legislation to include aviation in the European Emissions Trading Scheme (EU-ETS). Although full climate impact of aviation is more comprehensive, the proposal puts forward a CO_2 based scheme.

In this paper the economic theory of externalities is reviewed. Subsequently the particularities of climate externalities (in aviation) are pointed out and discussed in the context of economic evaluation approaches. It was shown that human-induced climate change is at its most basic level an externality. However, climate change has some special features that together distinguish it from other environmental externalities. Furthermore aviation-induced climate impacts take a special position in climate externalities. Evaluating and regulating short- and long-lived climate impacts in parallel present a great scientific, economic and political challenge. Economic evaluation methods focusing on well-mixed GHG fall short when looking at the aviation sector.

The role of market-based option emissions trading as internalization strategy is highlighted and exemplified by the planned EU-ETS in aviation. It is a first step towards an internalization of climate externalities in the aviation sector. A short evaluation of the planned CO_2 EU-ETS finalizes the paper.

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Abbreviations

CO_2	**Carbon dioxide**
EU-ETS	**European Emissions Trading Scheme**
H_2O	**Water vapour**
IPCC	**Intergovernmental Panel on Climate Change**
GHG	**Greenhouse gas emissions**
GTP	**Global Temperature Potential**
GWP	**Global Warming Potential**
NO_x	**Nitrogen oxides**
O_3	**Ozone**

1 Introduction

The proposal for inclusion of aviation into EU-ETS (COM/2006/0818 final) puts forward a carbon dioxide (CO_2) based scheme even though full climate impact of aviation is more comprehensive. From an economic point of view it is of great interest which effects are induced by a fragmentary internalization of external costs by a market-based option: To what degree will the climate impact be reduced and does the inclusion of aviation into the CO_2 based EU-ETS lead to negative trade-offs, i.e. unintentional increases in non-CO_2 effects as a result of efforts to reduce CO_2? Which role does the mitigation potential of non-CO_2 effects in aviation play in the context of internalization strategies? Which policy approaches are appropriate to internalize all climate externalities including those of non-CO_2 effects? These research questions are addressed in the PhD project "Incentive structures and climate impacts of the planned CO_2 EU-ETS in aviation". The climate effects and possible trade-offs of the planned CO_2 EU-ETS in aviation are assessed, compared to climate impacts of alternative mitigation strategies and evaluated on the basis of economic valuation standards.

This working paper provides some theoretical background on the phenomenon of externalities, with special regard to climate externalities (in aviation). Methodological challenges to evaluate the externalities on the basis of economic evaluation standards are highlighted. An evaluation framework is pointed out containing cause-effect relations between air transport output and climate impacts. Two central evaluation approaches to evaluate the climate impact in monetary values, the damage cost and the avoidance cost approach are discussed in the context of particular climate externalities of aviation. Against this background the role of planned EU-ETS in aviation is highlighted as internalization strategy.

2 External climate effects of aviation

Air transport activities lead to environmental damages, accidents and congestion. In contrast to the benefits, the costs of these effects, the so called external effects are generally not taken into account by air transport users when they make their transport decision. In the following the economic theory of (climate) externalities will be illustrated, especially focusing on those of aviation.

2.1 Welfare economic theory of externalities

The concept of external effects was first introduced by Marshall (1890) and later refined by Pigou (1920), introducing welfare economics into the scope of economic analysis. The concept of externalities is often defined in terms of its effects. A widely used definition (Baumol and Oates, 1988) has the general form: "An

externality is present whenever some economic agent's (Y's) welfare function includes real variables whose values are chosen directly by others (X) without particular attention the effect upon the welfare of the agent Y they affect". In other words external effects are economically relevant impacts that agent X imposes on agent Y without recognising or accounting for them. External effects cause economic inefficiencies because social costs are not fully taken into account in decision-making, a prerequisite for efficient economic decisions.[1]

In this context one can be distinguish between real "technological" and pseudo "pecuniary" externalities. As explained by Baumol and Oates (1988, p. 29-30), the fundamental, distinctive feature of a real externality is that its introduction causes a shift in output or utility as a function of the resources used, while pecuniary externalities result from mere price changes in outputs or inputs, in other words ordinary economic interdependence. In case of pecuniary externalities, efficiency is unaffected, solely income is redistributed. A technological externality, however, is present whenever there is an insufficient incentive for a potential market to be created for some good and the non-existence of the market leads to a non-Pareto-optimal equilibrium. In this case of market failure policy intervention is needed to assure, in theory, a pareto-optimal market situation.[2]

The persistence of such inefficiency can be traced to different causes: either property rights are not fully defined, individual transaction and information costs exceed the gains from trade or individuals cannot agree on the division of gains from the exchange. Some form of insufficient control over commodities and lack of well-defined property rights is the main cause of environmental externality problems (Schipper et al. 2001).

2.2 Climate externalities

In common with many other environmental problems, human-induced climate change is at its most basic level an externality. Those who produce greenhouse gas emissions (GHG) are triggering climate change, thereby imposing costs on the society and on future generations but they do not face directly, neither via markets nor in other ways, the full consequences of the costs of their action. Furthermore the global climate is a classical example of a public good, see Samuelson (1954).[3]

However, climate change has some special features that together distinguish it from other environmental externalities (like e.g. air pollution) and which shape the

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[1] In case of negative externalities the activity level goes beyond the optimum; in case of positive externalities it is lower than the optimum.

[2] The so called "pareto-optimality" (named after the Italian economist Vilfredo Pareto) of the allocation is fulfilled if no rearrangement of the allocation could benefit some people without any deleterious effects on at least one other person (Tietenberg 1992).

[3] Those who fail to pay for it cannot be excluded from enjoying the good's benefits (non-excludability) and one's person's enjoyment of the good does not diminish the capacity of others to enjoy it too (non-rivalry).

economic analysis. As the impact of GHG emissions is not dependent on the location of emission climate change is global in its causes and consequences. GHG especially CO_2 have a long lifetime in the atmosphere so that present emissions contribute to impacts in the distant future. The effects of climate change are highly inequitable and there are uncertainties that prevent precise quantification of the economic impacts. Furthermore there is a serious risk of major irreversible change with non-marginal economic effects (Stern 2007; CE Delft et al. 2007).

Standard welfare-economic cost-benefit approaches, e.g. in the transport sector (Friedrich et al. 2001) have their usefulness for analysing externalities. However, as the methods focus on evaluating marginal changes and generally abstract from dynamics and risk, they can only be starting points for the evaluation of climate externalities. Furthermore due to the nature of climate change impacts several ethical perspectives are central, such as those focusing on welfare, justice, freedoms and rights as well as intra- and inter-generational equity are relevant, which are not or not sufficiently accounted for in the standard welfare-economic approaches. The structure of science of climate change dictates the structure of economic approaches needed as internalisation strategy (Stern 2007).

2.3 Climate externalities of aviation

Air transportation is responsible for a variety of external effects. According to Schipper et al. (2001) (including Janic 1999, Morisette 1996, Button 1990 and 1993) the negative technological external effects can be categorised in the following way:

- **External effects depending directly on output in airline markets: Local air pollution, global atmospheric pollution, soil pollution and noise annoyance around airports, accident risk and congestion.**
- **Indirect external effects, upstream or downstream: Pollution associated with aircraft or kerosene production, disposal of scrapped aircraft, costs associated with the "over exploitation" of carbon-based fuels, airport waste and environmentally harmful materials used in aircraft servicing and maintenance.**
- **External effects associated with presence of infrastructure: Modification of river courses and field drainage and deterioration in ecosystem through airport construction, water and soil pollution through airport waste water and leakage from storage tanks, impacts on flora and fauna around airports.**

Optimal policy approaches take into account all externalities simultanously. However, as each type of externality on its own is already complex, a discrete assessment of climate externalities and its interdependencies seem to be worthwhile. It could contribute as a main pillar to overall internalisation strategies.

While local environmental pollution at airports was already addressed in the 1970-ies[4], climate impacts of aviation came to the fore in the 1990-ies. In 1999, the Intergovernmental Panel on Climate Change (IPCC) published a comprehensive assessment of aviation-induced climate effects (IPCC 1999) which represents an important milestone in this area.

In general, there are different mechanisms by which emissions affect climate by:

- **emissions of direct GHG, mainly CO_2**
- **emission of indirect GHG, i.e. precursors of tropospheric ozone or gases affecting the oxidation capacity of the atmosphere**
- **the direct effect of emission of aerosols and**
- **the indirect effect of aerosols which trigger changes in the distribution and properties of clouds.**

Current climate polices focus on the well-mixed GHG. Therefore the general discussion of climate externalities in this paper also refers to long-lived GHG. The effects of long-lived GHG, especially of CO_2, are scientifically well understood (IPCC 2007); policy approaches to limit CO_2 emissions are widely established (e.g. Kyoto Protocol, EU-ETS) and as the problem is directly linked to the consumption of fossil fuels, energy taxes in some sectors already provide incentives to reduce this type of externality.

However, looking at the transport sector, there is strong evidence that other emissions and mechanisms play also an important role, notably in aviation (Fuglestvedt et al. 2008). As climate effects of aviation are particularly complex and the indirect effects contribute significantly to the overall climate impact, more than in any other sector, they merit to be analysed separately and in full detail.

The climate impacts of aviation depend on a number of exogenous physical and chemical factors and vary depending on the altitude in which aircraft emissions are released. Aircraft emissions in the upper troposphere and lower stratosphere contribute to climate change through the emission of the direct GHG CO_2 and water vapor (H_2O). Furthermore the emissions of nitrogen oxides (NO_x) act as precursor. At cruise altitude they are particularly effective in changing the distributions and concentrations of ozone and methane. Water vapour and particle emissions also trigger the formation of contrails and are suspected of enhancing formation of cirrus clouds, both of which tend to warm significantly the earth's surface. Direct soot and sulfate emissions also have effects on the climate, even though their impact is small. In contrast to other economic sectors and transport modes the sum of all effects may exceed at least by a factor of 2 the effect of CO_2 alone. Considering the potential impact of cirrus cloud enhancement, an area in which the scientific knowledge is still poor, the factor could turn out to be up to 5,

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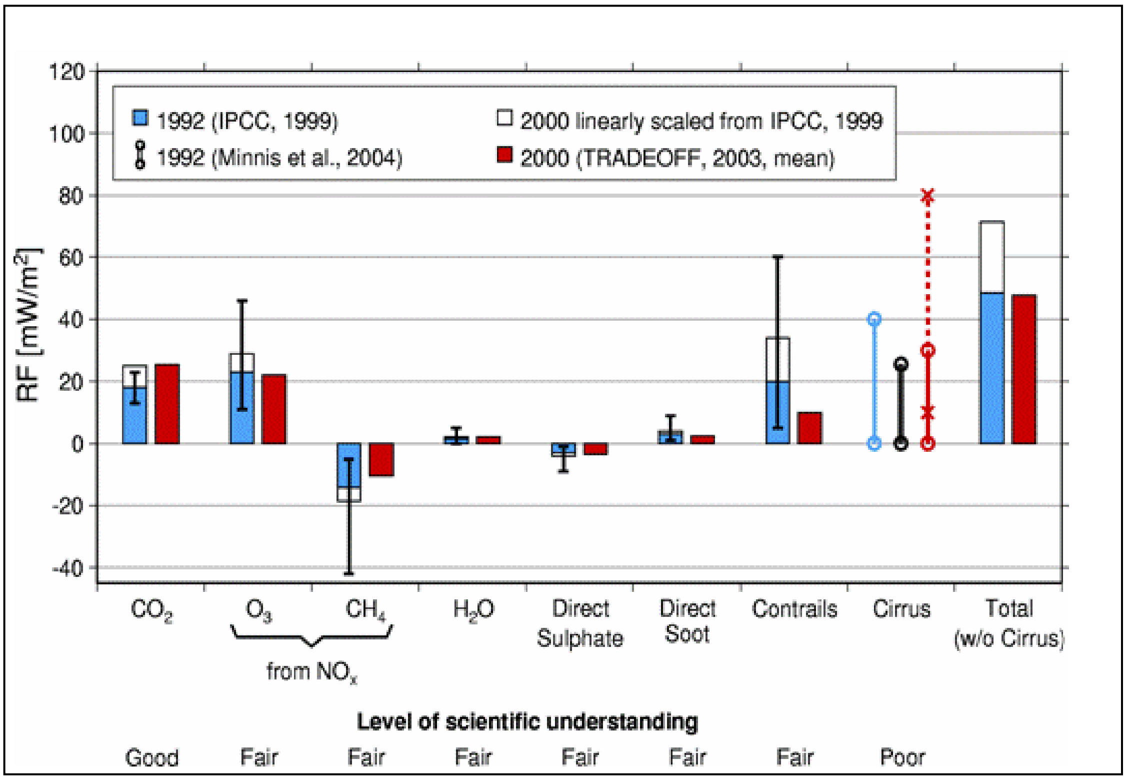
[4] **E.G. civilian initiatives and protest against the construction of the "Landebahn West" at Frankfurt airport in the 1970 and 1980-ies.**

see Sausen et al. (2005). Figure 1 quantifies aviation induced radiative forcing, according to IPCC (1999) a proxy for global mean climate impact, for the years 1992 and 2000.

Figure 1: Radiative Forcing (mW/m^2) from aviation for 1992 and 2000, based on IPCC (1999) and TRADEOFF results



Source: Sausen et al. 2005

Long-lived gases and concentration changes (CO_2, CH_4) which show the classic features of the Kyoto-gases as well as short-lived effects (ozone, cloud formation) which contribute to regional climate change and occur only under certain atmospheric conditions are highly relevant. Evaluating and regulating the short-lived climate effects parallel to the long-lived GHG, however, presents a great scientific, economic and political challenge. One of the most important scientific issues in which the short-lived effects distinguish from long-lived GHG is that their climate effects depend on where the emission takes place. Further challenges are, firstly, that the complex short-lived effects must be fully understood in their appearance and climate impacts. Secondly, adequate strategies to internalize these climate externalities tend to be more complex as in case of direct GHG externalities: incentives should be provided to reduce reaction products and effects and not to direct emissions. Thirdly the non-CO_2 climate impacts of aviation comprise partly heating effects, partly cooling effects: atmospheric chemical reactions on the basis of NO_x increase ozone formation (heating) and convert methane (cooling). Furthermore water vapour leads to the formation of contrails

(cooling in daytime and heating at night) (Rypdal et al. 2005). All these aspects have important implications on the level of climate impact, on the choice of an appropriate economic evaluation method and internalization strategies.

Economic evaluation and internalization of all aviation-induced climate externalities is facilitated if the climate impacts and interdependencies are quantifiable on the basis of a metric. Metrics place emissions of gases with different lifetimes and radiative properties on a common scale. To compare and aggregate the climate impacts of long-lived GHG, the international community agreed on using the emission metric Global Warming Potential (GWP), taking into account a time horizon of 100 years.[5] With this metric one can determine the amount of CO_2 emissions that have an equivalent radiative forcing over the chosen time horizon to another long-lived GHG. As a result climate impacts of long-lived GHG are usually expressed as impacts of CO_2 equivalents. However, the GWP is only a reliable metric for long-lived GHG e.g. (Fuglestvedt et al. 2003).[6]

With regard to aviation, the IPCC (1999) recommends radiative forcing as a proxy for global mean climate impact. Though recommended, this metric has a variety of decisive limits for quantifying aviation-induced climate impacts; see Fuglestvedt et al. (2003), Wit et al. (2005) and Deuber (2007). Therefore alternative metric approaches located further down the cause-effect chain from emission to impacts are developed. For example the Global Temperature Potential (GTP), once it is fully understood and developed, may provide an equitable way of comparing short- and long-term effects (Shine et al 200b). However, currently there is no metric sufficiently robust and mature enough for comparing the non-CO_2 effects by aviation with Kyoto GHG which could serve as basis for an market-based instrument like emissions trading, see Forster et al. (2006), Wit et al. (2005) and Shine et al. (2005a).

To be clear, any common metric of long- and short-lived effects (also GTP) premises a weighting of temperature changes over time. This phenomenon goes hand in hand with the fact that any common economic evaluation of short- and long-term damages requires a weighting of damages over time. The use of different time horizons or discounting factors leads to different perceptions of the relative importance of non-CO_2 effects and their damages. The weighting (discounting) factor in both cases cannot derive from science – an ethical and political decision has to be taken. The need to evaluate climate impacts over time and the problem of "discounting" the damages which is already a challenge in the context of direct GHG is even more pronounced if additionally short-lived effects are taken into consideration.

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[5] **The GWP integrates the radiative forcing produced by a given mass of a given gas after its pulse emission over a chosen time horizon and compares this to an equal mass of CO_2 emissions. In the context of the UNFCCC the international community agreed on a time horizon of 100 years after the pulse emission.**

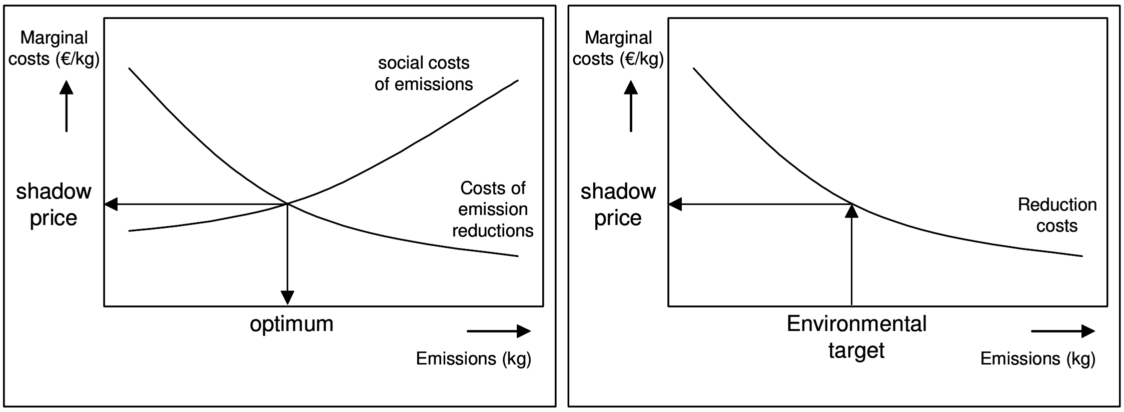
[6] **While with contentious calculation and large uncertainties some approximation could be made for an aircraft NOx GWP, a "contrail GWP" cannot be calculated (Wit et al. 2005).**

3 Economic evaluation of climate externalities of aviation

Economic valuation of environmental externalities is often controversial and challenging as the externalities are traditionally not expressed in monetary terms. With regard to climate externalities, there is still a lack of knowledge about the physical impacts caused by global warming. Some impacts are rather certain while other possible impacts are often not taken into account due to lack of information on the relationship between global warming and these effects: the uncertainties in predicting climate change lead to uncertainty in valuation.[7] However, there are several good reasons to overcome the obstacles. For example monetary valuation of climate externalities provides economic rationality of investing in climate protection and demonstrates the importance of climate policies (Pearce 1990).

According to the economic theory, the optimal price of an externality, the shadow price to obtain a pareto-optimal market situation ("first best approach") is where marginal social costs are equal to marginal avoidance costs (e.g. Endres 1998 p.3). The key aim of climate policy should therefore be to ensure that those generating GHG face a marginal cost of emissions that reflects the damage they cause, see Figure 2.

Figure 2: Obtaining a shadow price from a) damage-cost approach b) environmental targets



Source: CE Delft (2002)

In practice, however, due to large uncertainties associated with economic evaluation of damages and social costs from climate externalities a fundamentally different approach, the avoidance cost approach, can be taken into account to obtain a shadow price. This approach may be considered when long-term across-the-board emission reduction targets are in place that have been politically agreed and are duly respected as in case of climate change, see e.g. Stern (2007). This

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[7] **Secondary impacts such as socially contingent damages (e.g. regional conflicts) are even more difficult to assess and are rarely covered by studies estimating external costs, see Watkiss (2005b).**

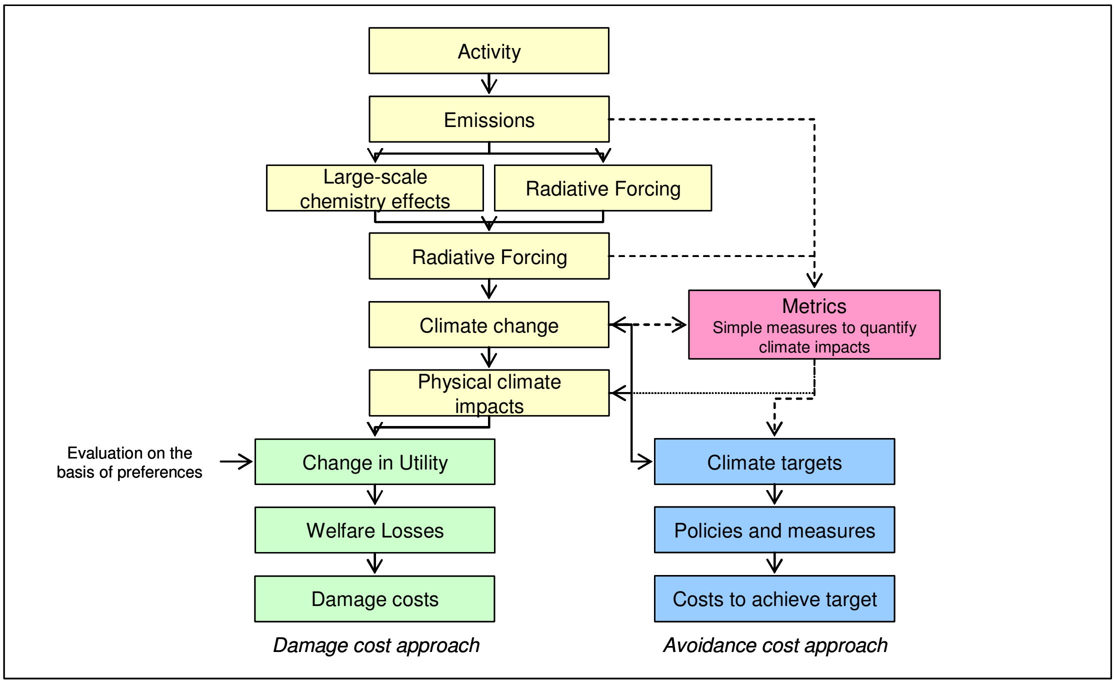
approach is based on the assumption that agreed targets are implicitly backed by underlying assumptions on necessary damage and risk reduction strategies. In this case, one extra unit of emission does not lead to extra damage costs, but rather to additional abatement measures – somewhere in the economy – to reduce emissions to the agreed target level (CE Delft 2002). In such cases, the shadow price of an emission can therefore be represented by the marginal costs of reducing emissions to the agreed target, see Figure 2b. The costs associated with the achievement of the target can be interpreted as collective willingness-to-pay of the society to reduce the damages or as opportunity costs (UBA 2007).

3.1 Evaluation methods for climate externalities in aviation

As starting point to evaluate climate externalities, it is recommended to take into account the complete emission-exposure-effect- value-chain which has been termed a "pathway" in literature, see Krupnick et al. (1997), Friedrich et al. (2001) and ExternE (2005). In case of emissions affecting global warming, the information on physical processes by global climate models seems indispensable in order to arrive at an adequate dose-response function. Many open questions arising in the function cannot be answered by economics, leading us to the "interdisciplinary imperative" of empirical monetisation of environmental damages (Endres 1998 p.142).

Economic evaluation of climate externalities is usually the last but not necessarily the weakest link in a long chain of analysis steps in the pathway approach. The damage and avoidance cost approach provide a basis for this economic evaluation. Figure 3 provides an overview of the "extended pathway methodology", a pragmatic approach to evaluate climate externalities. In this approach the pathway from the environmental impact to the monetary evaluated damages will be pursued as far as possible. However, in the case insufficient knowledge is available regarding the relation between environmental impact and physical damages the avoidance cost approach is applied.

Figure 3: Extended pathway methodology adjusted to climate externalities



Source: Own illustration based on UBA (2007), Friedrich et al.(2001), Sausen (2007)

Following the damage cost approach the marginal damage and risk resulting from one unit of climate impact like sea level rise, agricultural, water supply, health ecosystems and biodiversity impacts, the increase of extreme weather events and the risk of major catastrophic events have to be evaluated terms of monetary values, see Watkiss (2005a) and (2005b).[8] Evaluation methods should be used which comply with the characteristics of this type of externality.[9] In economics, individual preferences are the most important indicator to value costs imposed on society (externalities) (e.g. Schipper et al. 2001). Preference methods attempt to value external effects using information on preferences of individuals and can help to determine the value of an unpriced good in practice. However, the preference techniques are not suitable for valuing global GHG as individuals are not confronted with climate impacts in a direct factual, spatial and temporal way as they occur on global scale and in long term.[10]

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[8] The cost of sea level rise could e.g. be expressed as the costs of land loss. Agricultural impacts can be expressed as costs or benefits to producers and consumers, and changes in water runoff might be expressed in new flood damage estimates (CE Delft et al. 2007).

[9] Climate impacts occur on a global scale; they are associated with high uncertainty and risk pattern are difficult to anticipate. Furthermore one has to evaluate irreversible damages and to judge today about damages that will take place in distant future which addresses ethical intergenerational questions (UBA 2007, Stern 2007).

[10] Distinction can be made between revealed and expressed preference methods. Using the revealed preference method (e.g. hedonic pricing methods, travel cost method) cost is assigned to external effects on the basis of their observed impact on market prices. Expressed preference techniques like e.g. contingent valuation method determine the willingness-to-pay or

Available damage cost estimations of GHG (Stern 2007; Watkiss 2005a,b, ExternE (2005), see CE Delft et al. (2007) p.263) comprise implicit valuation of the monetary value of lower mortality risk, ecosystems and quality of life.[11] However, due to special theoretical valuation problems related to inter- and intra-generational equity, irreversibility and uncertainty the results vary by orders of magnitude. Much of the variation in social carbon costs estimates arise from a few key parameters in the choice of decision perspectives, most importantly, the discount rate used; the approach to weighting impacts in different regions (equity weighting) and the time-horizon chosen (Watkiss 2005b, Tol 2005). Finally, as social costs of climate change today depend on assumed emission path in future, underlying assumptions on future emissions are needed and might influence strongly the social costs of carbon (Stern 2007).

The avoidance cost approach is based on the rationale that the social optimal emission level cannot be identified because the information necessary is not available to governments. Baumol and Oates (1971), therefore, recommend as "second best solution" that government should fix some socially "desirable" level of pollution and implements this environmental standard with minimal overall costs. The so called standard-price approach based on long term-targets is widely used in climate economics. The dimensions of irreversibility, equity and uncertainty which are associated with climate change and which make ethical and political decisions necessary can be reflected in policy targets. The approach is based on implicit valuation. It provides an order of magnitude of the expected, however not measurable damages.

The robustness of this approach depends on the politically agreed target. Additionally it requires great knowledge of the costs of the abatement measures as a function of the target. To estimate the abatement costs, one has to understand and predict adequately the dynamics of technological development, the behaviour changes, possible market failures and transaction costs (CE Delft 2002).

Different studies[12] estimate the avoidance cost towards different existing climate change targets[13]. The spread of results from these studies assessing external costs based on avoidance costs is significantly smaller than for studies using the damage cost approach (CE Delft et al. 2007).

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willingness-to-accept for hypothetical changes in the availability of a particular environmental good via surveys, see Garrod et al. (1999); Endres et al. (1998); Faucheux et al. (2001).

[11] **Implicit valuation comprises two analysis steps: The dose-response function between GHG emissions and climate impacts is determined. Subsequently an economic assessment of the climate impacts on the basis of market values is undertaken.**

[12] **Stern (2006), Capros et al. (2000), ExternE (2005), SEC (2007) 8; CE Delft et al. (2007) p. 264**

[13] **Avoidance costs towards climate change targets like the Kyoto target, the IPCC long term target of 50% emission reduction and the stabilisation target at 2°C temperature increase are investigated.**

3.2 Discussion of methods with regard to climate externalities of aviation

Depending on the scope of analysis marginal, average or overall external costs of climate change can be determined. In this paper marginal external costs are in the fore as they are important for the design of economic instruments like emissions trading. Referring to marginal external costs of aviation, the pathway methodology must be taken into account as the level of the marginal climate impact depend on the atmospheric interaction and can therefore only be estimated on a flight-to-flight basis.

In general, the climate impact of a specific flight is more difficult to estimate than the climate impact of other transport and industry activities due to the fact, that not primarily long-lived GHG emissions but also reaction products and indirect effects are extremely relevant. The scientific understanding for some short-lived effects (e.g. cirrus clouds) is not as well elaborated as for long-lived GHG resulting in higher uncertainties with regard to climate externalities.

Following the damage cost approach it can be assumed that the marginal damage cost of a specific flight is also more challenging to evaluate than marginal damage cost of a GHG emission as not only economic damages from global but also from regional climate change have to be evaluated. Evaluation methods for regional climate externalities are associated with uncertainties which are in the same order as those of global climate externalities. Additionally they are not yet well elaborated as this type of externality play a minor role in other sectors.

The avoidance cost approach is significantly hampered by the lack of a reliable metric to compare the climate impact of short- and long-lived gases. The formulation of a target addressing all significant climate impacts of the aviation sector is impossible as long as no reliable metric is available. Or the other way around, the climate targets which are agreed on international level on the basis of the GWP (Kyoto target, EU -30% target for 2020) are not appropriate as targets for non-CO_2 effects. Furthermore abatement options addressing different types of emissions or climate impacts cannot be directly compared so that marginal avoidance cost for one unit of climate impact cannot be defined in a consistent comparable manner. Neither interactions nor trade-offs can be easily described.

To conclude, economic evaluation of climate externalities in aviation is challenging. The damage cost approach, which is favourable from a theoretical welfare economic perspective, is associated with high uncertainties. The avoidance approach, however, is hampered by difficulties to compare short- and long-lived resp. direct and indirect climate effects.

4 Emissions trading as internalisation strategy

After a long political debate on policy options to internalise aviation-induced climate impacts, the EU Commission adopted in December 2006 a proposal for

legislation to include aviation in the EU-ETS (COM/2006/0818 final).[14] This is the first step towards an internalization of climate externalities in the aviation sector. It follows a review of the economic theory of emissions trading and a short discussion of the key elements of the planned scheme in the context of aviation-induced climate impacts.

4.1 Concept of emission trading

Without policy intervention technological externalities lead to market failure. Internalising these effects means to reduce the external effects to a social optimum. In the standard theory of externalities, there are four ways in which negative externalities can be approached to increase the efficiency of the market (Stern 2007):

- **a tax can be introduced so that emitters face the full social cost of their emissions (Pigou 1920) i.e. A carbon price can be established that reflects the damage caused by CO_2 emissions.[15]**
- **Quantity restrictions can limit the volume of emissions, using a "command and control" approach.**
- **a full set of property rights can be allocated among those causing externality and/ or those affected, which can underpin bargaining or trading (Coase 1960).[16]**
- **A single organisation can be created which brings those causing the externality together with all those affected (Meade 1951).**

Basically, the concept of emissions trading roots back to ideas of Pigou and Coase (Rudolph 2005). John H. Dales elaborated 1968 the concept of transferable property rights for public goods. He was convinced, similar to Coase, that private property rights of public goods have to be defined and ought to find their way into the price mechanism of the market.[17] Cap-and-trade emission trading schemes combine quantity restrictions and property rights. They control the overall quantity of emissions, by establishing binding emissions commitments. Within this

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[14] While either tax or emission trading would, in principle, be effective ways to price emissions from this sector, the choice of the instrument is driven rather by political viability as by economics.

[15] In 1920, Arthur Cecil Pigou (1932) developed the thesis that all costs of economic activities should be covered by prices including those costs which where borne by third parties (external costs). He suggested internalising these effects through taxing those activities which cause external cost (Pigou tax).

[16] Ronald Coase (1960) challenged the polluter pays principle and showed that assigning property rights to public goods would result in efficient allocation of resources in the case of external effects (efficiency thesis) independently whether the property rights are assigned to one or the other of the involved parties (invariant thesis).

[17] "Transferable property rights stand in a one-to-one relationship to prices; everything that is owned is priced, and everything that is priced is owned" (Dales 1968).

quantity ceiling, allocation of emission rights take place (Stern 2006). Summarizing, emissions trading contains aspects of the command and control, pricing and negotiation approach "in a way that advantages of the three approaches are combined" (Holzinger 1987 see Rudolph 2005).

In theory market-based options like pricing and trading schemes fulfil the pareto-efficient criteria. In practice, however, due to high informational requirement (social cost and abatement cost curve) a first best solution is virtually impossible (Endres 2007). An emission trading scheme in practice is a second-best solution as it leads to the best allocation of resources which can be achieved under the constraint of asymmetric information.[18] This instrument aims at the cost efficient attainment of a given environmental target, while the exact internalisation of external costs is ignored.

4.2 Planned inclusion of aviation in EU-ETS

The European Commission commissioned a project "to develop concepts for amending Directive 2003/87/EC to address the full climate impact of aviation through emissions trading". However, based on the final project recommendations (Wit et al. 2005) the planned EU-ETS in aviation addresses only CO_2 (COM/2006/0818 final). Due to scientific and methodological issues[19] it seems to be currently impossible to design allowances referring consistently to all climate impacts of aviation and which are, additionally, compatible with the allowances under the EU-ETS. As a consequence the internalisation of aviation-induced externalities can only be obtained on the basis of a policy mix.

As long as external costs of non-CO_2 effects are not addressed by other policy instruments, a fragmentary internalisation is shaping the market. What does that mean in the case of aviation? By far not all climate impact mitigation options will be addressed even though they might be less cost-intensive than the allowance price in the EU-ETS. The higher the abatement costs of CO_2 emissions compared to non-CO_2 effects and the smaller the overall reduction potential of CO_2 compared to non-CO_2 climate impacts, the larger are the efficiency losses with which one has to put up if CO_2 is considered as sole basis for assessment.

Due to the direct relation between kerosene combustion and CO_2 emissions, cost efficiency reasons lead, even though indirectly, to a CO_2 optimisation of aircraft operations. The already existing strong incentives to reduce CO_2 are enforced; however, low-cost CO_2 abatement options (which are not hampered by other constraints) are very limited. Contrariwise economic incentives to abate the non-CO_2 climate impact have not (cloud formation) respectively rarely (NO_x) been established. While some of the CO_2 mitigation strategies reduce the full climate impact by aviation, there are additional strategies not addressed in a CO_2 based

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[18] This approach is based on the theory of Lipsey and Lancaster (1956-57).

[19] E.g. complex atmospheric interactions and the lack of a reliable metric, see section 2.3 and 3.2.

scheme (Deuber 2007), which might have a large and cost-effective potential to reduce the overall climate effect by aviation (Cames et al. 2003). Furthermore enforcing particularly CO_2 reductions might result in climate-relevant trade offs.[20] These aspects suggest that efficiency gains from CO_2 internalisation are very limited compared to hypothetical internalisation of non-CO_2 effects respectively of the full climate impact.

As the EU-ETS is limited to CO_2 emissions the monitoring scheme is rather easy to implement. Monitoring and reporting of fuel consumption on the relevant flights is sufficient. A sophisticated model to estimate all aviation-induced emissions and reaction products is redundant which would be necessary if non-CO_2 effects were addressed.

The draft Directive (COM/2006/0818 final) proposes a cap for the European aviation sector on the basis of the 2005 CO_2 emission level (stabilisation target). The European Parliament calls explicitly for an emission target in line with the European target of limiting global temperature increases to more than 2°C compared to pre-industrialised levels (European Parliament 2006). References in literature, however, cannot be found, that the 2005 stabilisation target proposed by the EU Commission is based on scientific reasoning in line with the overall climate target. Therefore the assumption stands to reason that the cap is rather set on the basis of political feasibility.

In a closed system the price signal generated through the EU-ETS would be equal to the marginal CO_2 avoidance cost in the aviation sector to reach the stabilisation target. The draft proposal (COM/2006/0818 final), however, envisage an open trading scheme; the aviation sector will be included in the EU-ETS. As the demand for allowances in the aviation sector will be very limited compared to the market volume of emission allowances in EU-ETS, the aviation sector is predicted to be a "price taker" of the EU-ETS (ICF Consulting 2006). The costs of an extra unit of CO_2 emissions in aviation will be equal to the marginal avoidance costs of CO_2 in the energy intensive industry. Thus the CO_2 price in the EU-ETS will rather reflect abatement costs for future emissions of the energy intensive sector than of aviation emissions; the latter tend to be significantly higher (CE Delft 2002). An open scheme is favourable for efficiency reasons, but one has to accept that the allowance price does not provide information on abatement costs in the aviation sector.

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[20] **The best understood trade-off with regard to engine technology is between CO_2 and NO_x, stemming from the technological trend towards higher engine pressure ratios and combustion temperatures and pressures that improve fuel efficiency but, perversely, generate more NO_x, see for example Green (2005). Another important trade-off concerns CO_2 and contrail formation. If propulsion efficiency of aircraft increases as a result of CO_2 optimisation of engines contrails tend to form at progressively lower altitudes under the same atmospheric conditions (Schumann 2000; Schumann et al. 2000).**

5 Summary and conclusion

In this paper an overview of the climate externalities in aviation is provided. It was shown that in common with many other environmental problems, human-induced climate change is at its most basic level an externality. However, climate change has some special features that together distinguish it from other environmental externalities and which shape the economic analysis: standard welfare approaches are not sufficient to address global climate externalities which deal with long time horizons, have risk and uncertainty at its core and are characterised by the possibility of major, non-marginal changes.

It was highlighted that aviation-induced climate impacts take a special position in climate externalities. Beside the direct GHG CO_2 other indirect climate effects like ozone formation, methane reduction and cloud formation are highly relevant. As the characteristics of the non-CO_2 effects deviate strongly from direct long-lived GHG – e.g. the complexity of the climate impact and its dependence on where the emission take place – evaluating and regulating short- and long-lived climate impacts in parallel present a great scientific, economic and political challenge. Currently there is no metric sufficiently robust and mature enough for comparing the two types of climate impacts which could serve as a basis for a market-based option.

There are different approaches to evaluate climate externalities. The first-best evaluation method, the damage cost approach, provides in theory the optimal shadow price of an externality. However, in practice, first-best solutions are impossible; economic evaluation of damages and social costs from environmental externalities in general is associated with large uncertainties; referring to climate change the valuation problems are even larger: Standard welfare economic evaluation methods based on individual preferences do not comply with critical dimensions of climate change. To avoid these valuation problems, a second-best economic evaluation approach the so called avoidance cost approach based on political targets is widely used in climate economics.

Current climate policies and economic evaluation methods focusing on well-mixed GHG fall short when looking at climate externalities in aviation. In general, when evaluating climate effects, the weighting of impacts over time plays a central role. In aviation, however, this challenge is much more pronounced due to the relative importance of short-lived effects. Therefore the particular challenge consists in the strong need to weigh short- and long-term effects, be it the climate impact itself on the basis of a metric or be it the resulting economic damage on the basis of a discount factor.

Due to scientific and methodological issues the planned EU-ETS in aviation addresses solely CO_2. As long as external costs of non-CO_2 effects are not internalised by other policy instruments, a fragmentary internalisation of climate externalities is shaping the market. While some of the CO_2 mitigation strategies reduce the full climate impact of aviation, there are additional strategies not

addressed in a CO_2 based scheme, which have a potentially large and cost-effective potential to reduce the overall climate effect by aviation. Furthermore enforcing particularly CO_2 reductions might result in climate-relevant trade offs. These aspects suggest that efficiency gains from CO_2 internalisation are very limited compared to those associated with internalisation of the full climate impact of aviation. An open emissions trading scheme is definitely favourable for efficiency reasons but one has to accept that abatement options are predominantly taken in the energy intensive industry.

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