

The Environmental Impact of Aviation in the Highlands and Islands

Highlands and Islands Enterprise

Final Report

August 2003

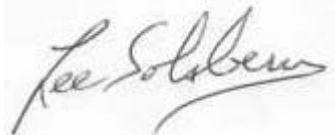
Highlands and Islands Enterprise

The Environmental Impact of Aviation in the Highlands and Islands

August 2003

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EXECUTIVE SUMMARY

We estimate that current annual CO₂ emissions from air traffic in the Highlands and Islands are 62,500 tonnes CO₂ which represents 0.2% of CO₂ emissions from aviation for the whole of the UK in 2000.

The total climatic impact for the region, calculated by applying an appropriate Radiative Forcing Index is 34,100 tonnes of Carbon (tC), which represents 0.17% compared to the UK as a whole (20 million t C in 2000).

The total climatic impact is a measure accounting for the range of climate change-inducing effects that are additional to CO₂ emissions, and is particularly strong in the case of long-haul flights. The major contributors to the total climatic impact from aviation in the region are the routes from Inverness to Gatwick and Inverness to Luton served by the airlines BA CitiExpress and EasyJet.

In common with these routes are longer distances, higher overall passenger numbers, engine types and higher altitudes. The latter two factors affect atmospheric responses (such as contrail formation and tropospheric ozone emissions) that further contribute to anthropogenic climate change beyond CO₂ emissions from fuel consumption alone.

Overall, emissions from aircraft are lower than those of alternative surface modes of transport (car and ferry) for comparable routes, but this is based on assumptions of low environmental efficiencies for car journeys and relates to CO₂ emissions only. This therefore excludes the additional radiative forcing effects, which are a significant factor on the total climatic impact of aviation in the region and its associated financial cost, which constitute the main objectives of this study.

The UK Government is proposing to cost impacts of aviation by an illustrative cost of £70 per tC emitted, rising by £1 per tC for each subsequent year. According to this methodology, we estimate that the climate change impact of air traffic in the region would represent a cost to society of £2.5 million in 2003. This represents 0.17% of the estimated £1.4 billion for the UK as a whole in 2000).

Flights to airports outside Scotland contribute much more by far to the total climatic impact of air travel in the Highlands and Islands region overall, contributing 83% of the total climatic impact of the region, and hence the same proportion of the potential financial cost.

This is reflected in the average climate change impact cost per passenger flight, which according to our calculations is £3.37 for flights to and from UK airports outside of Scotland and £1.19 for flights within Scotland.

The number of UK LTOs for 2001 was 1,691,647 of which 32,882 were associated with the Highlands and Islands, using aircraft that emit substantially less pollutants per LTO. In this context emissions from the Highlands and Islands airports are insignificant.

The Scottish Highlands and Islands, due to the nature of the routes, use smaller classes of aircraft. As such, associated emissions are much smaller in magnitude, both in terms of total pollutant loadings, and average emissions per plane. This results in the relative contribution of these routes to the UK airline industry's total contribution to local air quality impacts being very small.

However, even these comparisons over emphasise the contribution of the Highlands and Islands airports to local air quality impacts. This is due to the existing good quality air in the region. The additional emissions from aircraft to the local environment have very little effect on the overall air quality health impacts. The quality of the air around airports in the southeast of England, such as Heathrow, is dominated by emissions from road vehicles as well as aircraft. The resulting air quality in these areas is in breach of national standards for local air quality on occasions, these events may cause significant health impacts in exposed populations.

The 10 airports in the Highlands and Islands region are situated in areas where air quality is good by UK standards. Concentrations of pollutants such as nitrogen dioxide, sulphur dioxide and PM₁₀ are low and there is no difficulty in complying with the Government's air quality objectives. Given the rural nature of the area, the potentially exposed populations are also significantly lower when compared to population densities throughout the rest of the UK. In 2001 the total number of aircraft movements in the Highlands and Islands region generated 51 tonnes of nitrogen dioxide, which represent less than 1% of the 5330 tonnes generated by aircraft movement at Heathrow.

Using the population annoyed indicator it is apparent that the Highlands and Islands airports have low noise impacts compared to many UK airports simply because they are situated in lesser populated areas. Hence the environmental noise impact of each of the Highlands and Islands airports is considered to be far lower than a typical UK regional airport and any taxation system proposed based on the 'polluter pays principle' should take this into account.

ERM was commissioned by Highlands and Islands Enterprise (HIE) to conduct research to establish the environmental impact of air services in the Highlands and Islands region.

The principal objective of this study is to quantify the environmental impact of aviation in the Highlands and Islands, based on the damage cost function adopted by the UK Government for use in the design of economic instruments for the aviation industry. As such, it aims to inform HIE in light of the stakeholder consultation on the future of aviation in the UK, taking place over the next few months.

1.1**ROUTES OF THE STUDY**

This study focuses on the routes from and between airports in the Highlands and Islands region.

Table 1.1 shows the aviation routes that have been included, as well as those that have been excluded from the study.

The routes included in the study are:

- All passenger air traffic from and between airports within the Highlands and Islands region; and
- Routes that serve other UK airports. These comprise flights departing from the region's airports to Glasgow, Edinburgh, Aberdeen, Manchester, London Gatwick and London Luton.

The following routes have been excluded from the study:

- As requested by HIE, the route to Norway (Kirkwall to Bergen, served by Loganair) has not been considered as a part of this study, as it represents a small proportion of the overall air traffic in the region.
- Scottish ambulance service (Loganair) – data available upon request.
- Two of the routes serviced by Highland Airways have passenger numbers that represent an average of only 15% of the total weight carried. As these routes are dedicated to freight transport and would therefore not be affected by passenger transport policies, we have removed them from our results. Data available on request.

Table 1.1 Study routes

| Airline | Route |
|------------------|--|
| BA CitiExpress | Benbecula - Glasgow |
| | Inverness - Gatwick |
| | Stornoway - Glasgow |
| | Sumburgh - Aberdeen |
| Bmi | Stornoway - Edinburgh |
| Eastern Airways | Wick - Aberdeen |
| | Inverness - Manchester |
| EasyJet | Inverness - Luton |
| | Inverness - Gatwick |
| Highland Airways | Stornoway-Benbecula-Stornoway |
| | Inverness - Stornoway - Inverness - <i>excluded</i> |
| | Inverness - Kirkwall - Sumburgh - Inverness (round-trip) - <i>excluded</i> |
| | |
| Loganair | Glasgow - Campbeltown |
| | Glasgow - Tiree |
| | Glasgow - Barra |
| | Glasgow - Islay |
| | Benbecula - Barra - Benbecula |
| | Glasgow - Inverness - Kirkwall - Sumburgh |
| | Glasgow - Inverness |
| | Kirkwall - Inverness - Edinburgh |
| | Edinburgh - Inverness - Stornoway |
| | Edinburgh - Wick - Kirkwall |
| | Stornoway - Inverness - Stornoway |
| | Edinburgh - Stornoway |
| | Edinburgh - Sumburgh |
| | Aberdeen - Kirkwall |
| | Orkney inter-island |
| | Shetland inter-island |
| | Scottish Ambulance Service - <i>excluded</i> |
| | Kirkwall - Bergen - <i>excluded</i> |

1.2 ABBREVIATIONS AND DEFINITIONS USED IN THIS REPORT

The abbreviations and definitions used in this report are presented in *Table 1.2*.

Table 1.2 Abbreviations and Definitions Used in this Report

| Abbreviation | Definition |
|---------------------|---|
| CO ₂ | Carbon dioxide |
| CH ₄ | Methane |
| GHG | Greenhouse gas |
| H ₂ O | Water vapour |
| HI | The region of the Highlands and Islands |
| HIAL | Highlands and Islands Airports Limited |
| HIE | Highlands and Islands Enterprise |
| ICAO | International Civil Aviation Organization |
| IPCC | The Intergovernmental Panel on Climate Change is the authoritative scientific assessment of the science and impacts of climate change that informs the policy process of the UNFCCC |
| LTO | Landing and Take Off |

| Abbreviation | Definition |
|---------------------|---|
| RF | Radiative Forcing: A change imposed upon the climate system, which modifies the radiative balance of that system. The causes of such a change may include changes in the sun, clouds, ice, greenhouse gases, volcanic activity, and other agents. Radiative forcing is often specified as the net change in energy flux at the troposphere (watts per square meter). Many climate models seek to quantify the ultimate change in Earth's temperature, rainfall, and sea level from a specified change in radiative forcing. |
| RFI | The Radiative Forcing Index is used to measure the total RF as a function of CO ₂ emissions. It accounts for the contribution of NO _x and H ₂ O emissions, as well as contrail and cirrus cloud formation. The IPCC estimates that the total RF caused by aircraft is 2.7 (1992 global average) |
| SBSTA | The Subsidiary Body for Scientific and Technical Advice is one of the 2 standing bodies of the UNFCCC |
| UNFCCC | The United Nations Framework Convention on Climate Change is the legal basis upon which industrialised countries have agreed to take action to reduce the adverse impacts of climate change, by agreeing, through the Kyoto Protocol of that Convention, to quantified emissions limitation commitments. |

2.1 CLIMATE CHANGE

Trends in air traffic and emissions

The aviation industry generates more than 600 million tonnes of CO₂ per year worldwide. Aviation is the world's fastest growing source of GHG emissions, due to the rapid expansion of air traffic, which has grown at 2.5 times average economic growth rates since 1960. Associated CO₂ emissions represent 2 % of total anthropogenic CO₂ emissions (1992 figures ⁽¹⁾). However, the total climate change impacts caused by emissions of CO₂, as well as the emission of other gases and indirect atmospheric responses, is measured in terms of 'radiative forcing'. For aviation, this represents 3.5% of that caused by other human activities (energy, industry, agriculture and transport).

In the absence of policy intervention, these emissions are projected to increase, in absolute terms and as a share of total anthropogenic emissions. This is because continuing technological fuel-efficiency improvements do not outpace the unconstrained growth of demand, in parallel with the increasing number and expansion of airports.

Climate impact

The climate impact can be measured using the concept of radiative forcing (RF). This is used to measure the greenhouse effect in terms of the change in solar and thermal radiation at the tropopause. The globally averaged net radiative forcing of aviation is positive with best estimates for 1992 of 0.05 Wm⁻². This is shown in *Figure 2.1* where the last bar on the graph represents the total radiative forcing of aviation as the sum of the radiative forcings of all the emissions sources and atmospheric responses linked to aviation and contributing to climate change, identified as CO₂, O₃, CH₄, H₂O, contrails, cirrus clouds, direct sulphate, direct soot. This corresponds to the RFI of 2.7 times the radiative forcing caused by CO₂ alone, which underpins DEFRA's cost estimations for aviation.

These individual components have different characteristics based on:

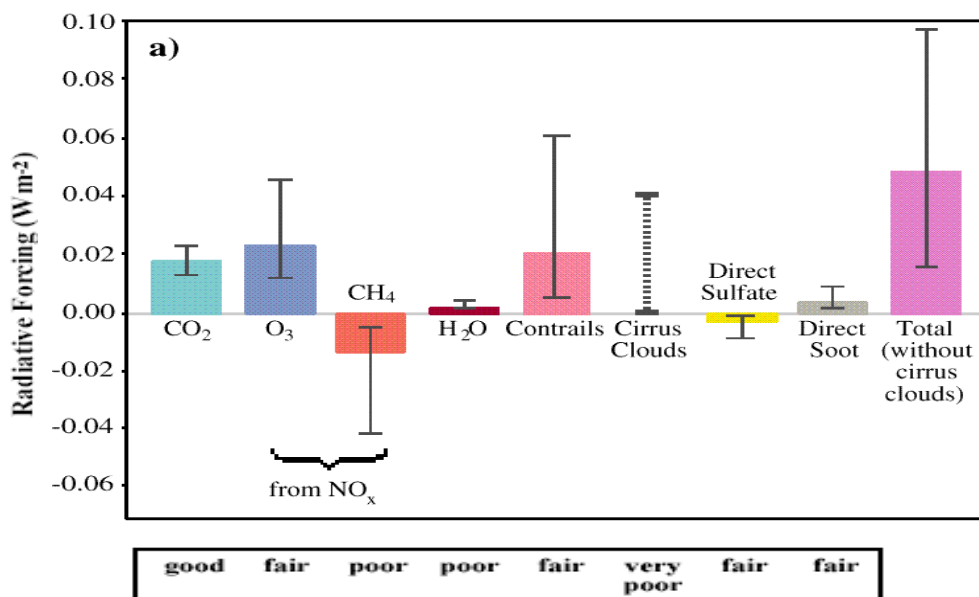
- *Direct or indirect impact:* Climate impact occurs as a result of emissions from the combustion of jet kerosene and aviation gasoline (CO₂, NO_x, SO_x, soot), as well as indirect atmospheric responses. For example, NO_x emissions cause changes in concentrations of methane (CH₄) and ozone (O₃). The increased complexity of the physical process adds to the *level of scientific understanding* defined under the graph in *Figure 2.1*. For example, the level of understanding on cirrus cloud formation that sometimes results from persistent contrail is classed as 'very poor'.

(1) IPCC Special Report on Aviation and the Global Atmosphere, 1999

Indeed, the process is twice removed from the original source: aerosols of sulphate and soot contribute to the formation of contrails, which in turn, under certain atmospheric conditions can trigger the formation of cirrus clouds.

- *Geographical forcing*: CO₂ has a long atmospheric residence time and is globally well mixed, and its contribution can be measured in terms of its proportion of global emissions from other CO₂ sources. Other gases have shorter residence times and remain concentrated at the location where they were emitted. Although O₃ and CH₄ changes occur from the same source, the influence of CH₄ is a long-lived, well-mixed GHG whereas photochemical ozone production in the stratosphere is more regional. Another example is the line-shaped contrails that cover 0.1 % of the earth's surface in northwestern latitudes, where air traffic is the most concentrated.
- *Altitude*: most processes described above occur at the top of the troposphere and in the lower stratosphere, corresponding to altitudes of between 9 km and 13 km. Studies indicate that in national airspace most (60-90%) emissions of NO_x, SO_x and CO₂ are emitted at altitudes above 914 m.

Figure 2.1 Estimated radiative forcing from subsonic aviation in 1992



The bars indicate best estimate of forcing and the line associated with each bar is a 2/3 uncertainty range based on best available information. (The 2/3 uncertainty range means that there is a 67% probability that the true value falls within this range). The evaluations below the graph (very poor to good) indicate the level of scientific understanding.

Source: IPCC 1999 Special Report on Aviation and the Global Atmosphere

Aviation and the United Nations Framework Convention on Climate Change (UNFCCC)

Despite the growing share of aviation's contribution towards global GHG emissions, the emissions from aircraft are not part of the quantitative target agreed under the Kyoto Protocol of the UNFCCC. Emissions from aircraft are in the UNFCCC category known as 'bunker fuels', which includes fuel sold to ships or aircraft engaged in international transport. The UNFCCC requests that countries not report 'bunker fuel' emissions under their National GHG inventories, but report them separately. The UNFCCC stipulates that Parties must report the methodology and calculations they used to separate international marine and aviation bunker fuels from domestic consumption. Work is being undertaken by the UNFCCC on methodologies of refining the reporting on bunker fuel emissions.

As of 2002, 29 Annex I Parties provided estimates of emissions from international aviation, based on either Tier 1 or Tier 2 methodologies of the Intergovernmental Panel on Climate Change (IPCC). Tier 1 is the simpler method, which is based on 'an aggregate figure for fuel consumption for civil aviation multiplied by average emissions factors'. More data is made available through Tier 2 and a distinction is made between emissions below and above 914 m (3,000 ft) in order to reflect the altitudinal aspect of the emissions, and how it impacts on the total climatic impact.

The data that the UNFCCC's Subsidiary Body for Scientific and Technical Advice (SBSTA) has received to date indicates that international aviation emissions from industrialised countries increased at an average annual rate of 4 per cent between 1990 and 2000. The increase from 1990 has been significant with emissions in 2000 being 48 % higher than those in 1990. Although there has been this rapid emission growth in the past, in 2001 and 2002 there was a slowing down of emissions (attributable primarily to the events of September 11th 2001 causing a 2-3 % reduction in 2000 aviation traffic figures).

The issue of international GHG emissions from aviation has been discussed in SBSTA meetings to date and the upcoming 18th meeting will address the following specific issues:

- (a) Summarised GHG inventory information submitted in 2002;
- (b) A discussion on definitions for domestic and international emissions;
- (c) A description of the methodologies for estimating emissions from international and domestic aviation and maritime transportation included in the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (IPCC Guidelines);
- (d) A description of sources of activity data and other related information available under the ICAO and IMO process;

- (e) A proposal for possible future work.

International Civil Aviation Organization

As part of its role to coordinate the international effort to address emissions from aviation and inform the policy-making process, the ICAO has commissioned the 'Special Report on Aviation and the Global Atmosphere, 1999' which was conducted by the IPCC. The report assesses the state of understanding of the relevant atmospheric science, aviation technology, and socio-economic issues associated with mitigation options for both subsonic and supersonic fleets. It identifies past and potential future effects that the aviation industry may have on global warming and outlines options for mitigating future impacts the aviation industry may have on global warming.

A study entitled *Regional Differences in International Airline Operating Economics: 1998 and 1999* has been published by ICAO, this is aimed at estimating and comparing airline costs in different regions of the world. The next publication (due in 2004) will present estimates for years 2000 and 2001.

The UK context

The UK has provided all the information requested by the UNFCCC (i.e., fuel consumption and emission data for CO₂, CH₄, N₂O, CO, NO_x, NMVOC and SO₂). Domestic consumption was estimated from landing take off data (LTO) and total domestic air kilometre using IPCC default fuel consumption factors. Aviation bunkers are estimated from total sales of aviation fuel in the UK less domestic military consumption.

For 2000, estimates from the National Environmental Technology Centre (NETCEN) show that UK civil passenger aviation produced 30 million tonnes of CO₂, which corresponds to 18 % of all UK transport CO₂ emissions and 5 % of UK CO₂ emissions from all sectors.

Britain expects air passenger numbers to more than triple to 500 million a year by 2030 (UK Government Press Release 17/03/2003). The prediction is that from 2001, air traffic will increase by 3.5 % per annum.

3 *CO₂ EMISSIONS FROM AVIATION AND SURFACE TRANSPORT ALTERNATIVES IN THE REGION*

3.1 *METHODOLOGIES*

3.1.1 *CO₂ emissions calculations from aircraft*

Assumptions and calculations that were made to determine the CO₂ emissions from aircraft include:

- Calculations of the carbon content, used to estimate CO₂ emissions were made from fuel burn data, using the IPCC emission factors for jet kerosene and jet gasoline.
- It was assumed that all the fuel consumed is combusted.
- The type of fuel (jet kerosene or gasoline) was either provided by the airline, the fuel supplier (Air BP), or assumed on the basis of the type of aircraft engine. Where not specified by the airlines and as advised by Air BP, we assumed jet kerosene to be the fuel used in the case of turbine engines (turbojet, turbofan or turboprop), and gasoline in piston engine (reciprocating piston or opposed piston).
- Information on the routes, frequency and amount of fuel consumed was obtained from the airlines and the fuel provider (Air BP).
- In order to present results in terms of CO₂ emissions per passenger journey, total passenger numbers per route per year were obtained from the airlines directly or indirectly via HIE.

3.1.2 *CO₂ emissions for alternative modes of transport*

Assumptions and calculations that were made to determine the CO₂ emissions from alternative modes of transport include:

- Emissions for alternative transport modes were calculated on the basis of actual car and ferry distances for each route, and not the straight-line distance.
- Distances were measured from airport to airport, to allow comparability with actual aircraft distances.
- The shortest route, rather than the fastest was chosen.
- CO₂ emissions for car journeys were calculated using the methodology set out in the Design Manual for Roads and Bridges (DMRB) (Volume 1.0(c), February 2003), based on distance and average speeds for the different

types of roads (50 km h⁻¹ on National and country roads and 100 km h⁻¹ on A roads and motorways, for journeys to Manchester, Luton and Gatwick); and

- We assumed that a car journey would transport a single passenger.
- In the case of ferry journeys, CO₂ emissions were calculated per passenger by applying a conversion factor of 0.047kg km⁻¹ ⁽¹⁾ per passenger to the distance travelled.

3.1.3 *Calculating the Radiative Forcing Index (RFI)*

In order to estimate the total climatic impact of aviation in the region, we have separated the routes into different categories of aircraft and flight types, in view of applying an appropriate RFI (see Table 3.2). This has been done in line with a methodology developed by CE Delft.

Table 3.1 *Types of aircraft and flight*

| Type | Description |
|------|---|
| 1 | Aircraft with about 40 seats flying about 200km (typical of short-distance domestic airport) |
| 2 | Aircraft with about 100 seats flying about 500km (typical of short-haul intra-EU transport) |
| 3 | Aircraft with about 150 seats flying about 1500km (typical of longer distance intra-EU air transport) |
| 4 | Aircraft type with about 400 seats flying about 6000 km (relevant for intercontinental travel) |

For the purpose of calculating the total climatic impact for the Highlands and Islands, only type 1 and type 2 aircrafts are relevant. Most of the region's routes were attributable to type 1; only the 3 following routes were attributable to type 2:

- Inverness to Gatwick (BA CitiExpress) by BAe 146-200 (maximum 110 seating), over a distance of 899.8 km;
- Inverness to Luton (EasyJet) by Boeing 737 (maximum 149 seating), over a distance of 675 km;
- Inverness to Gatwick (EasyJet) by Boeing 737 (maximum 149 seating), over a distance of 899.8 km.

(1) for a typical journey under 500km; data from the Centre for Energy Conservation and Environmental Technology; Netherlands

Table 3.2 *RFI adjustment based on aircraft and flight type*

| | 1992 IPCC estimate | Type 1 | Type 2 |
|--------------------------------|--------------------|---------------|---------------|
| CO ₂ | +0018 | +0.018 | +0.018 |
| O ₃ | +0.023 | 0 | +0.023 |
| CH ₄ | -0.014 | 0 | -0.014 |
| Stratospheric H ₂ O | +0.002 | 0 | 0 |
| Contrails | +0.02 | 0 | +0.02 |
| Cirrus | (0-0.04) | 0 | (0-0.04) |
| Sulphate aerosols | -0.003 | (-0.003) | -0.003 |
| Soot aerosols | +0.003 | (+0.003) | +0.003 |
| Total | +0.049 | +0.018 | +0.047 |
| RFI | 2.7 | 1 | 2.6 |

As can be seen in *Table 3.2* the RFI was adjusted by subtracting the effect of the following components from the estimated NASA-1992 scenario of globally averaged RFI used by the IPCC:

- Changes in tropospheric ozone (O₃) occur as a result of NO_x emissions at altitudes of 9 km or above, that type 1 do not reach;
- Changes to methane (CH₄) concentrations also occur as a result of NO_x emissions and the level of scientific understanding of the process is classed as ‘poor’ by the IPCC;
- Sulphate aerosols and soot have been removed from type 1 for simplicity, based on the cancellation of the two effects on a globally averaged level, and the assumption that all the carbon contained in the fuel is combusted and transformed to CO₂;
- Contrail formation typically occurs in ice-saturated air masses at 10 km altitude in mid-latitudes, conditions that do not apply to type 1 situations; and
- Most water vapour emitted by subsonic aircraft is rapidly removed by precipitation. Stratospheric water vapour (H₂O) has a longer residence time and may lead to greater accumulations, however, as it is emitted from supersonic aircraft (such as Concorde) it has therefore been removed from both categories.

The total climatic impact is calculated on the basis of CO₂ emissions factored by the representative RFI of each route, based on the type of aircraft and distance presented in *Table 3.1*.

3.1.4 *The cost of carbon*

The cost of aviation is calculated by applying a cost of £73 per tC, to represent 2003 prices, to the total climatic impact calculated using the methodologies described in *Section 3.1.3* above. This is based on the illustrative value of £70

per tC proposed by the Government in the working Air Transport White Paper. The latter concludes that:

'a value of approximately £70 per tC (2000 prices, with equity weighting) ⁽¹⁾, seems like a defensible illustrative value for carbon emissions in 2000. This figure should then be raised by £1 per tC in real terms for each subsequent year ⁽²⁾.'

3.2

CLIMATIC IMPACT OF AVIATION IN THE HIGHLANDS AND ISLANDS REGION

Data have been obtained on the fuel consumed and the passenger loadings for each individual route in the Highlands and Islands region. This data has then been used to calculate the total CO₂ emissions for each route.

The results of this calculation are shown in *Table 3.4*. The table allows a comparison of climate change-inducing emissions between aircraft and alternative modes of surface transport (car and ferry) for comparable actual routes. The emissions are expressed in terms of CO₂ emissions per passenger, as well as in terms of the total climatic impact, which includes the factorisation of the RFI. Weighted averages are shown for aviation from the Highlands and Islands as a whole and for the flights to and from Scottish airports only.

Table 3.4 and *Figure 3.1* show that overall air travel within and from the region's airports contributes an average of 86 kg CO₂ per passenger compared to 90 kg of CO₂ for the comparative car and ferry journey. One can conclude that in terms of CO₂ generation, air travel is a slightly more favourable means of transport along these routes from the alternative means of travelling by car and ferry. This is illustrated in *Figure 3.2* and *Figure 3.3*, which make the comparison between annual emissions from aircraft and alternative surface travel for selected routes.

The environmental differential between the different transport modes is surprising compared to the global assumption that air travel is the most polluting form of transport. However in this case it can be explained by the following reasons:

- Air travel in the region has a relatively low polluting impact compared to the UK as a whole or globally, mostly due to low travelling altitudes.
- Most of the car trips would be made at speeds either below or above the optimum speed for engine-efficiency of approximately 90 km h⁻¹.
- Our assumption that each car journey is for one passenger. Should this be changed to two passengers per car, this would significantly improve the fuel efficiency of the trip and clearly change the relative impact of air travel compared to surface transport alternatives.

(1) Equity weighting is used to take account of differences in income between geographical regions of the world

(2) Note, these values were originally in dollars, so have been converted using an exchange rate of £1=\$0.56

- The pattern applies to the flights making the longest journeys. These longer-haul aircraft are flying at relatively high passenger loading efficiencies. Indeed, this is an increasingly important determinant of environmental efficiency as travel distances increase. The majority of passenger numbers used in this study are travelling on these longer routes, which affects the weighted average when compared to that of per passenger emissions for alternative surface travel.

On the routes where per passenger emissions for surface transport were observed to be larger than those of the corresponding aircraft journey, it would take the following number of passengers sharing a car for the environmental effect of the air trip, including the RFI, to be identical to those by surface travel.

Table 3.3 *Required number of passengers per car for emissions to be equal to per passenger aircraft emissions*

| Selected route | Passengers per car |
|-----------------------------------|--------------------|
| Stornoway - Glasgow | 1.1 |
| Stornoway - Edinburgh | 1.4 |
| Edinburgh - Inverness - Stornoway | 1.3 |

On the other hand, inter-island routes are those where the comparative surface transport per passenger emissions are the lowest. This is due to very low passenger loadings on aircraft (three passengers per trip on average) leading to relatively high emissions per passenger for aircraft journeys, coupled with the frequency of the landing and take-off phases; indeed the average Orkney inter-island flights are composed of three legs.

Figure 3.2 and *Figure 3.3* show that for the climate impact can be different for the same route. This is the case for the Inverness and Gatwick route, where lower emissions on the EasyJet route are related to lower flight frequency and higher fuel efficiency as a result of higher percentage passenger loading capacity.

Figure 3.3 also shows the climate impact differential for each route between aircraft and alternative transport modes (car and ferry), but this time including the application of the RFI. Here the contribution of factors other than CO₂, primarily contrail formation and emissions of NO_x, is clearly shown to have a significant influence on the overall climatic impact of aviation. Indeed, even though the globally averaged index was applied only to 3 routes in this study, their contribution results in an absolute shift, for the region as a whole, whereby alternative modes become the preferable environmental option.

Table 3.4 *Climate-change inducing emissions in the Highlands and Islands*

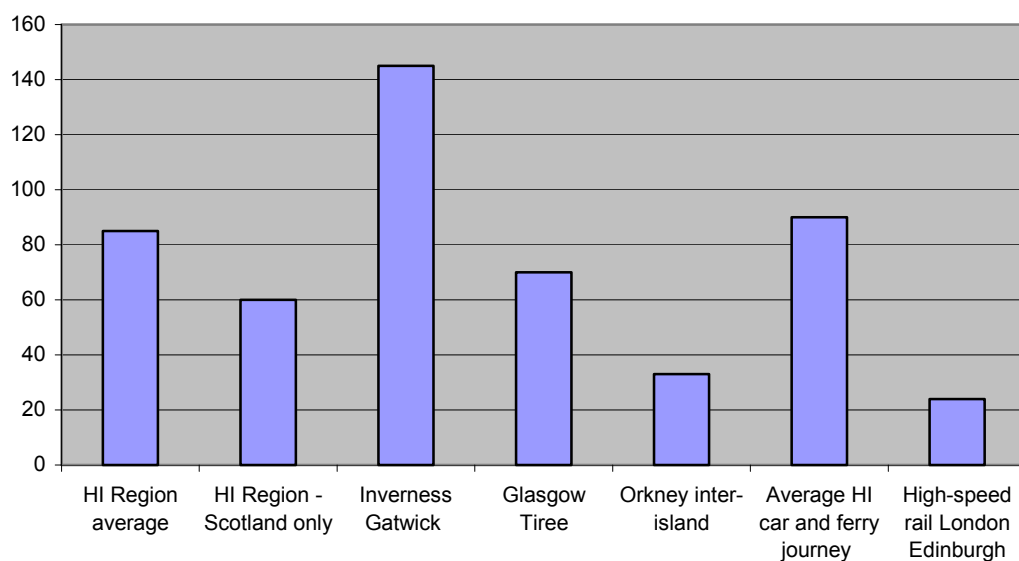
| Route | Air travel | | Surface travel |
|--|--|--|--|
| | Emissions per passenger per journey (kgCO ₂) | Climate impact (including RFI) per passenger (kgCO ₂)* | Emissions per passenger (kgCO ₂) |
| BA CitiExpress | | | |
| Benbecula Glasgow | 59 | 59 | 34 |
| Inverness Gatwick | 145 | 377⁽¹⁾ | 148 |
| Stornoway Glasgow | 50 | 50 | 55 |
| Sumburgh Aberdeen | 57 | 57 | 24 |
| Bmi | | | |
| Stornoway Edinburgh | 39 | 39 | 54 |
| Eastern Airways | | | |
| Wick Aberdeen | 70 | 70 | 48 |
| Inverness Manchester | 147 | 147 | 101 |
| EasyJet | | | |
| Inverness Luton | 81 | 211⁽¹⁾ | 141 |
| Inverness Gatwick | 83 | 216⁽¹⁾ | 148 |
| Highland Airways | | | |
| Stornoway Benbecula | 71 | 71 | 22 |
| Loganair | | | |
| Glasgow Campbeltown | 48 | 48 | 20 |
| Glasgow Tiree | 70 | 70 | 27 |
| Glasgow Barra | 90 | 90 | 30 |
| Glasgow Islay | 46 | 46 | 17 |
| Benbecula Barra | 45 | 45 | 11 |
| Glasgow Inverness Kirkwall Sumburgh | 149 | 149 | 86 |
| Glasgow Inverness | 63 | 63 | 41 |
| Kirkwall Inverness Edinburgh | 116 | 116 | 72 |
| Edinburgh Inverness | | | |
| Stornoway | 43 | 43 | 54 |
| Edinburgh Wick Kirkwall | 124 | 124 | 72 |
| Stornoway Inverness | 41 | 41 | 17 |
| Edinburgh Stornoway | 92 | 92 | 54 |
| Edinburgh Sumburgh | 96 | 96 | 49 |
| Aberdeen Kirkwall | 47 | 47 | 14 |
| Orkney inter-island | 33 | 33 | 9 |
| Shetland inter-island | 51 | 51 | 7 |
| Weighted average H&I - Scotland flights | 60 | 60 | 36 |
| Weighted average H&I - all UK flights | 86 | 171 | 90 |

NB: all data in this table are rounded to whole numbers

⁽¹⁾: RFI of 2.6 applied to these routes. All other routes have RFI of 1.0 applied to reflect lower altitude of these flights.

* although the standard unit for climatic impact is tonnes of Carbon, it is expressed in this graph in tCO₂ equivalent, to allow the comparison with the comparable emissions (CO₂) from surface transport alternatives)

Figure 3.1 CO₂ emissions per passenger journey (kg)



NB: unless otherwise stated in the graph (x axis legend), the values presented are for aircraft journeys.

Figure 3.2 Emissions per year (CO₂ only) in tonnes

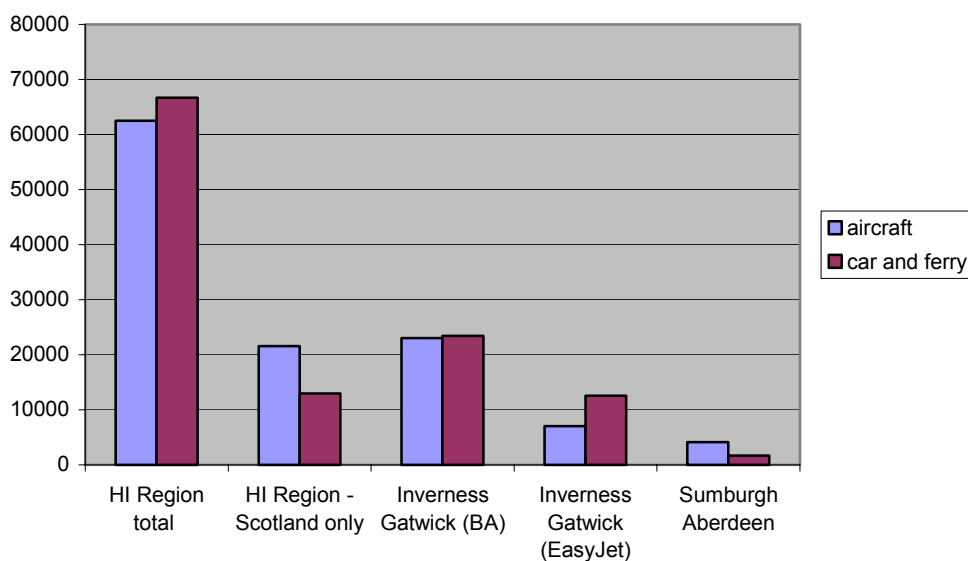
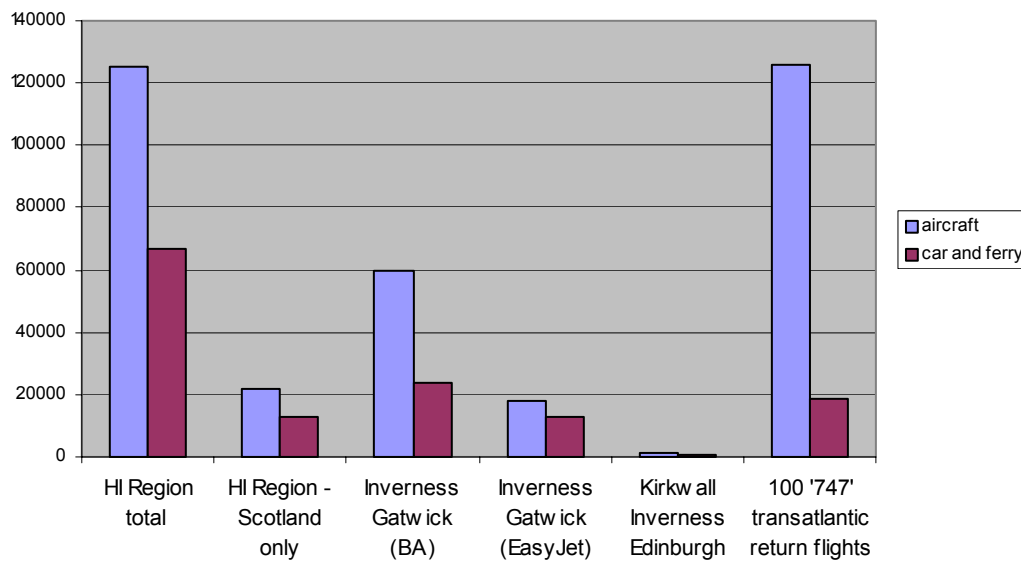


Figure 3.3 Comparisons of total climate impact from aircraft with other transport modes (tCO₂eq*; including RFI)



**NB: although the standard unit for climatic impact is tonnes of Carbon, it is expressed in this graph in tCO₂ equivalent, to allow the comparison with the comparable emissions (CO₂) from surface transport alternatives)*

4.1 LOCAL AIR QUALITY

The 10 airports in the Highlands and Islands region are situated in areas where air quality is good by UK standards. Concentrations of pollutants such as nitrogen dioxide, sulphur dioxide and PM₁₀ are low and there is no difficulty in complying with the Government's air quality objectives. Given the rural nature of the area, the potentially exposed populations are also significantly lower when compared to population densities throughout the rest of the UK.

The UK National Atmospheric Emission Inventory (UKNAEI) considers emissions within a 1000 m ceiling of landing and takeoff (LTO). This height, roughly represents the boundary layer and emissions into it. Above 1000 m, aircraft emissions do not directly contribute to local air quality.

Table 4.1 shows the emission factors for typical aircraft using Highlands and Islands airports compared to the UK average.

Table 4.1 *LTO Emission Factors for Typical Highlands & Islands Aircraft versus Typical UK Aircraft Fleet (kg/LTO)*

| Type | Fuel Used | NO _x | CO | SO ₂ | HCs | Total Aircraft LTO's per year |
|--|-----------|-----------------|-------------|-----------------|--------------------|-------------------------------|
| HIAL | | | | | | |
| B737 (300) | 825 | 8.3 | 11.8 | 0.8 | 0.5 ⁽⁴⁾ | 1,668 |
| BAe 146 | 569.5 | 4.2 | 9.7 | 0.6 | 0.9 ⁽⁴⁾ | 2,190 |
| SAAB 340 | 75 | 0.5 | 0.4 | NA | 0.19 | 9,486 |
| Jetstream 32 | 62 | 0.5 | 0.8 | NA | 0.09 | 2,607 |
| Jetstream 31 | 45 | 0.4 | 0.5 | NA | 0.05 | 1,043 |
| Twin Otter ⁽²⁾ | 64 | 0.4 | 0.6 | NA | 0.034 | 2,682 |
| HIA Weighted Average ⁽⁵⁾ | | 1.54 | 2.45 | 0.13 | 0.30 | |
| UK Average | | | | | | |
| Domestic (B737 – 400) | 825 | 8.3 | 11.8 | 0.8 | 0.5 ⁽⁴⁾ | |
| International (B767) | 1617 | 26.0 | 6.1 | 1.6 | 0.2 ⁽⁴⁾ | |

(1) Source: EMEP/Corinair Emission Inventory Guidebook – 3rd Edition October 2002 Update, SNAP Codes 080501 – 800504

(2) Emissions based on 2 x the emissions listed for DH Turbo-Otter (single engine)

(3) NA – Not Available

(4) Non-Methane Volatile Organic Compounds

(5) The HIA Weighted Average emission rate is calculated using the known number of LTO's for each aircraft type.

As can be seen from Table 4.1, the UK average domestic aircraft (B737 – 300) is in use on two Highlands & Islands routes. This aircraft is operated by EasyJet for the Luton and Gatwick to Inverness routes. The other larger aircraft are used for Gatwick to Inverness, namely the BAe 146.

The NO_x and CO emission factors listed for aircraft that regularly run the other 47 routes are less than 7% of the UK average. Hydrocarbon emission factors from these planes represent at worst only 40% of the UK average emission factor. However, this factor is distorted by the UK average emission

factor detailing Non-Methane VOCs. The factor for the Highlands and Islands Airports, however, includes methane, which results in a higher emission factor being used for the Highlands & Islands aircraft.

Table 4.2 shows the average aircraft emission factors for Heathrow and Gatwick.

Table 4.2 *Average Aircraft Emission Factors for 1999 (kg/LTO)¹*

| Airport | NO_x | CO | NMVOG | SO₂ |
|----------------|-----------------------|-----------|--------------|-----------------------|
| Heathrow | 23 | 19.52 | 4.22 | 1.48 |
| Gatwick | 28.2 | 17.28 | 6.6 | 1.04 |

(1) Source: UK NAEI, amended to show kg/LTO

(2) Sulphur content based on the UK Petroleum Industry Association (2000)

The emission factors presented in Table 4.2 indicate the disparity between Heathrow and Gatwick average emissions factors and those detailed for the Highlands and Islands aircraft in Table 4.1. The difference is striking between the larger Highlands and Islands aircraft as well as the smaller aircraft which are used more frequently.

In 2001, Heathrow had a total of 231,730 LTOs (at an approximate average NO_x emission rate of 23kg/LTO) compared to the Highlands and Islands 32,882 LTOs (at an inflated maximum emission rate of 1.54 kg per LTO). This represents 5,330 tonnes of NO_x generated through LTOs at Heathrow every year with only 51 tonnes, or <1% of the Heathrow total, being generated by the Highlands and Islands airports in total.

The number of UK LTOs for 2001 was 1,691,647 of which 32,882 were associated with the Highlands and Islands, using aircraft that emit substantially less pollutants per LTO. In this context emissions from the Highlands and Islands airports are insignificant.

The Scottish Highlands and Islands, due to the nature of the routes, use smaller classes of aircraft. As such, associated emissions are much smaller in magnitude, both in terms of total pollutant loadings, and average emissions per plane. This results in the relative contribution of these routes to the UK airline industry's total contribution to local air quality impacts being very small.

However, even these comparisons over emphasise the contribution of the Highlands and Islands airports to local air quality impacts. This is due to the existing good quality air in the region. The additional emissions from aircraft to the local environment have very little effect on the overall air quality health impacts. The quality of the air around airports in the southeast of England, such as Heathrow, is dominated by emissions from road vehicles as well as aircraft. The resulting air quality in these areas is in breach of national standards for local air quality and on occasions, these events may cause significant health impacts in exposed populations.

The environmental noise impact of air travel is generally taken to be limited geographically to areas around the airports at either end of a given journey. Noise can have effects far from airports, in particular degrading tranquil areas, but these are not generally quantified or used in comparative aircraft noise studies. Conventionally aircraft noise is assessed in terms of the average noise levels throughout the day ($L_{Aeq, 0700 \text{ to } 2300 \text{ hours}}$) and night ($L_{Aeq, 2300 \text{ to } 0700 \text{ hours}}$).

Much research has been done on the effects of aircraft noise over the past four decades and whilst various indicators of impact have been studied, it is the relationship between $L_{Aeq, \text{period}}$ noise levels community noise annoyance that has gained popularity for the assessment of aircraft noise impacts around airports in the UK and across Europe. The level of low noise annoyance can be taken (from English and Scottish planning guidance, PPG24 and PAN56 respectively) at a level of 57 dB $L_{Aeq, 0700 \text{ to } 2300 \text{ hours}}$. Thus, for many years now a routine way of assessing zone of noise impact around an airport has been to model aircraft noise so as to plot noise contours and to count populations within the 57 dB band. Some examples of populations affected by noise in this way are given in *Table 4.3*.

Table 4.3 *Populations Affected by Noise At Selected UK Airports*

| Airport | Population within $L_{Aeq, 16 \text{ hour}}$ 57 dB Contour | Year |
|-----------------|---|------|
| London Heathrow | 307,000 ^a | 2000 |
| London Stansted | 6,000 ^a | 2000 |
| Newcastle | 1,200 ^b | 1999 |
| Edinburgh | 4,400 ^b | 1999 |
| Glasgow | 25,000 ^b | 1999 |
| Aberdeen | 9,900 ^b | 1999 |
| Inverness | 0 ^b | 1999 |

Source:
a - South East Regional Airports Study (SERAS)
b - DfT, 2002, Regional Air Services Co-ordination Study (RASCO)

The extent of community annoyance (the Estimated Population Annoyed) is also used in the UK government's Guidance on Methodologies for Multi-Modal Studies (GOMMMS).

Across the UK most regional airports have carried out noise modelling studies. Indeed under the new EC Directive on the Assessment and Management of Environmental Noise all airports with over 50,000 movements per year are now required to carry out such studies. As far as we are aware no comparable figures are available for any of the Highlands and Islands Airports because noise-modelling studies have never been undertaken. This is presumably because the level of public concern has not required it, given the low population density in the region and Scotland as a whole compared to the rest of the UK and the EU (*see Table 4.4*).

Table 4.4 *Population Densities*

| Region/Sub-region | 1000 inhabitants 2001 | Population density per sq km 2001 |
|-----------------------------|-----------------------------|--------------------------------------|
| EU | 377,508 | 118.3 |
| UK | 58,789 | 243.2 |
| Scotland | 5,064 | 65.0 |
| The Scottish Borders | 109 | 23.0 |
| Dumfries and Galloway | 148 | 23.0 |
| Angus | 109 | 50.0 |
| Argyll and Bute | 90 | 13.0 |
| Midlothian | 81 | 229.0 |
| Eilean Siar (Western Isles) | 28 | 9.0 |
| Orkney Islands | 19 | 19.0 |
| Shetland Islands | 22 | 15.0 |
| Highland | 205 | 8.0 |

Source: Office for National Statistics, General Register for Scotland.

Using the population annoyed indicator it is apparent that the Highlands and Islands Airports have low noise impacts compared to many UK airports simply because they are in lesser populated area. However, this can be considered in a little more detail by analysing the two main dimensions of the issue:

- 1) how noisy are the airports?
- 2) how many people live around each airport?

The level of aircraft noise (strictly speaking ‘air noise’) produced by an airport is a function of the types and numbers of aircraft. It is beyond the scope of this study to consider this in detail. Indeed modelling noise in detail is a complex time consuming task. However, both the types of aircraft and their numbers indicate that all the Highlands and Islands Airports produce relatively low levels of noise. Aircraft size is restricted by runway length and demand, so that few jets operate, except from Inverness. Smaller, turboprop aircraft tend to be quieter. Numbers of aircraft are small due primarily to demand but also runway and air services capacity.

Whilst to some extent airports attract development including housing near them, this is true of all airports and these figures demonstrate quite clearly that the numbers of people living near the Highlands and Islands Airports are considerably lower than those around typical UK regional airports.

5.1 COST OF TOTAL CLIMATIC CHANGE - INDUCING EMISSIONS

Table 5.1 shows that the total cost of the region's climatic impact, estimated at £2,488,572 is equivalent to two hundred long-haul 747 flights (covering a distance of 3,724 nautical miles) estimated to represent a cost of £12,534 each.

The climatic impact of aviation in the region is presented in Table 5.2, for each route, in the standard unit of tC, and as a financial cost, based on an illustrative cost of £73 per tC described in Section 3.1.4.

As can be expected from the higher RFIs and the long distances, the routes with the highest climatic impact, and therefore associated cost to society, are the longer-haul flights to and from non-Scottish airports. These are highlighted in the table.

The difference is striking when comparing the total impact for all UK flights and that of routes concentrated within Scotland. This impact is reflected in the average cost per passenger shown in the last column, which varies from 35 pence per passenger for a flight from Stornoway to Benbecula to £7.50 per passenger for the Inverness to Gatwick BA CitiExpress flight.

Table 5.1 *Cost of Climate Change Impact in the Highlands and Islands, per year*

| Route | Total CO ₂ emissions per year (t) | Total climate impact per year (tC) | Climate change cost (based on a cost of £73 per tonne) |
|-----------------------------------|--|------------------------------------|--|
| Total H&I - Scotland only | 21,558 | 5,880 | £429,205 |
| Total H&I - all UK flights | 62,478 | 34,090 | £2,488,572 |
| Weighted average - Scotland only | 1,228 | 335 | £24,451 |
| Weighted average - all UK flights | 3,598 | 2,080 | £151,857 |

Table 5.2 Cost of Climate Change Impact in the Highlands and Islands, per passenger

| Route | Frequency (number of single flights per year) | Climate cost per passenger journey |
|--|--|---|
| BA CitiExpress | | |
| Benbecula Glasgow | 648 | 1.17 |
| Inverness Gatwick | 2,190 | 7.50 |
| Stornoway Glasgow | 1,148 | 1.00 |
| Sumburgh Aberdeen | 1,982 | 1.14 |
| Bmi | | |
| Stornoway - Edinburgh | 730 | 0.78 |
| Eastern Airways | | |
| Wick Aberdeen | 1,043 | 1.39 |
| Inverness Manchester | 1,564 | 1.86 |
| EasyJet | | |
| Inverness Luton | 938 | 4.18 |
| Inverness Gatwick | 730 | 4.27 |
| Highland Airways | | |
| Stornoway Benbecula | 1043 | 0.35 |
| Loganair | | |
| Glasgow Campbeltown | 984 | 0.96 |
| Glasgow Tiree | 608 | 1.39 |
| Glasgow Barra | 622 | 1.79 |
| Glasgow Islay | 1120 | 0.92 |
| Benbecula Barra | 468 | 0.90 |
| Glasgow Inverness Kirkwall Sumburgh | 724 | 2.97 |
| Glasgow Inverness | 750 | 1.24 |
| Kirkwall Inverness Edinburgh | 724 | 2.32 |
| Edinburgh Inverness Stornoway | 516 | 0.86 |
| Edinburgh Wick Kirkwall | 620 | 2.47 |
| Stornoway Inverness Stornoway | 724 | 0.82 |
| Edinburgh Stornoway | 208 | 1.83 |
| Edinburgh Sumburgh | 724 | 1.90 |
| Aberdeen Kirkwall | 1,938 | 0.93 |
| Orkney internal | 1,665 | 0.67 |
| Shetland internal | 1,018 | 1.02 |
| Total H&I - Scotland only | 20,007 | N/a |
| Total H&I - all UK flights | 25,429 | N/a |
| Weighted average - Scotland only | 909* | £1.19 |
| Weighted average - all UK flights | 978* | £3.37 |

**simple average*

NB: all data in this table are rounded to whole numbers

5.2 COST OF LOCAL AIR QUALITY IMPACT

In monetary terms the environmental cost of the Highlands and Islands airports impact on local air quality is between £504,000 and £1,008,000 per year approximately. This represents approximately 0.6 % of the external LAQ cost of aviation for the UK as a whole, estimated at £82-163 million ⁽¹⁾.

(1) Using the conversion rate of 11/07/2003 of: 1€ = £0.69

These calculations are based on external LAQ costs of aviation varying between €1 to €2 (£0.69p to £1.38p) per passenger, an approach developed by CE Delft of measuring total external costs of air pollution from aviation and described in the reference CE Delft study, *External Costs of Aviation* ⁽¹⁾. The study sets out all the emissions of importance from a local air quality perspective and the range of health and environmental impacts.

Table 5.3 shows the basis of the LAQ cost calculation for the Highlands and Islands region, and the estimated value for each group of routes.

Table 5.3 *External LAQ cost of aviation in the Highlands and Islands, using the CE Delft approach*

| Route | Cost range | |
|---|-----------------|-------------------|
| | £0.69 | £1.38 |
| Scotland Internal Routes | | |
| Aberdeen to Sumburgh, Wick & Kirkwall | | |
| Glasgow to Campbeltown, Tiree, Barra, Islay, Inverness, Kirkwall, Sumburgh, Stornoway & Benbecula | | |
| Edinburgh to Inverness, Stornoway, Wick, Kirkwall & Sumburgh | | |
| Stornoway Benbecula | | |
| Benbecula Barra Benbecula | | |
| Stornoway Inverness Stornoway | | |
| Orkney internal | | |
| Shetland internal | | |
| Sub Total | £249,866 | £499,732 |
| UK Wide Routes | | |
| Inverness to Gatwick Manchester & Luton | | |
| Sub Total | £254,088 | £508,176 |
| Total H&I - Scotland only | £249,866 | £499,732 |
| Total H&I - all UK flights | £503,954 | £1,007,907 |

5.3 COST OF LOCAL NOISE IMPACT

As shown in Section 4, Table 4.3 shows that there are no people living within the 57 dB noise contour around Inverness Airport. Given the population densities in the Highlands and Islands region, coupled with the low frequency and type of aircraft flights this is perhaps not surprising.

Consequently, it is probably reasonable to assume that there would be very few people living within the 57 dB contour around any of the other Highlands and Islands airports. It is considered that there is little merit in calculating the cost of noise pollution in the Highlands and Islands using the 'hedonic pricing' technique as there are likely to be so few persons affected. Hence the environmental noise impact of each of the Highlands and Islands Airports is considered to be far lower than a typical UK regional airport and any taxation system proposed based on the polluter pays principal should take this into account.

(1) External Costs of Aviation, February 2002, CE Delft available on www.cedelft.nl