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A Comparative Study of the Environmental Effects of Rail and Short-haul Air Travel

A report produced for Commission for Integrated Transport

September 2001

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Executive Summary

This report, undertaken by AEA Technology Environment in collaboration with AEA Technology Rail and the Civil Aviation Authority, analyses the comparative environmental burdens of high-speed rail and short-haul air travel for regional domestic journeys.

The study has set out to compare the two modes for specific journeys from London to Manchester, Leeds, Newcastle, Edinburgh and Glasgow – the main domestic flight routes in Great Britain . The study has assessed the current environmental burdens for each route, per passenger carried, based on average load factors (33% average seat occupancy for rail routes, and typically 65-75% for air routes). It has also considered how these environmental burdens will change in future years as a result of planned upgrades and fleet changes (though future changes in average load factors have not been considered). The conclusions of the comparison are summarised below by category.

Greenhouse Gas Emissions

- ***Short-haul air journeys have higher CO_2 emissions, per passenger km, than high-speed rail.***

Domestic aircraft have CO_2 emissions per passenger km that are many times higher that of high-speed rail. Domestic aircraft have emissions of 200-300 gCO_2/passenger km compared to around 40gCO_2/passenger km for high-speed rail. The CO_2 emissions from aircraft landing and take-off are the same irrespective of journey distance and this increases the emissions per passenger km for shorter aircraft trips, i.e. from London to Leeds and Manchester. Higher altitude emissions of NO_x and VOCs from aircraft have not been considered, though these may further increase the greenhouse gas emissions per passenger km for domestic air journeys.

Other Atmospheric Emissions

The comparison of the other main atmospheric pollutants (SO_2, NO_x, CO, PM_{10} and VOCs) shows that the two modes have different emissions of different pollutants. In summary:

- ***High-speed rail journeys have higher emissions of SO_2, per passenger km, than domestic air.***

High SO_2 emissions from the UK electricity generating mix (from coal fired generation) result in higher SO_2 emissions for high-speed electric trains than for domestic aircraft. SO_2 emissions from high-speed trains are likely to fall significantly in future years due to changes in the future electricity generating mix, and in the medium term (by 2020) high-speed rail and domestic aircraft will have similar emissions per passenger km (assuming no changes in future load factors).

- ***Domestic Aircraft have higher emissions of ground level CO, NO_x and VOCs, per passenger km, than high-speed rail.***

The emissions from domestic aircraft, per passenger km, are highest on shorter trips, because of the emissions from take-off and landing. There was one exception to this. One rail route (London-Edinburgh) currently has a high proportion of high-speed diesel trains. These diesel trains have much higher emissions per km than high-speed electric trains. This increases the average emissions per passenger km for this route, so that emissions are greater than for the equivalent air journey. The diesel trains on this route will be phased out in the next few years. This finding is important as it shows there is a large difference according to train traction type (especially if looking to increase overall services of high-speed trains). Future emissions (beyond 2006) of CO, NO_x and VOCs per passenger km are likely to be even lower for high-speed electric trains relative to aircraft, as changes in the electricity generation mix lead to greater emissions reductions than occur from modern aircraft entering the fleet.

- ***Emissions of PM_{10}, per passenger km, are broadly similar for both modes.***

The relative emissions of PM_{10}, per passenger km, vary on different routes because of different aircraft and trains in use. Electric high-speed trains have slightly lower emissions of PM_{10}, per passenger km than aircraft. However, high-speed diesel trains have very high emissions of PM_{10}, and so domestic aircraft have lower PM_{10} emissions than for the ECML, which still has a proportion of diesel locomotives. The diesel trains on this route will be phased out in the next few years.

The emissions of PM_{10} from both modes are likely to fall in future years (2006 and beyond), due to reductions in the emissions from the electricity generation mix for rail and from modern aircraft entering the air fleet. In the medium term (by 2020) it is likely that PM_{10} emissions per passenger km will be slightly lower for high-speed rail compared to domestic aircraft. These benefits will be greatest on shorter trips (i.e. London to Leeds/ Manchester).

The relative balance of different pollutants from the two modes makes it difficult to conclude which has the lower burden for atmospheric emissions (which affect local and regional air quality). To make this judgement, the relative *impacts* of high-speed train and domestic air travel must be assessed, rather than the *burdens* (e.g. emissions) assessed here. We highlight this as a research priority from the current study.

- ***Emissions from surface access may be important***

The study has also investigated emissions from surface access trips to airports and railway stations. It is clear that the choice of surface access mode is extremely important in the relative comparison of high-speed rail and domestic aircraft. For longer surface access trips by car, the emissions of most pollutants (especially CO, NOx and VOCs) can be as large as the emissions from the regional journey itself. The reduction in car use for surface access is therefore a priority in reducing overall burdens from both modes. The inclusion of surface access emissions could change the comparison significantly. It is stressed that both short-haul air travel and high-speed rail have major emission advantages over road transport for domestic regional journeys (i.e. from London to the five cities).

For journeys from city centre to city centre, there will be additional surface emissions from short-haul aircraft, because of the location of the airports considered which are outside urban areas. Some data are available on surface access mode for passengers travelling to airports. This indicates that whilst the proportion of travellers using public transport is improving, the majority of surface access to regional airports, and approximately two-thirds of access to London airports, is by car. Data on surface access mode for passengers travelling to railway stations is available, however, data for passengers making specific high-speed rail journeys is not. The railway stations of interest for this study (Kings Cross and Euston) are located in central London and the proportion of surface access journeys by car are likely to be low. The lack of data means it is not possible to assess in detail surface access emissions for high-speed rail and domestic aircraft, though the indications are that surface access emissions are likely to favour rail over air. In addition surface access emissions are more important (i.e. have higher emissions as a proportion of the total) on shorter trips from London to Manchester and Leeds.

It is more difficult to compare surface access trips for a journey which starts and ends outside city centres, e.g. for a passenger travelling on a journey from the south-east to a regional destination (or vice versa). Emissions will vary with the length of surface access journey. No data are available on typical access distances for the two modes, nor on the access mode for rail. It is likely that the larger numbers of airports in the south-east would reduce journey distance (for each regional rail journey, there is only one London station, but potentially five London airports) though there is a higher probability that surface access to the airport will be by car. The lack of data means it is not possible to include these emissions in the comparison. Surface access mode is also likely to vary according with the direction of travel and the starting point of the individual's journey. Further analysis of surface access emissions is highlighted as warranting research.

Noise

Aircraft and railway noise are usually measured using slightly different noise metrics, though both use some form of equivalent continuous sound level (L_{eq}) during a defined time period. A number of difficulties arise when using L_{eq} to compare noise from one mode of transport with another. To get round these, the approach taken in this study has been to look at the number of people exposed to a given sound exposure level (SEL) per passenger carried. The study has used this approach to compare the noise burden for all the specific routes (London to the five cities), comparing high-speed trains and domestic aircraft. For London, trips from Heathrow, Gatwick and Stansted airports were considered. The study has also investigated the specific noise burden for additional trains or planes along one route (from London to Manchester), taking into account the existing noise levels from all other transport activity, to assess the marginal noise burden from the two modes. The conclusions are:

- The SEL evaluation shows that high-speed rail generally has a higher population weighted noise burden than domestic air, per passenger carried (assuming average occupancy factors), when no screening effects of buildings adjacent to the track are taken into account. The relative burdens between domestic aircraft and high-speed rail are closer if screening effects from buildings are added for the rail analysis.

- The noise burden from the five different high-speed rail trips do not show a strong correlation with journey length which is contrary to what might be expected , showing the very site-specific nature of noise for individual routes.

- The aircraft noise burden is independent of distance and depends on site-specific factors at each airport. The results show that the same aircraft may have significantly different noise burdens (measured in terms of the number of people affected by a certain noise level) for take-off/landing at different airports or even from different runways at the same airport.

- Older aircraft (e.g. 737-200) have much a higher noise burden. The removal of these aircraft from the fleet will reduce the noise burden in future years (i.e. for the period 2006-2020). Nonetheless, there will remain large differences (up to an order of magnitude) in the noise burdens of different aircraft in the remaining.

- Smaller aircraft generally have a lower noise burden (per passenger carried), due to the smaller size of their noise footprint.

- The analysis of future noise levels indicates that changes will occur in the relative comparison between high-speed rail and domestic air. In general, the noise burdens on high-speed rail routes will increase slightly as trains travel at higher speeds after line upgrades (with the exception of the London-Manchester-route, which sees very large reductions due to the phasing out of older vehicles). These changes do not take account of possible changes in passenger occupancy. In contrast, the future noise burdens from domestic aircraft will decrease (per journey) at most airports, as older aircraft are retired. For some airports, e.g. Glasgow and Gatwick, these decreases will be significant and will dramatically reduce the future noise burden for domestic aircraft (per journey).

Although the SEL analysis provides an indication of the sound exposure from a single high-speed rail or domestic aircraft journey, it is also important to evaluate the burden in the context of other noise sources for each route. This involves taking into account all train activity along a rail route or all international and domestic landings/take-offs at any airport. This is a more involved analysis and has been undertaken for one route (London to Manchester) for both modes. The analysis has looked at the increase in noise burdens from additional journeys for a thousand additional seats for both modes. For high-speed rail this involved two additional trains. For domestic air, the study assessed the difference for additional capacity provided by additional planes and by using larger aircraft.

The comparison between domestic aircraft and high-speed rail shows that, in both cases, the additional noise burden is similar per available seat and, after adjustments, per actual passenger carried. This is in sharp contrast to the SEL analysis (which showed much higher noise burdens for high-speed rail for the same route) and shows that marginal noise burdens from the two modes will be determined by prevailing levels and site characteristics for each route. It is not possible to make a clear statement as to whether one mode has a noise advantage without a more detailed analysis of all routes.

A closer analysis of domestic aircraft shows that the marginal noise burden changes according to the way capacity is added (or removed), so that there are different changes in noise burdens from adding capacity by running more services compared to increasing aircraft size. For example, increasing the number of movements leads to lower increased noise burdens than increasing aircraft size. This reflects the fact that smaller aircraft have smaller noise footprints. Similarly, decreasing the size of aircraft leads to a greater reduction in noise exposure than decreasing the number of movements. When expressed in terms of the additional noise burden per passenger carried, it is also clear that marginal noise burdens will be strongly non-linear (i.e. the burden per additional passenger varies non-linearly according to the overall change in movements or aircraft). This is very important with respect to potential substitution between modes.

Overall, the noise burden, for both existing and additional journeys, is extremely site and route specific. The results here indicate that aircraft in use on domestic routes may have a small advantage in terms of the absolute noise burden. We stress, however, that this does not translate to a lower noise impact because background noise levels determine the relative burden of a regional journey (due to the logarithmic nature of noise). Our conclusion is that without more detailed analysis, on a route by route basis, it is not possible to say categorically that one mode has a lower noise burden than the other. A number of research areas have also been identified.

Land-Take

Land-take does have a number of potential environmental impacts, e.g. habitat loss, fragmentation, community severance. An initial analysis shows that aviation requires less land than rail transport. However, it is difficult to separate out the specific land-take for regional journeys against the background of overall transport activity. This means it is not possible to compare the relative land-take for high-speed rail and domestic air. The issue will be important if additional land is required in order to meet any potential capacity increases for either mode. This is a subject highlighted as a priority for investigation should a second phase of the study be undertaken.

Other Effects

A summary of other potential environmental effects from rail and air has been undertaken. None of these other effects change the relative environmental comparison between.

Research Recommendations

A number of research priorities have been identified in the study. The most important of these are:

- To compare the environmental *impacts* of atmospheric emissions from domestic aircraft and high-speed trains, assessing the different locations of various emissions (and effects on receptors) and the relative damage of different pollutants (i.e. the impacts of SO_2 compared to say the impacts of NOx). One way to undertake this comparison would be through the analysis of external costs.
- To investigate surface access emissions from the two modes in more detail.

- To carry out further assessment of the noise burdens and impacts of the two modes. This includes assessing whether the use of different noise thresholds might change the relative comparison, as well further marginal analysis for other routes. Such an analysis is needed to determine conclusively if one mode has a noise advantage over the other.

Contents

1 Introduction

Increasing recognition of the environmental effects of transport, combined with government commitments to reduce greenhouse gas emissions, to improve local air quality, and to assess environmental noise, have placed greater emphasis on sustainable transport.

These concerns, together with the predicted growth in air transport over the next 20 years, have stimulated debate on the relative environmental effects of domestic air transport compared to regional high-speed train journeys[1].

This study, which was commissioned by the Commission for Integrated Transport (CfiT), aims to assess the relative environmental burdens of short-haul air travel and high-speed rail journeys for comparative domestic journeys in the UK.

The report is presented as follows.

- Chapter 2 sets out the outline to the study and details the approach.
- Chapter 3 quantifies the atmospheric emissions from rail and short-haul air transport.
- Chapter 4 assesses the relative noise levels from rail and aircraft.
- Chapter 5 compares the relative land-use from rail and aviation and assesses other environmental effects
- Chapter 6 summarises the conclusions and research recommendations.

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[1] As air transport is the only option for long-haul trips.

2 Study Outline and Approach

This study assesses the relative environmental burdens of domestic air travel from London airports to the major regional airports in the UK, and compares these to the environmental burdens of equivalent high-speed rail journeys. The study has set out to be comprehensive, using a consistent approach for all routes, whilst looking at the specific technologies in use on each route for current and future years.

A number of sensitivities have also been investigated to assess if different assumptions alter the relative environmental burden of the two modes. By doing so, we hope to provide an evaluation that is free from bias, that is independent, and that can be used to help inform the debate on the relative environmental performance of different modes for domestic journeys in the UK.

2.1 Routes

The project has compared five specific routes:

- London – Manchester;
- London – Newcastle;
- London – Glasgow;
- London – Edinburgh;
- London – Leeds.

For rail, the evaluation centres on the East Coast and West Coast Main Lines (ECML and WCML). The routes and train operating companies considered are presented in Table 1.

Table 1. Routes and Operators – Rail.

Route	Line	Operator
Euston - **Manchester**	WCML	Virgin West Coast
Euston - Carlisle/**Glasgow**	WCML	Virgin West Coast
Kings Cross - York – **Newcastle** - **Edinburgh** – (Glasgow Central)	ECML	GNER
Kings Cross – Peterborough - Doncaster - **Leeds**	ECML	GNER

The predominant trains used on these lines and their passenger capacities are shown below.

ECML

Edinburgh	Class 91 (electric locomotive) + 9 Mk 4 (coaches) + DVT[2]	526 seats
Newcastle	Class 91 + 9 Mk 4 + DVT	526 seats
Leeds	Class 91 + 9 Mk 4 + DVT	526 seats

WCML

Glasgow	Class 90 + 8 Mk 3 + DVT	494 seats
Manchester	Class 87 + 7 Mk 2 + 1 Mk 3 Buffet + DVT	520 seats

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[2] DVT=Driving Van Trailer vehicle, i.e. non-powered vehicle with driving cab, at the opposite end of the train from the locomotive.

All these trains use electric traction. However, a small number of high-speed diesel trains are still used on the ECML for these specific journeys. The emissions from diesel trains are included in the current analysis. An analysis with electric trains only is also presented, as the diesel trains on these routes will be phased out on these routes in the next few years (before 2006).

The study has also considered planned upgrades and changes to rolling stock in future years. For the lines considered, the following trains are likely to run from 2006 to 2020.

ECML

• Edinburgh	Class 91 + 9 Mk 4 + DVT (capable of 225 km/h)	526 seats
• Newcastle	Class 91 + 9 Mk 4 + DVT	526 seats
• Leeds	Class 91 + 9 Mk 4 + DVT	526 seats

WCML

• Glasgow	Class 390 Pendolino Britannico	470 seats
• Manchester	Class 390 Pendolino Britannico	470 seats

In the absence of detailed route data, it has been assumed that all trains, on all routes, have an average load factor equal to a 33% average seat occupancy (SRA, 2001). Possible changes in passenger occupancy in future years, as might be expected from implementation of the Government's 10 year transport plan (which include a target for an 80% increase in patronage on inter-city lines) have not been taken into account.

The numbers of trains running each day are shown in Table 2.

Table 2. Daily Rail Journeys for Domestic Routes.

ECML			**WCML**		
Edinburgh	40	(22N bound/18S)	Manchester	40	(20 each way)
Newcastle	57	(28N/29S)	Glasgow	17	(9 N bound/8S)
Leeds	39	(20N/19S)			

The study evaluates the same trips by domestic air travel. For London, the three major airports have been assessed – Heathrow, Gatwick and Stansted. A very large number of different aircraft are in use on these routes. The sensitivity of the results to different aircraft has been examined, though the results presented are for the main aircraft in use only. Data on aircraft and route occupancy are presented in Table 4 and 5.

The number of aircraft flying each year are shown in Table 3 (2000).

Table 3. Air Journeys for Domestic Routes.

	Heathrow	Gatwick	Stansted	Annual flights	Daily equivalent
Edinburgh	13262	3852	4659	21,773	60
Glasgow	13156	3895	1006	18,057	50
Leeds Bradford	2745	2	-	2,747	8
Manchester	12124	4774	1663	18,561	51
Newcastle	3868	3543	1200	8,611	24

Table 4. Domestic Aircraft and Load Factors (Present).

Current	Pass capacity	% of trips	Load Factor	Pass capacity	% of trips	Load Factor	Pass capacity	% of trips	Load Factor
	HEATHROW			**GATWICK**			**STANSTED**		
EDINBURGH									
Large twin-turboprop	50	-	-	50	-	-	50	12.0%	26.1
Avro RJ	95	-	-	95	-	-	95		
Fokker 100	106	0.1%	68.6	106	-	-	106		
Boeing 737-200	116	-	-	116	80.0%	79.1	116	2.6%	70.1
Boeing 737-300/400/500	128	23.9%	69.1	128	20.0%	79.1	128	85.4%	70.1
Airbus A319/320/321	149	20.4%	69.1	149	-	-	149		
Boeing 757-200	195	55.3%	69.4	195	-	-	195		
Boeing 767-300	252	0.4%	69.4	252	-	-	252		
AVERAGE	**170**		**69.3**	**118**		**79.1**	**118**		**64.8**
GLASGOW									
Large twin-turboprop	50	-	-	50	-	-	50	-	-
Avro RJ	95	-	-	95	-	-	95	-	-
Fokker 100	106	0.7%	68.2	106	-	-	106	-	-
Boeing 737-200	116	-	-	116	72.0%	75.9	116	-	-
Boeing 737-300/400/500	128	12.4%	65.8	128	28.0%	75.9	128	-	-
Airbus A319/320/321	149	42.9%	65.8	149	-	-	149	-	-
Boeing 757-200	195	43.7%	64.4	195	-	-	195	-	-
Boeing 767-300	252	0.3%	64.4	252	-	-	252	-	-
AVERAGE	**167**		**65.2**	**119**		**75.9**			
LEEDS									
Large twin-turboprop	50	-	-		-	-		-	-
Avro RJ	95	-	-		-	-		-	-
Fokker 100	106	11.0%	64.4		-	-		-	-
Boeing 737-200	116	-			-	-		-	-
Boeing 737-300/400/500	128	89.0%	64.4		-	-		-	-
Airbus A319/320/321	149	-	-		-	-		-	-
Boeing 757-200	195	-	-		-	-		-	-
Boeing 767-300	252	-	-		-	-		-	-
AVERAGE	**126**		**64.4**						
MANCHESTER									
Large twin-turboprop	50	-	-	50	-	-	50	94.8%	55.9
Avro RJ	95	-	-	95	-	-	95	5.2%	55.9
Fokker 100	106	2.6%	57.4	106	-	-	106		
Boeing 737-200	116	-	-	116	23.2%	78.7	116		
Boeing 737-300/400/500	128	36.9%	64.7	128	76.8%	78.7	128		
Airbus A319/320/321	149	21.5%	64.7	149	-	-	149		
Boeing 757-200	195	38.9%	68.7	195	-	-	195		
Boeing 767-300	252	0.1%	68.7	252	-	-	252		
AVERAGE	**158**		**66.1**	**125**		**78.7**	**52**		**55.9**
NEWCASTLE									
Large twin-turboprop	50			50	28.6%	68.3	50	100%	56.2
Avro RJ	95			95	71.4%	68.3	95		
Fokker 100	106	2.0%	69	106			106		
Boeing 737-200	116			116			116		
Boeing 737-300/400/500	128	6.3%	69	128			128		
Airbus A319/320/321	149	53.6%	69	149			149		
Boeing 757-200	195	37.5%	69	195			195		
Boeing 767-300	252	0.6%	69	252			252		
AVERAGE	**165**		**69.0**	**82**	**100%**	**68.3**	**50**		**56.2**

Table 5. Domestic Aircraft and Load Factors (Future).

2006-2020	Pass Capac.	% of trips	Load Factor	Pass Capac.	% of trips	Load Factor	Pass Capac.	% of trips	Load Factor
	HEATHROW			**GATWICK**			**STANSTED**		
EDINBURGH									
Large twin-turboprop	50	-	-	50	-	-	50	10.0%	26.1
Boeing 717-200	100	5.0%	68.6	100	5.0%	79.1	100	-	-
Boeing 737-300/400/500	128	10.0%	69.1	128	10.0%	79.1	128	70.0%	70.1
Boeing 737-600/700	135	5.0%	69.1	135	30.0%	79.1	135	10.0%	70.1
Boeing 737-700/800	170	4.6%	69.1	170	25.0%	79.1	170	-	-
Airbus A319/320/321	149	75.0%	69.1	149	30.0%	79.1	149	10.0%	70.1
Boeing 767-300	252	0.4%	69.4	252 -			252	-	-
AVERAGE	**145**	**100%**	**69.1**	**146**	**100%**	**79.1**	**123**	**100%**	**65.7**
GLASGOW									
Large twin-turboprop	50	-	-	50	-	-	50	-	-
Boeing 717-200	100	5.0%	68.2	100	-	-	100	-	-
Boeing 737-300/400/500	128	10.0%	65.8	128	45.0%	75.9	128	80.0%	70.0
Boeing 737-600/700	135	5.0%	65.8	135	5.0%	75.9	135	-	-
Boeing 737-700/800	170	5.0%	65.8	170	-	-	170	-	-
Airbus A319/320/321	149	74.7%	65.8	149	50.0%	75.9	149	20.0%	70.0
Boeing 767-300	252	0.3%	64.4	252	-	-	252	-	-
AVERAGE	**145**	**100%**	**65.9**	**139**	**100%**	**75.9**	**132**	**100%**	**70.0**
LEEDS									
Large twin-turboprop	50	-	-		-	-		-	-
Boeing 717-200	100	10.0%	64.4		-	-		-	-
Boeing 737-300/400/500	128	45.0%	64.4		-	-		-	-
Boeing 737-600/700	135	-	-		-	-		-	-
Boeing 737-700/800	170	-	-		-	-		-	-
Airbus A319/320/321	149	45.0%	64.4		-	-		-	-
Boeing 767-300	252	-	-		-	-		-	-
AVERAGE	**135**	**100%**							
MANCHESTER									
Large twin-turboprop	50	-	-	50	-	-	50	90.0%	55.9
Boeing 717-200	100	2.5%	57.4	100	-	-	100	10.0%	55.9
Boeing 737-300/400/500	128	15.0%	64.7	128	5.0%	78.7	128	-	-
Boeing 737-600/700	135	7.4%	64.7	135	5.0%	78.7	135	-	-
Boeing 737-700/800	170	-	-	170	-	-	170	-	-
Airbus A319/320/321	149	75.0%	64.7	149	90.0%	78.7	149	-	-
Boeing 767-300	252	0.1%	68.7	252	-	-	252	-	-
AVERAGE	**144**	**100%**		**147**	**100%**	**78.7**	**55**	**100%**	**55.9**
NEWCASTLE									
Large twin-turboprop	50	-	-	50	25.0%	68.3	50	100%	56.2
Boeing 717-200	100	2.5%	69	100	75.0%	68.3	100	-	-
Boeing 737-300/400/500	128	5.0%	69	128	-	-	128	-	-
Boeing 737-600/700	135	5.0%	69	135	-	-	135	-	-
Boeing 737-700/800	170	-	-	170	-	-	170	-	-
Airbus A319/320/321	149	86.9%	69	149	-	-	149	-	-
Boeing 767-300	252	0.6%	69	252	-	-	252	-	-
AVERAGE	**147**	**100%**		**88**	**100%**	**68.3**	**50**	**100%**	**56.2**

2.2 Study Remit and Boundaries

The remit of the current project, as set out in the invitation to tender document, was ‘To assess the relative environmental burdens of travel by rail and air from UK regions to London and its airports’. The main focus of the study was to assess the atmospheric emissions and the noise burdens of the two modes.

The study was constrained to environmental burdens alone – the remit did not extend to cover environmental impacts. To illustrate, *emissions* of local air pollutants such as NO_x are quantified (in grammes emitted), but the *impacts* these might have on local air pollution concentrations, the associated populated weighted pollution increases, and the possible health impacts, are not.

The study was constrained to assess environmental issues only. It did not aim to include practicability, safety, risk, market influences, costs or economic benefits of the two modes, and as such cannot present a comprehensive picture of overall benefits and dis-benefits between the two modes.

In order to investigate the study methodology, and to assess previous comparisons of the environmental effects of short-haul air and rail, a literature review was undertaken. The resulting approach was taken for the project (see Figure 1 below) – the specific analysis and methods are presented in the following chapters.

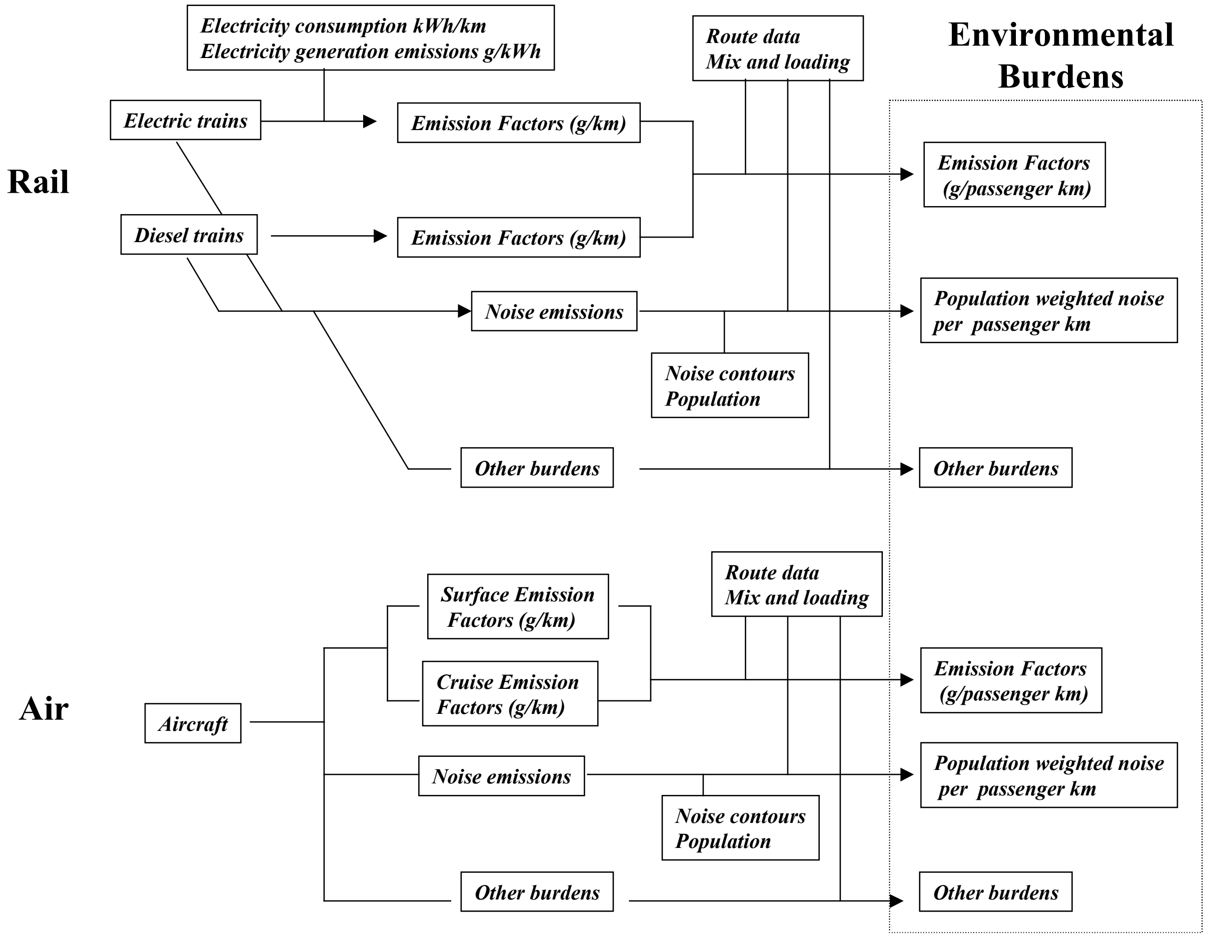

Figure 1. Study Approach and Tasks.

Both current and future environmental burdens of each mode are assessed, where possible expressed as the environmental burden per passenger journey or passenger km. The results are presented assuming ***average*** load factors (derived by estimating the total burden per vehicle for each route and then dividing by the average number of passengers and, for passenger km, by the journey length). It does not assess the specific marginal environmental burden for one additional train or aircraft. However, as well as the average analysis, the current study reports values for the environmental burdens per passenger km based on maximum occupancy (all available seats are used). These values provide the building blocks for marginal analysis, should this be required, e.g. looking at marginal increases in load factors, or additional capacity.

This point is particularly important when looking at potential substitution between modes. It is mis-leading to use the average values to assess the environmental benefits of any modal switch – the exact nature of the marginal change and the associated increase or decrease in occupancy needs to be assessed separately to properly assess substitution. Such an assessment falls within a follow-up phase to the study (phase II). The remit of phase II as set out in the invitation to tender was 'To assess measures for encouraging modal switch and the implications (economic, social and environmental) of such substitution'. This phase was only to be undertaken if one mode had an environmental advantage over the other.

The distinction between the two phases of the study is important. Even if this study shows that one mode has an environmental advantage, we do not seek to make recommendations that substitution should occur. In order to make these judgements, further analysis is needed to see what measures could be put in place, what their effects would be, possible capacity issues, and if such a policy might lead to other economic, social or environmental issues.

3 Atmospheric Emissions

This chapter compares the atmospheric emissions for high-speed rail and short-haul air travel. The study has sought to quantify all major pollutants, including both greenhouse gas emissions and most of the regulated pollutants included in the UK's National Air Quality Strategy. The pollutants considered are:

- CO_2
- NO_x
- CO
- NMVOC
- SO_2
- Particulates (PM_{10})

The study has sought to be as comprehensive as possible. Data has therefore been taken from consistent emission factor databases. The analysis has been undertaken for current and future years. The study has also considered how sensitive the results are to a number of assumptions, and where important, these have been fed through to the overall study conclusions.

3.1 Estimating Emissions from High-Speed Rail

Domestic high-speed journeys from London to regional cities are predominately undertaken by electric trains. The emissions from these trains depend on two parameters - the energy consumption for the train and the emissions from the electricity generated to power the train.

Energy consumption varies along individual sections of track and with different journey conditions, depending on whether there is dedicated or conventional electric track, according to train speed, track gradient, etc.

Trying to estimate average electricity consumption values for different train types along each of the East Coast and West Coast line would be an extremely time consuming process, and the data needed to do this is not available. For this study, *estimated* data on average electricity consumption for each of the high-speed routes has been used and combined with average electricity generation emissions. Further work to derive specific electricity consumption factors for high-speed trains is highlighted to improve the accuracy of the results.

Emissions for electricity production were taken from the National Atmospheric Emissions Inventory (NAEI), run by AEA Technology Environment for the DETR (Salway et al, 2000). Electricity generation emissions will vary significantly with the exact type of generation plant used for generation supply. For this study, we have assumed electricity is supplied from the national grid, and have used emissions based on the average electricity generation mix (based on 1999 data).

The estimated energy consumption per km, and therefore the emissions per km for high-speed electric trains, is similar for all five routes (London – Manchester, Leeds, Newcastle, Edinburgh and Glasgow), shown in Figure 2.

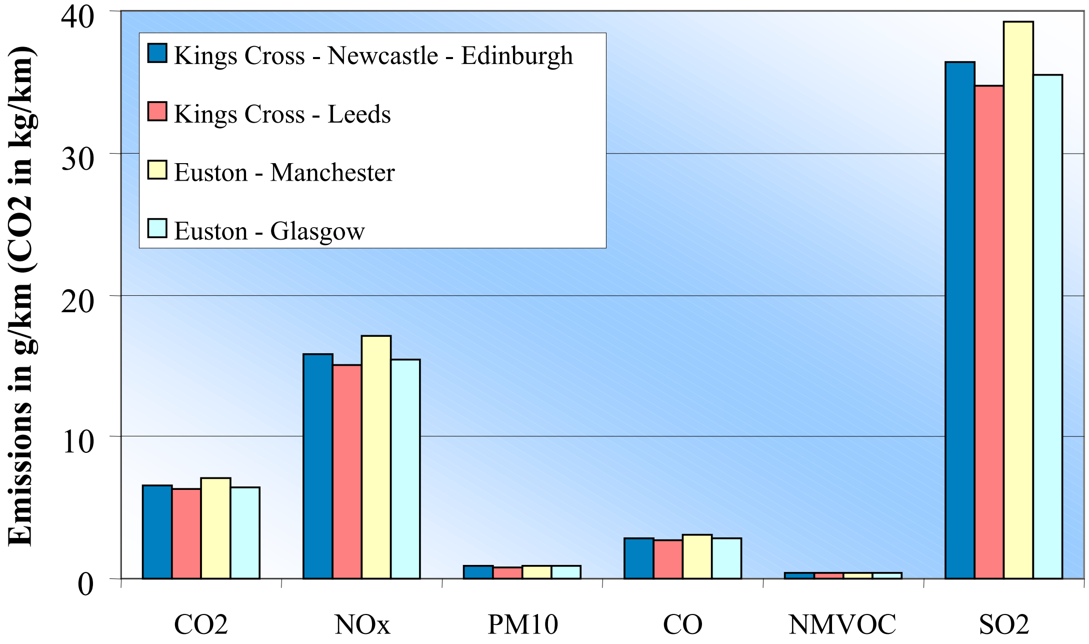

Figure 2. Estimated Emissions from Regional High-Speed Electric Train Journeys.

The estimated electricity consumption per km for the high-speed UK routes (shown above) are slightly lower than for European high-speed lines. The estimated values on the ECML and WCML are around 15 kWh/km, compared to values for TGV/ICE trains of around 20 kWh/km (see Appendix 1 for more details). Further investigation of actual energy consumption for specific UK high-speed routes is needed to confirm these differences. It is stressed that the values presented in this report are specific to the UK. They should not be used to evaluate the potential environmental effects of Eurostar trains or high-speed train journeys into and through Europe, as the electricity generation mix will change the emissions from electric trains in each country.

The planned upgrades on the WCML (with speeds increasing from 200 km/hour up to 225km/hour) may increase emissions slightly in future years. However, much greater differences will occur in emissions due to changes in the future electricity generation mix (discussed in a later section).

Of course the surface level emissions for the different rail journeys will increase in proportion to distance (note, however, that the same is not true for surface emissions from aircraft). This can be seen in Figure 3, which shows total emissions for high-speed journeys to the five cities.

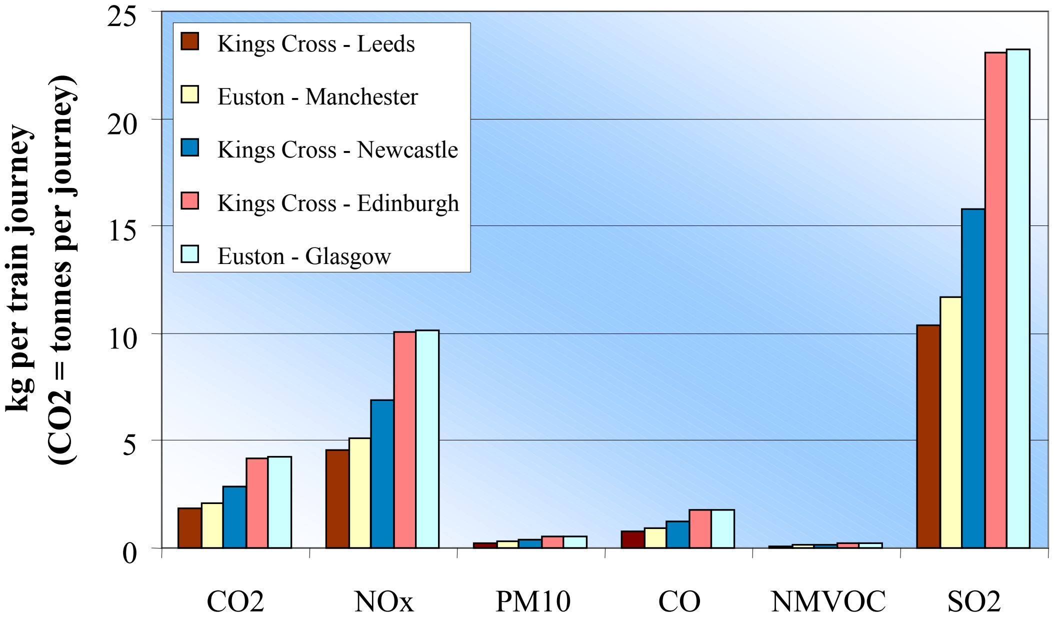

Figure 3. Emissions per Train Journey (High-Speed Electric Traction).

3.1.1 Diesel High Speed Trains

Electric traction is the primary power source for high-speed regional travel. All the direct WCML trips (London to Manchester and Glasgow) are by electric high-speed train. However, a number of direct regional journeys on the ECML are by diesel high-speed trains (InterCity 125s). The proportion of diesel trains for weekday direct services are:

- Edinburgh 22.5 % diesel;
- Newcastle 15.7 % diesel;
- Leeds 5.1% diesel.

The current emissions for the ECML journeys have therefore been adjusted to account for these diesel high-speed trains. As with electric traction, emissions from diesel trains vary with speed, line gradient, loading, acceleration and deceleration cycles, stops, etc. For the analysis here, average emission factors have been used. Data is taken from the diesel locomotive emission factors included in the UK National Atmospheric Emissions Inventory (Salway et al, 1999). These are consistent with the values included in the UK emissions factor database (LRC, 1998).

The emissions from an InterCity 125 train (assuming two power cars per train) against those of a high-speed electric train are shown in Figure 4[3]. The comparison shows that diesel trains have much higher emissions of all pollutants (except SO_2) than electric trains. SO_2 emissions from electric trains will decline sharply in future years as the electricity generation mix changes. Indeed, with the exception of SO_2 and CO_2, diesel trains have emissions almost an

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[3] There will be also differences in the noise from the two train types. However, at high speed the dominant source is wheel/rail noise, so there is less difference between diesel and electric vehicles. At low speeds diesels can be substantially noisier especially when applying power, though modern high-power electric traction equipment requires a lot of cooling. This can also lead to high levels of fan noise (transformers and traction motors) at low speed (e.g. such as the Eurostar and Class 91 locomotives).

order of magnitude greater than for electric high-speed journeys. There therefore needs to be a clear distinction between the type of trains used for regional high-speed trips

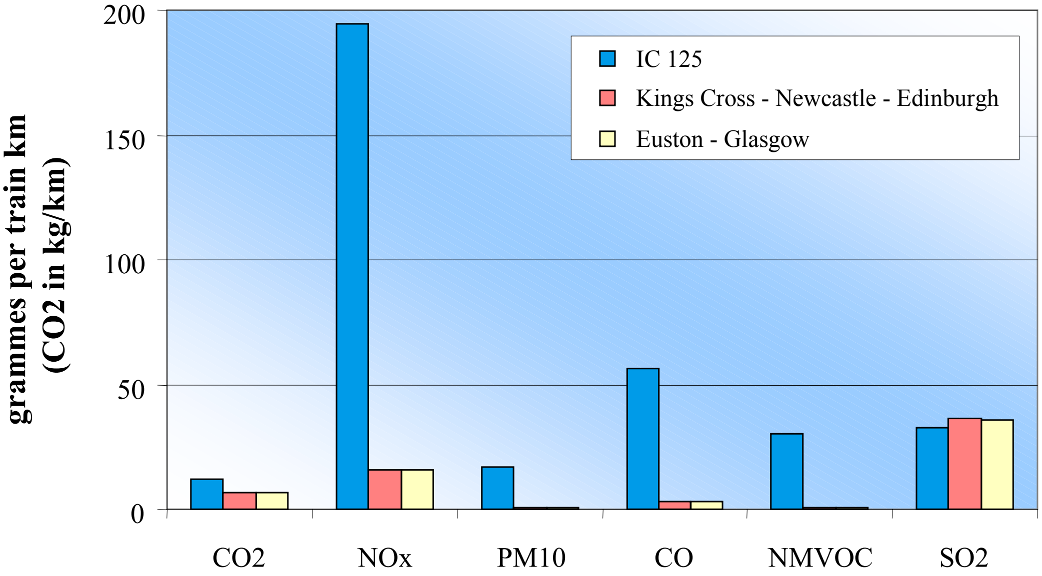

Figure 4. Comparison of Diesel and Electric Trains.

The above comparison is also important if policies are introduced to encourage regional rail travel – one way train operators might respond is to run additional diesel high speed stock. The analysis here shows that this would have a detrimental effect on the relative environmental performance of high-speed rail relative to domestic air.

In the results at the end of this chapter, the average emissions presented for the EMCL are the weighted-average of electric and diesel train emissions. This has the effect of significantly increasing emissions along the London – Edinburgh route, as the proportion of diesel stock run is relatively high. However, as diesel trains will be phased out on these specific high-speed routes in the next few years (i.e. before 2006), the values for high-speed electric trains on the ECML have also been presented separately as a sensitivity analysis.

3.1.2 Changes in the Electricity Generation Mix

The emissions from electric trains will vary with the electricity generation mix. These emissions will vary in future years as the electricity generation mix changes. They could also change if operators made a deliberate decision to switch to renewable energy .

Electricity generated by renewable energy has lower emissions than from the average generating mix. The exact emissions will vary with the renewable technologies included. Renewable energy sources traditionally include wind, solar, hydro (large and small-scale), biomass (energy crops, agricultural and forestry wastes, landfill gas and incineration) and geothermal (IEA, 1998). ‘Green electricity’ usually excludes large-scale hydro, incineration and landfill gas, though often includes fossil fuel generated combined heat and power.

For most renewables, emissions from power generation itself are low. However, emissions arise from other life-cycle stages in the production, manufacture and decommissioning of the generation plant. These are often more important than with fossil fuels because of the relatively low energy intensity of renewables - life-cycle emissions also arise for fossil fuels, but are low per unit of power produced. Even including life-cycle emissions (IEA, 1998), electric high-speed trains supplied by renewable electricity lead to much lower atmospheric emissions, shown in Figure 5. The largest benefits from the use of renewable energy would be to reduce emissions of CO_2 and SO_2, though there are also benefits for other pollutants.

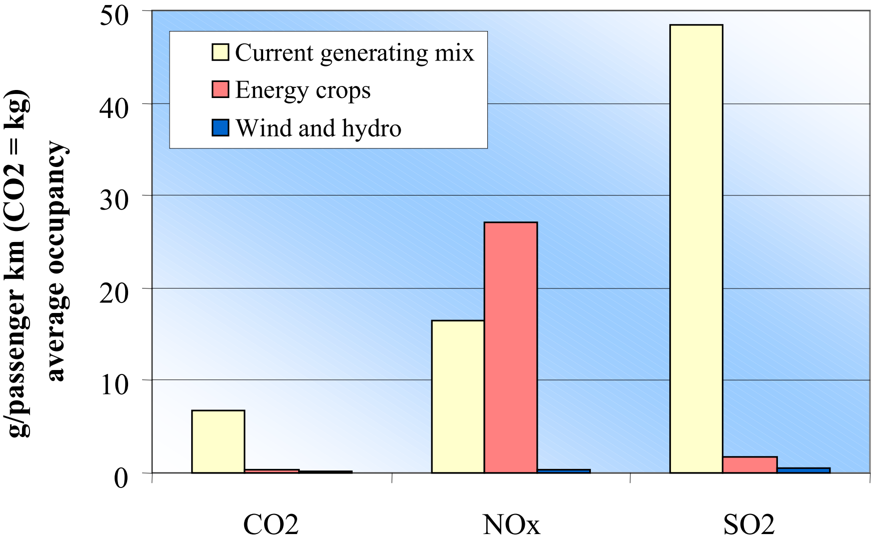

Figure 5. Emissions per Passenger km with electricity Supplied by Renewables Average Occupancy (Kings Cross – Edinburgh).

Large changes in emissions from electric trains will occur regardless of the use of renewables, because of changes in the future UK electricity generation mix. These changes will be significant, even by 2006. Electricity generation emissions have been estimated for future years, based on forecasts from the DTI (DTI: Energy Projections for the UK, Working Paper, 2000). These projections included two central forecasts of the electricity generation sector, based around central GDP growth, but assuming low and high world energy prices. The electricity mix associated with these scenarios is presented in Appendix 1. The key difference between the low and high scenarios is the proportion of coal fired generation – this has a large effect on emissions of CO_2 and SO_2.

The emissions for the five routes for 2006 and 2020 are presented in the tables at the end of the chapter. An example of how significantly emissions will change in future years is shown in Figure 6. This shows the emissions, per train, over future years for a high-speed journey on the ECML, based on the central high forecasts, when compared against current high-speed electric trains (reductions relative to the current diesel/electric mix would be even greater).

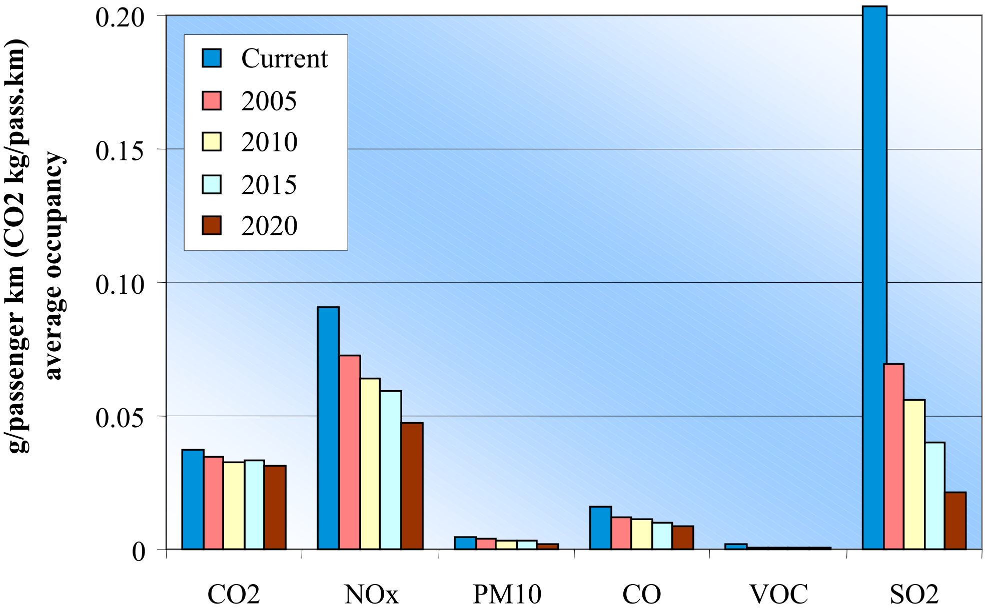

Figure 6. High-Speed Train Emissions for Future Electricity Supply Mix. (Central GDP Growth, High Energy Prices).

The figure shows that emissions from electric rail journeys will decrease significantly in future years. For key regulated pollutants (NO_x, PM_{10} and especially SO_2) these reductions will be large. This arises because of the lower proportion of coal in the electricity generation mix and because abatement technology (FGD) is fitted on remaining coal fired plant. Less dramatic improvements arise for CO_2 emissions. There are CO_2 benefits when coal fired plant replace by natural gas plant, but these benefits are offset when natural gas plants replace nuclear plant. The values in the figure assume no changes in future passenger occupancy. Increases in passenger occupancy, as might be expected from the implementation of the Government's 10 year plan, would lead to further reductions in average g/passenger km.

3.2 Estimating Emissions from Aircraft

Two sets of emissions are important when evaluating air transport: those from the Landing and Take-Off Cycle and those from aircraft climbing, cruising and descending. Within the analysis, it is important to consider these two sets of emissions separately, because a number of pollutants have different effects when emitted at the surface and at altitude.

3.2.1 LTO Emissions

There are a large number of different aircraft in use from London to the regional airports. This study has quantified the emissions from a very large number of different types of aircraft, though results are only presented for the main aircraft in use. LTO emissions have been derived from existing data in the ICAO database. The times for Approach, Land (roll), Take-off (roll), Initial climb (0-450 m) and Climb-out (450-1000 m) are based on Stansted and Gatwick data with APU (Auxiliary power units) running times based on Heathrow data. Adjustments have been made to examine the potential values from future, newer, aircraft, in order to examine if aircraft emissions will decrease in future years as more modern planes are bought into the fleet.

The surface emissions from a landing and take-off are effectively the same irrespective of the flight distance (though there will be small differences from fuel loading). Surface emissions will therefore be lower for longer flights, when adjusted into emissions per passenger km. An example is shown in Figure 7, showing the surface emissions per passenger km for the same plane on different regional journeys.

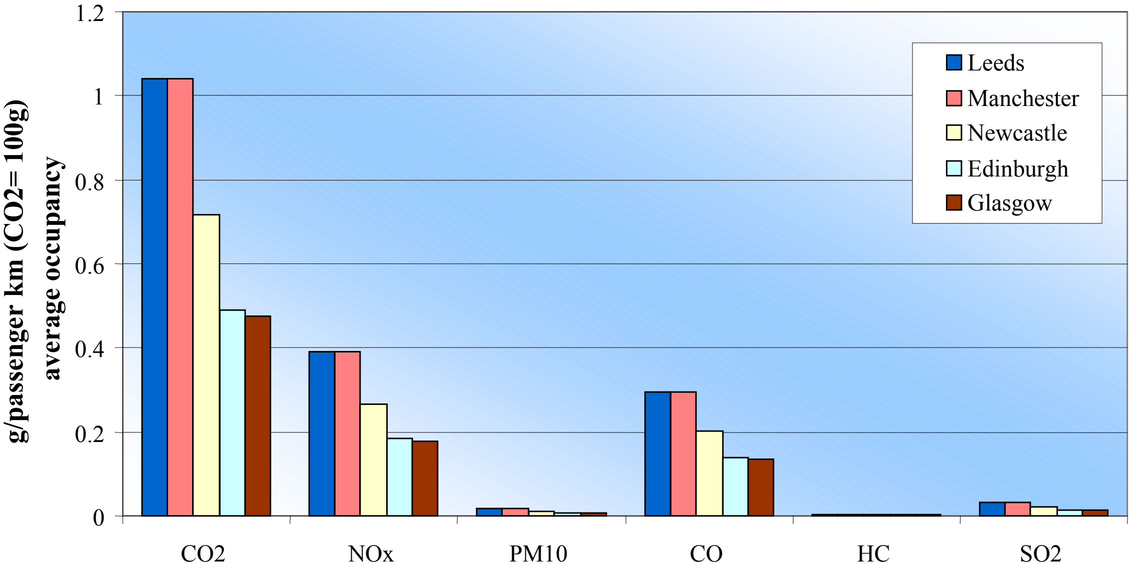

Figure 7. Surface Emissions (LTO) per Passenger km for a Boeing 757 on Different Routes.

Large differences in emissions do occur between different aircraft. However, when adjusted into emissions per passenger km, the differences for most planes are small. The values for a LTO cycle for various planes, per passenger km (average occupancy) are shown in Figure 8.

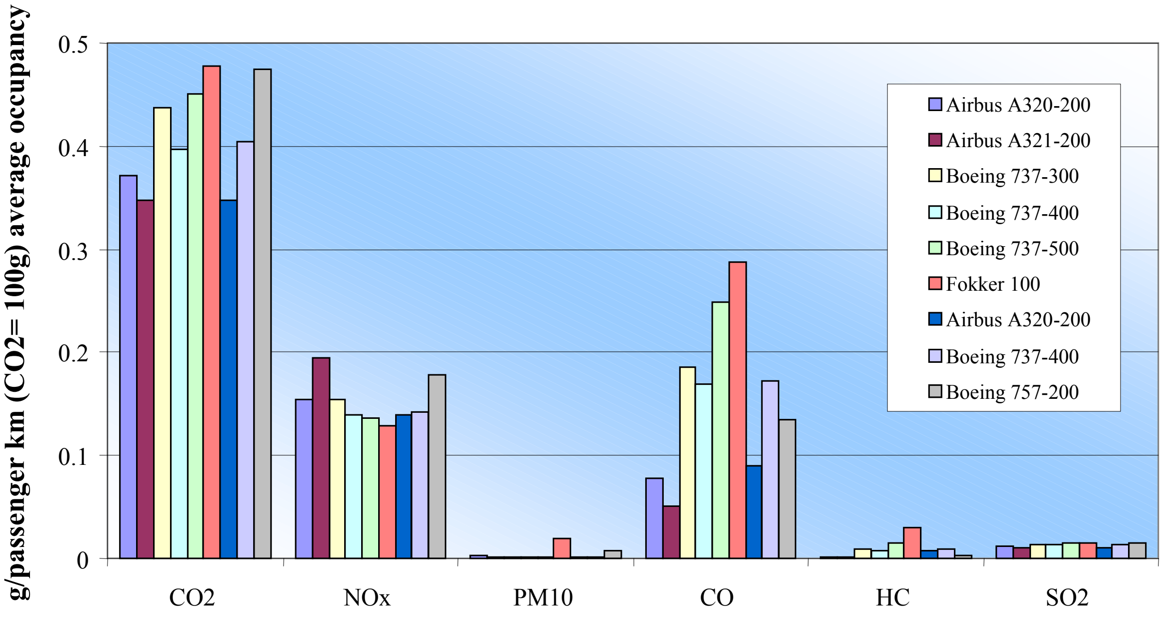

Figure 8. Surface Emissions (LTO) per Passenger km for Different Aircraft.

3.2.2 The Future Aircraft Mix

Emissions from aircraft will fall in future years as older aircraft are retired (e.g. 737-200 and 757-200). Further emissions reductions will occur as newer, more efficient, aircraft are introduced. No emissions data are available on future aircraft (e.g. the new generation Boeings such as the 737-600, 737-700, 737-800 and 737-900), however, this study has made preliminary estimates for these aircraft. It is stressed that the confidence in new aircraft values is low, not least because of uncertainty about seat capacity of the planes. Data for current and future aircraft have been combined to estimate weighted fleet emissions in future years (2006 – 2020) along each route. In general, the change in emissions is modest for future years, due to the long lifetimes for most aircraft and the relatively slow fleet turnover.

3.2.3 Cruise Emissions

Aircraft emit pollutants from fuel combustion in addition to the landing and take-off cycle. Several pollutants may affect climate change but CO_2 has been used as the key indicator. However, there is evidence that high level emissions of NOx and VOCs are also important as greenhouse gases. Recent evidence from the IPCC special report on aviation and the global atmosphere (IPCC, 1999) highlighted the potentially greater effects of emissions from aircraft in the upper atmosphere and their potential role in climate change, though the report acknowledges these effects are complex. The IPCC report states that the NO_x emissions from aircraft at altitude increase ozone in the upper troposphere. These ozone increases result in greater radiative forcing than increases of ozone at lower altitudes. However, aircraft sulphur and water emissions in the stratosphere tend to deplete ozone, partially offsetting NO_x induced ozone increases. In addition, the release of NO_x decreases concentrations of methane, a greenhouse gas. However, changes in ozone occur in the Northern Hemisphere, whilst methane concentrations are global in extent. Therefore even though the global average radiative forcings of NO_x and CH_4 are of similar magnitude and opposite in sign, the location of the forcing is such that the effect do not cancel each other out. Aircraft also release water vapour, which is a greenhouse gas, though the effect is smaller than CO_2 or NO_x. Aircraft emissions also form contrails, which may also have radiative effects. Finally, as aircraft emissions affect ozone in the stratosphere, they have a small beneficial effect regarding solar ultraviolet radiation.

It is stressed that the state of understanding concerning many of these effects is low. Within this study, additional greenhouse gas emissions from aircraft at altitude have not been considered, though they may increase the relative greenhouse gas emissions of aircraft relative to air. Further investigation of such issues is highlighted as requiring further analysis.

The easiest way to calculate emissions of CO_2 from aircraft climb, cruise and descent stages, is based on actual fuel use, using a standard conversion factor (typically 3160gCO_2 per kg of fuel consumed, IPCC 1999). The large number of different aircraft and operators means it is difficult to get this data for all the aircraft and routes in this study. The alternative is to calculate fuel consumption for different aircraft on different routes, based on flight profiles (flight time, thrust and altitude) for climb, cruise and descent cycles, for example following the methods set out in the EC MEET project ((Kalivoda and Kudrna, 1997). Again, this requires considerable data for all the aircraft and routes under analysis here. In the absence of specific data, typical flight profiles and fuel consumption for specific aircraft on the specific routes have been taken and used to estimate approximate fuel use for different aircraft.

The resulting values are added to surface emissions to show total CO_2, per passenger km, in the result tables.

3.3 Surface Access

When comparing domestic air or high-speed rail journeys, it is important to consider the entire journey. For this reason, the study has investigated the potential differences in surface access emissions, i.e. from journeys to and from the airport or railway station.

Two types of journeys were considered. Journeys from city centre to city centre, and other journeys (e.g. from an origin point in the south-east to one of the regions served by the domestic airports or stations, or vice versa). In assessing surface access emissions, two issues are important: the choice of surface access mode, and the distance of the surface access journey.

3.3.1 Surface access mode

Some data are available on surface access mode for travel to airports. Table 6 shows data on surface access trips by mode to London and the regional airports (from information collected by the CAA). For regional airports, 90% or more of surface access trips are by car (i.e. by either private cars, taxi and hire car). For London airports, around two-thirds of journeys are by car.

Table 6. Mode of transport (%) used to travel to or from UK airports.

	Private car	Hire car	Taxi/ Minicab	*(Total Car)*	Under-ground	Rail	Bus/ coach	Terminating passengers (million)
Heathrow[1]	35	4	26	*65*	14	7	14	62.0
Gatwick[1]	49	3	15	*67*	0	22	11	30.4
Stansted[2]	56	3	8	*67*	0	19	14	4.5
Manchester[1]	61	2	27	*90*	0	7	3	17.4
Leeds[1]	64	4	29	*97*	0	0	3	1.5
Newcastle[1]	65	3	24	*92*	0	5	2	2.9
Edinbugh[2]	61	7	23	*91*	0	0	8	5.3
Glasgow[2]	53	10	28	*91*	0	0	9	3.7

Source: How do passengers travel to and from UK airports? DETR.[1] 1999 data.[2] surveyed in 1994/95 or 1996

Of course, not all travellers embarking or departing at these airports will be making domestic journeys, especially for the London airports. This is likely to lead to slightly higher rates of car use for UK domestic travellers than for international travellers or non-UK residents at London airports. Data in Appendix 1, Table A3, supports this.

Some data on surface access to railway stations is also available. There is information on surface access to railway stations by region. These data are shown in Table 7. A high proportion of people walk or cycle to railway stations and the proportion of surface access by car is very much lower than for airports. However, this data is based on *all* surface access to stations – this data clearly will not apply for passenger embarking on regional trips, i.e. for passenger travelling from specific London railway stations (Euston and Kings Cross).

Some data is available on surface access to/from specific London stations, shown in the final column of Table 7. This shows that the majority of people travelling to or from Euston station use the Underground. The proportion of surface access by car is very low, which is not surprisingly given the location of this station in central London. However, this data is also not appropriate for assessing surface access for high-speed journeys, as it does not separate passengers taking regional trips from those taking shorter commuter journeys.

Table 7. Surface Access to Rail Stations (%).

Mode	London	North Eastern England	North Western England	Scotland		Euston
Foot	49	33	42	47	Foot	15
Cycle	2	2	1	0	Cycle	1
Bus	10	23	20	19	Bus	5
Underground	19	1	2	1	Underground	53
Taxi	3	8	5	6	Taxi	8
Car	20	32	28	28	Car	5
					Other train	13

Source: SRA.

In the absence of specific data, it is difficult to conclude what differences exist in the choice of surface access mode for passengers travelling by domestic aircraft or high-speed rail.

3.3.2 Surface access distance

The other key variable in calculating surface access emissions is distance. All the rail stations in this study are located in urban centres. The same is not true of airports. Therefore, for any trip from the centre of London to the centre of one of the five regional cities (or vice versa), air travel will involve a longer surface access trip. The approximate distance between airports and cities (urban edge and urban centre) are shown in Table 8.

Table 8. Straight line distances from Airports to Urban Areas/City Centres.

Airport	Distance (km) to Urban Edge	Distance (km) to Urban Centre
Heathrow	2.5 km	22 km
Gatwick	17 km	40 km
Stansted	29 km	48 km
Glasgow	0.8 km	10 km
Edinburgh	2.2 km	9 km
Leeds	2.3 km	10 km
Manchester	1.8 km	12 km
Newcastle	1.7 km	9 km

For journeys to or from a regional airport or railway station, the difference in surface access distance is likely to be small (though surface access to the airport will be slightly longer). A greater difference is likely to exist for the London airports. The significance of these additional emissions is presented in the following section.

For other journeys, i.e. from an origin point in the south-east to one of the regions served by the domestic airports (or vice versa), it is much harder to evaluate surface access distance. Passengers travelling from the south-east to one of the regional cities could potential come from a very large area and there is no data to suggest typical surface access distance. To investigate the potential importance of these surface trips, a sensitivity analysis has been undertaken with possible surface access trips, presented in the following section.

3.3.3 The potential importance of surface access emissions

The data available for surface access mode and distance does not allow an evaluation of the additional emissions. However, it is possible to assess if these emissions are potentially important by assessing a variety of surface access trips. Values have been estimated, by mode, for:

- A 10 km urban journey by road or rail (e.g. to/from the station/airport to/from a destination point in a regional urban centre);
- A 25 km road or rail journey (e.g. to/from a London airport to/from a destination point in London);
- A 50 km road or rail journey (e.g. to/from a London airport/station to/from a destination point in the south-east).

Emissions from road and rail vehicles have been based on emission factors from the National Atmospheric Emissions Inventory (Salway et al, 2000). Separate factors are used for urban driving to other trips. The values for cars and buses are based on the average fleet mix. The values for rail represent the average mix for non-Intercity diesel trains. Emissions per passenger journey from these surface access trips are shown in Table 9, as well as emissions for regional high-speed train or domestic air. The occupancy assumed for surface trips has a very strong influence on the importance of the emissions. In the table, cars are assumed to have an average occupancy of 1 or 2 passengers, buses an occupancy of 10 passenger, and rail an average occupancy of 40%.

Table 9. Emissions per Passenger Journey from Surface Access.

	Total Emissions (g/passenger journey)					
Mode	CO_2	NOx	PM_{10}	CO	VOC	SO_2
10 km car trip to station/airport (1 pass)	1,765	10.3	0.3	112	18.2	0.2
10 km car trip to station/airport (2 pass)	882	5.1	0.1	56	9.1	0.1
10 km bus trip to station or airport	1,147	13.3	0.5	6.6	2.0	0.04
10 km rail trip (diesel)	500	6.4	0.03	0.9	0.2	0.5
High-speed rail journey (Manchester)	12,920	31	1.7	5.5	0.7	71
High-speed rail journey (Edinburgh)	23,915	57	3.2	10.3	1.4	132
Domestic air journey (Manchester)	99,046	99	2.9	130	13.4	9.2
Domestic air journey (Edinburgh)	126,028	104	3.9	137	18.9	10
25 km trip to London by car (1 pass)	4,412	27	0.7	180	25	0.6
25 km trip to London by car (2 pass)	2,206	14	0.3	90	12	0.3
25 km trip to London by bus	2,867	26	1.1	12.2	3.9	0.1
25 km trip to London by rail (diesel)	1,250	16	0.075	2.5	0.5	1.2
50 km trip to destination by car (1 pass)	8,824	55	1.3	360	49	1.2
50 km trip to destination by car (2 pass)	4,412	27	0.7	180	25	0.6

50 km trip to destination by bus	5,733	53	2.3	24.5	7.9	0.2
50 km trip to destination by rail (diesel)	2,500	32	0.15	4.9	1	2.3

From this comparison, we conclude:

- CO, NOx and HC emissions from surface access are all significant compared to the emissions from the regional trip by high-speed rail or domestic aircraft.
- For these pollutants, surface access by car can lead to higher emissions than for the entire regional journey by domestic aircraft or high-speed rail.
- Surface access emissions will also increase CO_2 and PM_{10} emissions, particularly for longer surface trips.
- Surface access emissions are relatively more important on shorter trips.

3.4 Comparing to Regional Road Transport

Aircraft and trains are both public transport modes. In evaluating regional trips from these modes, it is also interesting to compare results to private car transport, shown in Table 10.

Table 10. Emissions from Regional Journeys by Private Car, High-Speed Rail and Domestic Aircraft.

London - Manchester	**Grammes per passenger journey**					
	CO_2	NOx	PM_{10}	CO	NMVOC	SO_2
Car journey (single person)	52,943	330	8	2162	297	7
High-speed rail (current)	12,920	31	2	6	1	71
Domestic air	99,046	99	3	130	13	9

London - Edinburgh	**Grammes per passenger journey**					
	CO_2	NOx	PM_{10}	CO	NMVOC	SO_2
Car journey (single person)	112,063	698	17	4576	628	16
High speed rail (electric only)	23,915	57	3	10	1	132
Domestic air	126,028	104	4	137	19	10

The Table shows that car transport has very much higher emissions of PM_{10}, CO, HC, and NO_x than either rail or air. Domestic aircraft and cars have similar emissions of SO_2, though both lower than rail. Cars have similar CO_2 emissions to domestic aircraft on longer flights, but lower CO_2 emissions on shorter trips. Rail has significantly lower CO_2 emissions than either mode.

3.5 Results

The emissions from rail and air are shown in Tables 11 and 12 below, in terms of the emissions per passenger km assuming average passenger occupancy[4] for current and future years. Results for maximum occupancy are shown in Appendix 1. The relative emissions are

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[4] Note, these results should not be used to assess the environmental effects of marginal changes. They also do not provide an indication of the possible environmental benefits from possible substitution. Adjustments to the values would be needed to properly consider changes in load factors, capacity issues, and other factors, for such conclusions to be drawn.

shown in Figures 9-13. Note, both current and future results are based on average load factors. They do not take account of possible future changes in occupancy for either mode.

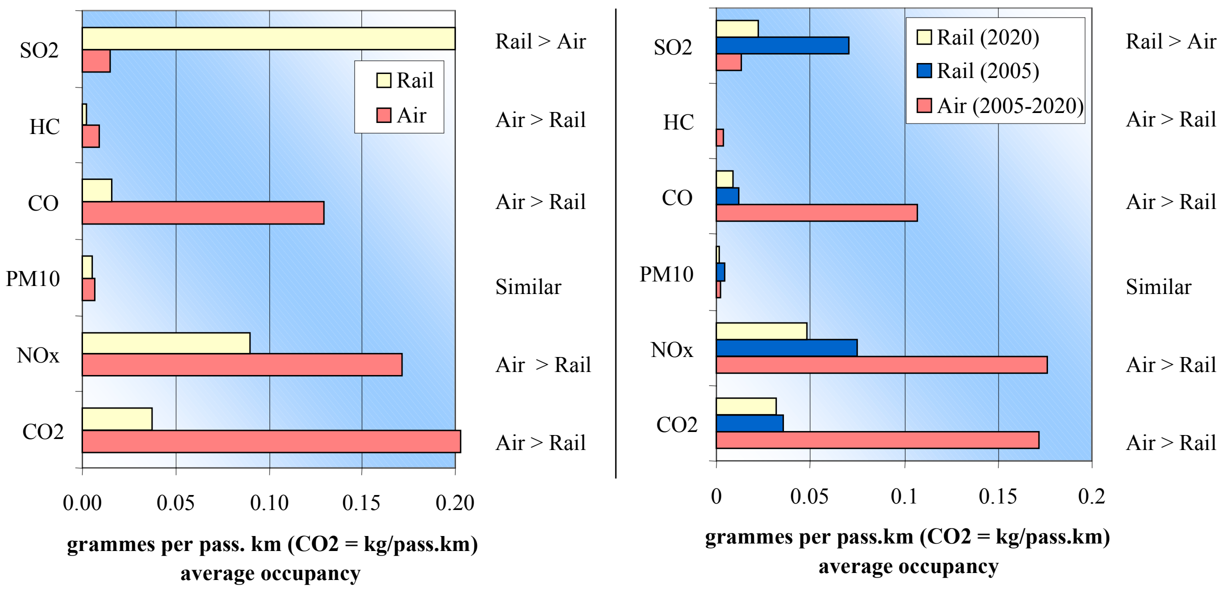
Table 11. Current Emissions from Domestic Air and High-Speed Train (Average Occupancy).

	grammes per passenger km (average occupancy)					
	Total	**Surface Emissions**				
	CO_2	**NOx**	**PM_{10}**	**CO**	**HC**	**SO_2**
London – Glasgow						
Rail	37.2	0.09	0.0049	0.016	0.0021	0.20
Air (weighted average)	203	0.17	0.0065	0.13	0.009	0.015
London – Edinburgh						
Rail (weighted average*)	94.8	0.71	0.06	0.19	0.086	0.50
Air (weighted average)	198	0.16	0.0061	0.22	0.030	0.015
London – Leeds						
Rail (weighted average*)	37.6	0.14	0.0094	0.031	0.011	0.20
Air (weighted average)	355	0.32	0.0092	0.60	0.040	0.035
London – Manchester						
Rail	43.2	0.10	0.0057	0.019	0.003	0.24
Air (weighted average)	330	0.33	0.0098	0.43	0.045	0.031
London – Newcastle						
Rail (weighted average*)	42.6	0.25	0.019	0.064	0.029	0.20
Air (weighted average)	230	0.16	0.0060	0.46	0.085	0.020
Sensitivity						
High speed train - electric only						
London – Edinburgh	37.7	0.09	0.005	0.02	0.002	0.21
London – Leeds	35.9	0.086	0.0047	0.015	0.002	0.20
London – Newcastle	37.7	0.090	0.0050	0.016	0.002	0.21

* Includes weighted average of electric and diesel trains.

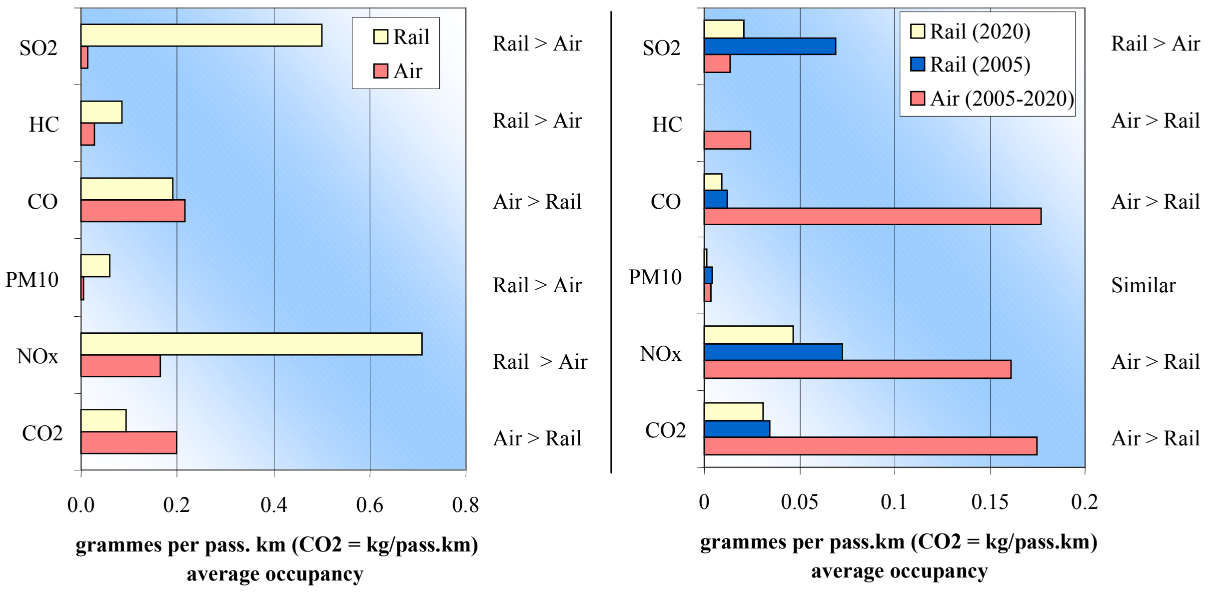
Table 12. Future Emissions from Domestic Air and High-Speed Train (Average Occupancy). For Rail, the future electricity generation mix assumed corresponds to the central high scenario.

	Grammes per passenger km (average occupancy)					
	Total	Surface Emissions				
	CO_2	NOx	PM_{10}	CO	HC	SO_2
London – Glasgow						
Rail (2006 central high)	35.4	0.075	0.0044	0.012	0.0009	0.071
Rail (2020 central high)	32.0	0.048	0.0018	0.0088	0.0009	0.022
Air (2006-2020 weighted average)	172	0.18	0.0026	0.11	0.004	0.013
London – Edinburgh						
Rail (2006 central high)	34.5	0.073	0.0043	0.012	0.0009	0.069
Rail (2020 central high)	31.2	0.047	0.0017	0.009	0.0009	0.021
Air (2006-2020 weighted average)	175	0.16	0.0033	0.18	0.024	0.013
London – Leeds						
Rail (2006 central high)	37.2	0.079	0.0046	0.013	0.0009	0.075
Rail (2020 central high)	33.6	0.051	0.0018	0.009	0.0009	0.023
Air (2006-2020 weighted average)	321	0.40	0.0049	0.36	0.017	0.031
London – Manchester						
Rail (2006 central high)	36.5	0.077	0.0045	0.013	0.0009	0.073
Rail (2020 central high)	33.0	0.050	0.0018	0.009	0.0009	0.023
Air (2006-2020 weighted average)	303	0.34	0.0058	0.33	0.035	0.028
London – Newcastle						
Rail (2006 central high)	34.5	0.073	0.0043	0.012	0.0009	0.069
Rail (2020 central high)	31.2	0.047	0.0017	0.0086	0.0009	0.021
Air (2006-2020 weighted average)	246	0.21	0.0039	0.43	0.075	0.021



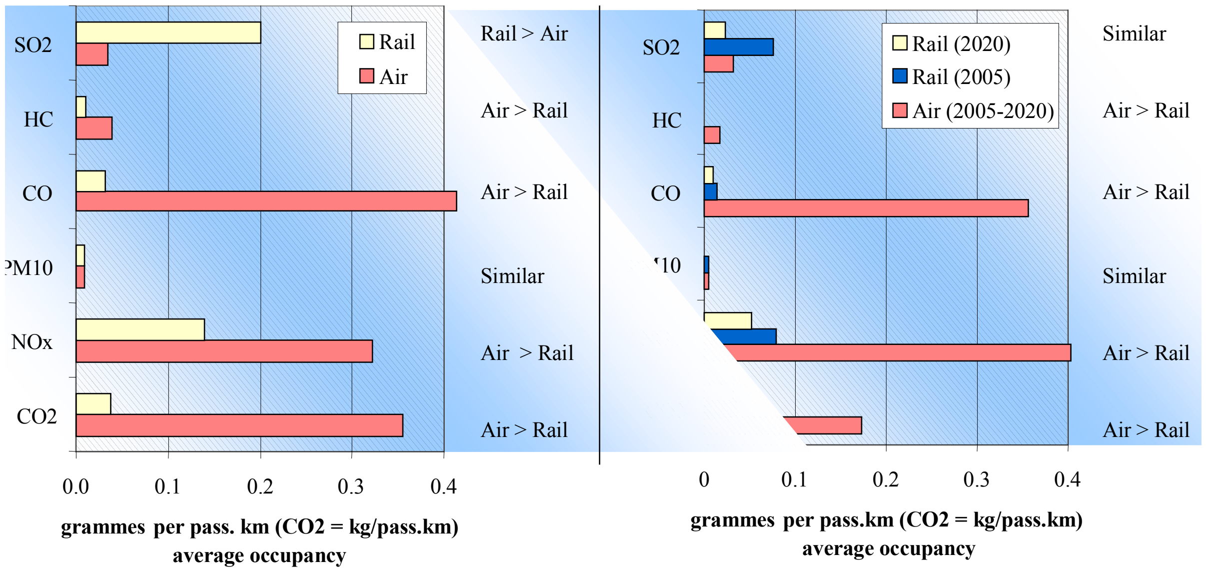
(Current) (Future 2006 - 2020)

Figure 9. Glasgow.



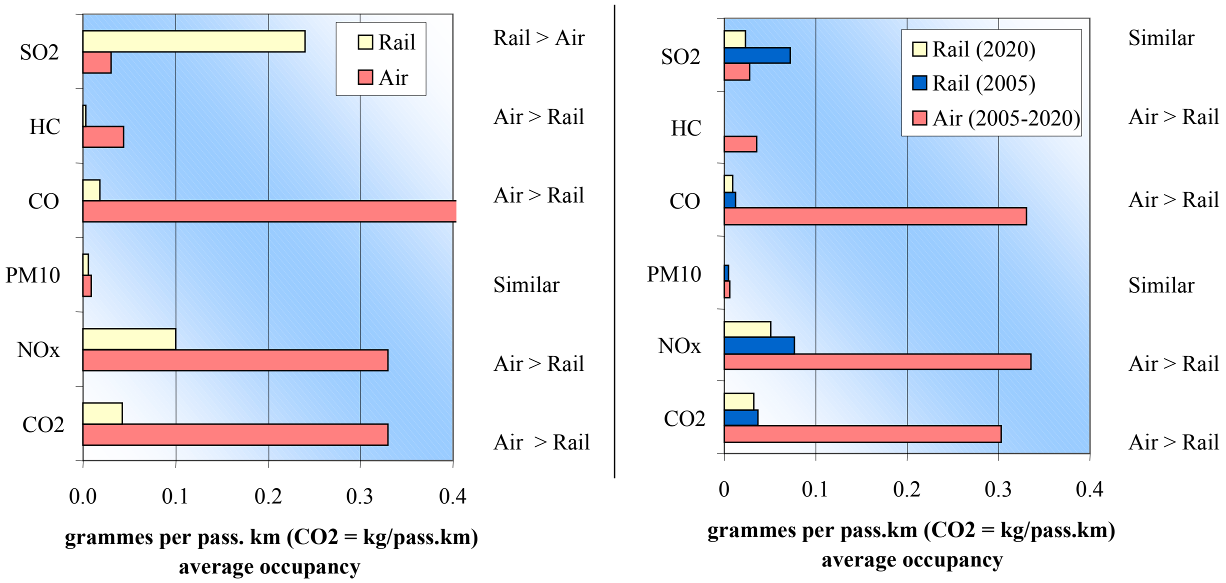
(Current) (Future 2006 - 2020)

Figure 10. Edinburgh.



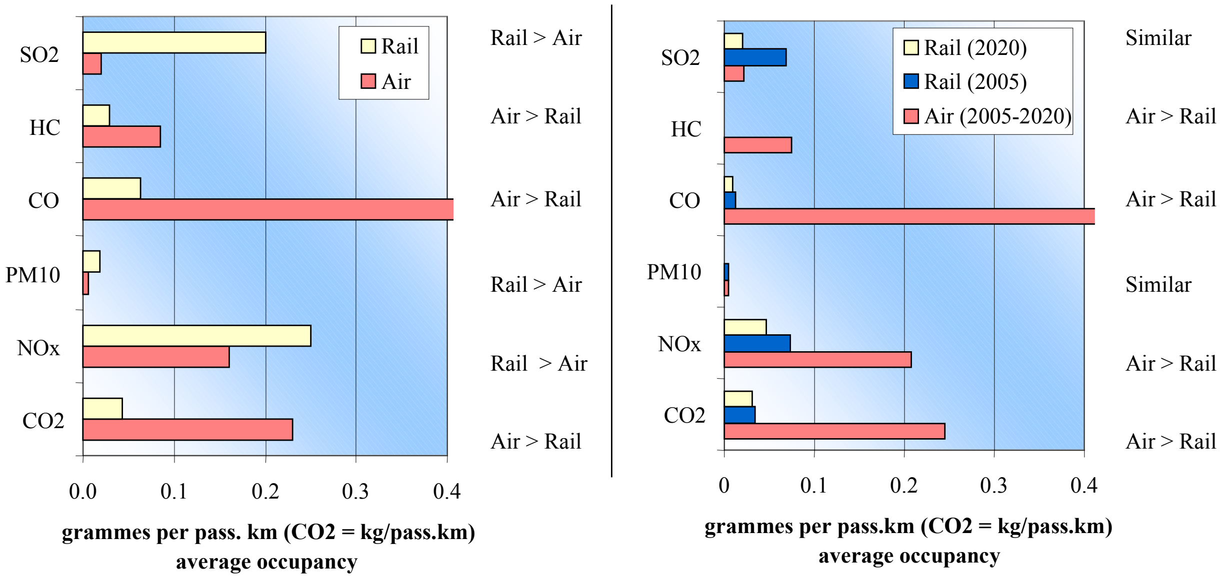
(Current) **(Future 2006 - 2020)**

Figure 11. Leeds.



(Current) **(Future 2006 - 2020)**

Figure 12. Manchester.



(Current) **(Future 2006 -2020)**

Figure 13. Newcastle.

The results show:

- Domestic air journeys have higher CO_2 emissions, per passenger km, than high-speed rail journeys.

Domestic aircraft have CO_2 emissions per passenger km that are many times higher than that of high-speed rail. Domestic aircraft have emissions of 200-300 gCO_2/passenger km compared to around 40 gCO_2/passenger km for high-speed rail. The CO_2 emissions from aircraft landing and take-off are the same irrespective of journey distance and this increases the emissions per passenger km for shorter aircraft trips, i.e. from London to Leeds and Manchester. Higher altitude emissions of NO_x and VOCs from aircraft have not been considered, though these may further increase the relative greenhouse gas emissions per passenger km for domestic air journeys.

- High-speed rail journeys have much higher emissions of SO_2, per passenger km, than domestic air travel.

High SO_2 emissions from the UK electricity generating mix (from coal fired generation) result in higher SO_2 emissions for high-speed electric trains than for domestic aircraft. SO_2 emissions from high-speed trains will fall significantly in future years due to changes in the future electricity generating mix, and in the medium term (by 2020) high-speed rail and domestic aircraft will have similar emissions per passenger km (assuming no changes in future load factors). From the above analysis, it appears that emissions of SO_2 will be higher for domestic aircraft than for high-speed rail on short journeys (Leeds and Manchester) and higher for rail compared to aircraft on longer journeys (Edinburgh and Glasgow).

- Domestic Aircraft have higher emissions of ground level CO, NO_x and VOCs, per passenger km, than high-speed rail.

The emissions from domestic aircraft, per passenger km, are highest on shorter trips, because of the emissions from take-off and landing.

There was one exception to this. One rail route (London-Edinburgh) currently has a high proportion of high-speed diesel trains. These diesel trains have much higher emissions per km than high-speed electric trains and this increases the average emissions per passenger km for this route, so that emissions are greater than for the equivalent air journey. The diesel trains on this route will be phased out in the next few years.

This finding is important. With the exception of SO_2 and CO_2, high-speed diesel trains have emissions almost an order of magnitude greater than for high-speed electric traction. There therefore needs to be a clear distinction between the type of trains used for regional transport (especially if looking to increase overall services of high-speed trains).

Future emissions (beyond 2006) of CO, NO_x and VOCs per passenger km will be even lower for high-speed electric trains relative to aircraft, as changes in the electricity generation mix lead to greater emissions reductions than occur from the introduction of more modern aircraft into the fleet.

- Emissions of PM_{10}, per passenger km, are broadly similar for both modes.

The relative emissions of PM_{10}, per passenger km, vary on different routes because of different aircraft and trains in use. Electric high-speed trains have slightly lower emissions of PM_{10}, per passenger km than aircraft. However, high-speed diesel trains have much higher emissions of PM_{10} than electric trains or aircraft, and so domestic aircraft have lower PM_{10} emissions for all the routes that still have a proportion of diesel locomotives (the ECML).

The emissions of PM_{10} from both modes will fall in future years (2006 and beyond), due to reductions in the emissions from the electricity generation mix for rail and from modern aircraft entering the air fleet. In the medium term (2020) it is likely that PM_{10} emissions per passenger km will be lower for high-speed rail compared to domestic aircraft. These benefits will be greatest on shorter trips (i.e. London to Leeds/ Manchester).

The relative balance of different pollutants from the two modes makes it difficult to conclude which has the lower burden for atmospheric emissions (which affect local and regional air quality). To make this judgement, the relative *impacts* of high-speed train and domestic air travel must be assessed, rather than the *burdens* (e.g. emissions) assessed here. We highlight this as a research priority from the current study. Such a study would need to assess pollution concentrations and exposure (i.e. the difference in pollution exposure for emissions from airports vs. power stations) and also the relative importance of different pollutants (i.e. the health and non-health impacts of a tonne of SO_2 compared to a tonne of NO_x).

- ***Emissions from surface access may be important***

It is clear that the choice of surface access mode is extremely important in the relative comparison of high-speed rail and domestic aircraft. For longer surface access trips by car, the emissions of most pollutants (especially CO, NOx and VOCs) can be as large as the emissions from the regional journey itself (by rail or air). The reduction in private car use for surface access is therefore a priority in reducing overall burdens from both modes. The inclusion of surface access emissions could therefore change the comparison significantly. It is stressed that both short-haul air travel and high-speed rail have major emission advantages over road transport for domestic regional journeys (i.e. from London to the five cities).

For journeys from city centre to city centre, there will be additional surface emissions from short-haul air, because of the location of airports outside urban areas. Some data are available on surface access mode for passengers travelling to airports. This indicates that whilst the proportion of travellers using public transport is improving, the majority of surface access to regional airports, and approximately two-thirds of access to London airports, is by car. Data on surface access mode for passengers travelling to railway stations is available, however, data for passengers making specific high-speed rail journeys is not. The railway stations of interest for this study (Kings Cross and Euston) are located in central London and the proportion of surface access journeys by car are likely to be lower. However, the lack of data means it is not possible to include surface access emissions for high-speed rail and domestic aircraft, though surface access emissions would be likely to favour rail over air. Surface access emissions are more important (i.e. have higher emissions when expressed in g/passenger km) on shorter trips from London to Manchester and Leeds.

It is more difficult to compare other surface access trips, e.g. for a passenger travelling on a journey from the south-east to a regional destination (or vice versa). Emissions will vary with the length of surface access journey. No data are available on typical access distances for the two modes, nor on the access mode for rail. It is likely that the larger numbers of airports in the south-east would reduce journey distance (for each regional rail journey, there is only one London station, but potentially five London airports) though there is a higher probability that surface access to the airport will be by car. The lack of data means it is not possible to include these emissions in the comparison. Surface access mode is also likely to vary according with the direction of travel and the starting point of the individual's journey. Further analysis of surface access emissions is highlighted as warranting research.

4 Noise

This chapter compares the noise burden for high-speed rail and short-haul air travel.

The evaluation of noise is complicated by a number of issues, which make it more difficult to directly compare the two modes. Firstly, there are different time period weightings and measurement metrics that can be used to measure and report noise levels. Indeed, different metrics have typically been used for measuring railway and aircraft noise in the UK. Secondly, noise (as measured in dB) is a logarithmic quantity and there is good evidence of there being a noise below which no burden occurs. This makes the analysis of average and marginal noise burdens very site-specific and detailed.

For this study, it is important to consider what sound weighting scales and what time periods can be used to compare the noise emissions for the two modes, and to try to use a common metric that adequately reflects their potential noise nuisance. The approach taken has been to assess the absolute noise levels from high-speed trains and aircraft along the five specific routes to give an indication of the relative noise burden (all other things being equal). However, the study has also investigated the marginal noise levels for high-speed train and short-haul aircraft journeys taking into account the existing noise levels from all sources. This analysis has onely been completed for one route as an example of the likely results.

4.1 Noise Indicators

Harmonised indicators for the noise from railways and aircraft are currently not available. This matter has been the subject of considerable debate and is being addressed within the development of the European Directive on Environmental Noise (Council of the European Union, 2000).

In the absence of an established method for assessing the comparative noise exposure due to rail and air over the routes in question, it was necessary for the current study team to agree a methodology that would enable the two modes to be compared.

The basic measurement index for sound is the decibel (dB), a logarithmic quantity reflecting the nature of the human ear's response to sound pressure. As well as responding to sound in a logarithmic manner, the ear is also more sensitive at some frequencies than at others. It responds very poorly at low frequencies (eg 10 Hz) and not particularly well at very high frequencies (eg 20 kHz) when compared with mid frequencies (eg 1 kHz – 5 kHz). This frequency sensitivity is allowed for by applying an appropriate frequency weighting to measurements and calculations, the most common of these being the "A-weighting". A sound level to which A-weighting has been applied is presented in terms of "dB(A)".

Traditionally, noise impact in the vicinity of airports and railways has been assessed using the concept of the Equivalent Continuous Sound Level (L_{eq}). This technique for "energy-averaging" a fluctuating noise environment is defined as the steady noise level over a defined period that contains the same acoustic energy as the fluctuating level over that period. For aircraft noise it has been shown (Critchley et al, 1990) that the 16-hour (0700-2300) L_{eq} is well correlated with long term annoyance. For railways the 24-hour L_{eq} has been found to correlate well with annoyance (Fields, 1979). However, in the UK, the trigger levels for providing sound insulation at properties for new or additional railways under the Noise Insulation (Railways and Other Guided Transport Systems) Regulations (1996) are based on an 18 hour L_{eq} from 0600h – 2400h and a 6 hour night time L_{eq} from 0000h – 0600h. These values are used to align the Regulations with those for road traffic noise, which only consider an 18 hour day.

A useful associated index is the Sound Exposure Level (SEL). This index represents the sound level occurring for a duration of 1 second that contains the same acoustic energy as a fluctuating noise event, or events, over a given period. This enables the sound energy for a single event, or a series of events, to be normalised to a 1 second base.

More complex indices than L_{eq} have been devised (for characterising fluctuating noise events) to assess the potentially greater annoyance from noise at different times of the day, particularly at night. The usual method of achieving this is to divide the 24 hour day into separate time periods, calculating the L_{eq} within each period and adding a period-specific factor to reflect the relative level of annoyance within the period. This approach has been adopted within the European Directive on Environmental Noise in the form of the L_{den} indicator. Here the 24 hour period is divided into a 12 hour day, a 4 hour evening and an 8 hour night. The L_{eq} is calculated for each period in terms of dB(A), but 5 dB(A) is added to the evening value and 10 dB(A) is added to the night value. The three resulting values are then amalgamated into a single time-weighted L_{eq}, the L_{den}.

4.2 General Noise Methodology

The main noise metric used in the study was based on single journeys of one aircraft or one train. For each journey, the number of people exposed to a specified value of Sound Exposure Level (and above) in A-weighted decibels was calculated. This was then normalised to a value per passenger carried, based on maximum and average load factors. The values of SEL chosen as being indicative of typical exposure in the vicinity of railways and airports were 90 dB(A) and 100 dB(A). These values were “free field”, i.e. in the open and away from acoustically reflective surfaces, and not within properties.

Air and rail vehicle types constituting the passenger services that currently apply, and those that will occur from the years 2006 to 2020, were considered.

The SEL contours at 90 dB(A) and 100 dB(A) were defined for both air and rail by methods based on prediction and measurement, for trains or aircraft types typical of those used on the routes in question. Population density data along the affected routes was then used to establish the number of people exposed to those levels of SEL or greater. This enabled the number of people exposed per passenger to be calculated, based on a single journey.

The way in which the exposure metric “people exposed to a given SEL per passenger” has been defined allows the effect of different load factors to be calculated by dividing this metric by occupancy. Results are presented for both average occupancy and full occupancy for each mode. For rail, “full occupancy” includes all available seats, but not additional standing passengers.

The population density was assumed to be unchanged up to the year 2020.

The marginal effects of extra aircraft or trains were assessed for the Manchester-London route by consideration of the Day-Evening-Night level (L_{den}), the indicator adopted within the Draft European Directive on Environmental Noise. This index is currently considered to be the most appropriate general-purpose indicator of environmental noise exposure within the process of formulating the European Directive, and hence a suitable index for comparing different types of noise sources. Although it currently has no formal status, it is unlikely that the Directive will recommend any alternatives to L_{den} (and the associated L_{night}) for general use. In addition, since the aim is to compare marginal changes and not absolute levels, the choice of 24hr-L_{den}, over say a 16 hour or 24 hour L_{eq} should not affect the relative comparison. A base L_{den} level of 68 dB(A) was set for both modes, representing an environment typically occurring in the vicinity of a railway or airport where a significant proportion of the exposed population will display some degree of annoyance. This value is also the trigger level for L_{eq} from 0600h – 2400h within the Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1996.

For the marginal analysis, all current traffic occurring over the route was considered. This included all aircraft departing or arriving at airports, and all passenger and freight activity along the railway line. This was used to define the 68 dB(A) L_{den} contour for a typical week day[5]. A calculation was then made of the number of people within the contour. Additional rail or air traffic was then introduced, to accommodate an extra 1000 available seats over the route in one day, and the contours recalculated. For both rail and air it was assumed that these extra passengers would be carried in the daytime period. This meant that the contribution to L_{den} from the additional rail or air movements would not require weighting. The decision to add the additional passengers during the daytime rather than within the evening or night time periods will obviously have some influence on the results, due to the sensitivity of L_{den} to the time of day at which events occur. However, the chosen approach provides a pragmatic method for comparing the two modes. The additional number of people exposed indicates the marginal noise burden for additional journeys.

4.3 Railway Noise Prediction Methodology

The basis for all the railway noise predictions was the DETR Memorandum "Calculation of Railway Noise 1995" (CRN) (DETR, 1995). This procedure was specifically devised for use with the Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1996, for assessing entitlement to insulation under the Land Compensation Act 1993 for new or additional railways. It enables the SEL for a number of vehicle types to be predicted for a given speed and distance from the track, and allows the effects of intervening barriers and structures to be accounted for. From this the A-weighted Equivalent Continuous Sound Level (L_{Aeq}) can be calculated for comparison with trigger levels set out within the Regulations.

CRN was not, however, designed as an all-purpose railway noise prediction scheme, and has one serious drawback. Railway rolling noise, the major source from most high-speed railways, is very sensitive to rail head roughness. An extreme form of rail head roughness, which is widely found on all railways, is a periodic wear pattern with a wavelength typically between 30mm and 80mm, known as rail corrugation. As rolling noise is a function of the

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[5] Note that 68dB(A) L_{den} may be high with respect to the ambient noise in open country. However, in such areas there will be much lower population density, hence the effect will be reduced. Further investigation of these two competing factors for non-urban areas is warranted.

combined roughness at the wheel/rail interface, wheels that are comparatively smooth, as with disc-braked trains, are particularly sensitive to corrugation. Indeed, severe corrugation can increase rolling noise by as much as 20 dB, a subjective four-fold increase in loudness. Unfortunately, the Calculation of Railway Noise 1995 (CRN) assumes that the rail head is reasonably smooth and so any prediction of current or future levels using that procedure is likely to under-predict for a significant proportion of the network. Fortunately, AEA Technology Rail has a long experience of using a modified form of CRN to predict railway environmental noise for real situations, in particular for cases where the rail head is rough or corrugated. The distribution of rail head roughness over main line routes has been established by mounting a microphone beneath a disc-braked vehicle and measuring the rolling noise. The typical shape of this distribution, based on speed-normalised rolling noise, is shown in Figure 14 (Jones, 2000).

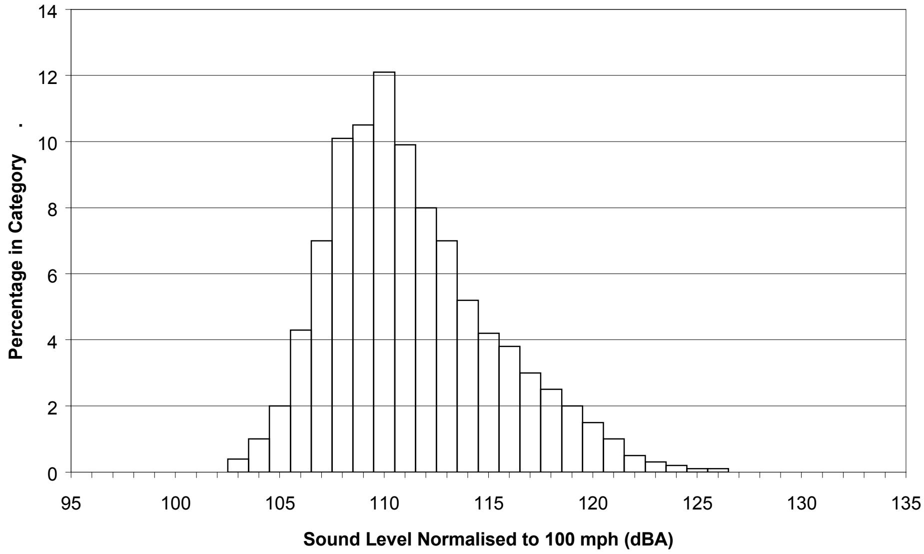

Figure 14. Distribution of acoustic track quality on a typical main line route

From such distributions it has been possible to derive corrections representing the average increases in rolling noise as a result of the real rail head roughness. These were 3.1 dB(A) for disc-braked vehicles and 1.8 dB(A) for vehicles with cast iron tread brakes, which are less sensitive to corrugations by virtue of their rougher wheel rolling surfaces. It has been assumed that the same rail head roughness distribution applies for the future scenarios; this is likely to be the case unless a regime of frequent targeted grinding is put in place.

4.3.1 Choice of railway rolling stock and routes

The current passenger services for each of the 5 routes, and likely future passenger services, can be adequately represented by a single dominant train type (see Chapter 2). As there are a number of alternative routes between the five cities and London, the dominant routes had to be defined. The specified routes were:

- Edinburgh – Newcastle – York – Doncaster – Peterborough – London King's Cross
- Newcastle – York – Doncaster – Peterborough – London King's Cross
- Leeds – Wakefield – Doncaster – Peterborough – London King's Cross
- Glasgow – Carlisle – Crewe – Lichfield – Rugby – London Euston
- Manchester – Stoke – Lichfield – Rugby – London Euston

4.3.2 Speed profiles over the chosen railway routes

In order to carry out the noise predictions it was necessary to define the speed of the trains at all points along the five routes. A database of speed vs grid reference was built up for all five routes for the current situation. Future speeds were calculated on the assumption that both East Coast and West Coast services will run at maximum speeds of 140 mph by 2006. The effects of higher speed limits on the five routes were predicted by scaling up the current speeds proportionately where the current value is above 30 mph, but assuming that locations where speeds are currently 30 mph or below remain unchanged.

4.3.3 SEL Contours and Exposure

The information on train types and route speeds, correcting for track with a realistic level of rail roughness, was used to predict the distance from the track at which the 90 dB(A) and 100 dB(A) SEL contours occurred. GIS data of population density within 1km squares along all routes was then used to determine the numbers of people within these contours, assuming uniform population density within each grid square. There was assumed to be no population within 4m of the railway line, to represent the area within the railway boundary fence. The evaluation was undertaken, using the prediction techniques described above, for both the current and future scenarios. For the majority of the predictions, the assumption was made that the railway was running at the same level as the surrounding terrain, and that the propagation of sound was unobstructed by any intervening structures such as fences and properties.

Although it would be possible using the prediction techniques to cater for track elevated on embankments etc, track in cuttings, and track obscured by intervening structures, it was not possible within the constraints of the current project to model the effects of such features in detail. An analysis was carried out on one route (Manchester), however, to indicate the possible sensitivity of the results to the screening effect of houses adjacent to the railway, leading to reduced noise in the acoustic “shadow zone” behind those properties. For this purpose a process was considered whereby it was assumed that typical properties adjacent to the railway would be 25m from it and 10m high. Such a barrier would provide at least a 20 dB(A) reduction in noise in the shadow zone, which led to the prediction that behind such properties SEL’s of 90 dB(A) and above could not occur. Therefore, for this model, the presence of a property effectively removes the population behind it from the calculation, leaving only those properties within 25m of the railway. Note, only property screening effects were considered. The analysis did not look at the potential screening from existing barrier effects such as cuttings and potential mitigation measures from upgrades.

The likelihood of the presence of such properties was obtained by considering the GIS population density data, with a high probability of there being a property present where the density was 6000 people/km^2 and above, and a low probability where the density was 2000 people/km^2 and below. The models were then re-run using the modified population densities. The results were found to be very sensitive to the building screening assumptions. The number of people exposed to an SEL of 90 dB(A) along the route without screening was 93,495 while the same route with screening along the entire route was 9,127, i.e. an order of magnitude difference. The combined probability function described above (assuming screening when the population density is high) reduced the number exposed to 51,154 people.

In the absence of sufficient information on the true form of the function, it was preferred to present the results on the assumption of no shielding, to represent the worst-case scenario along all routes.

4.3.4 Marginal effects of additional high-speed trains

Data on the current levels of all types of traffic on the Manchester to London route was used to predict the 68 dB(A) L_{den} contour along the route, and hence the number of people exposed to that level and above, by applying the same procedure as used for the SEL analysis. An additional two trains were assessed for the daytime service (1040 available seats) and the 68 dB(A) L_{den} contour recalculated. The additional number of people exposed was then also recalculated. There is almost no difference in the noise burden from a journey from Manchester to London compared to a trip from London to Manchester (this is not the case for air) and so the results are presented for a single journey.

4.3.5 The “Railway Bonus”

Work on behalf of the EC Working Group 2 (Miedama and Oudshoorn, 2000) in connection with the formulation of the European Draft Directive on Environmental Noise (Council of the European Union 2000), has inferred that rail has an approximate 10 dB(A) advantage over air in terms of human response to noise. An indication of the possible implications of this ‘Railway Bonus’ can be provided from the current analysis. A 100 dB(A) SEL from a railway might be expected, on the basis of the Working Group’s study, to generate a similar response to a 90 dB(A) SEL from aircraft. However, it must be stressed that, although the existence of such a “Railway Bonus” has been suggested for many years, its existence is by no means conclusive, and there are concerns that this is not a true phenomenon.

4.4 Method for Evaluation of Domestic Aircraft Noise

It has been shown (Critchley et al, 1990) that for aircraft noise, the 16-hour (0700-2300) L_{eq} is well correlated with long term annoyance. The night period (8-hours) is often considered separately, as sleep disturbance is better correlated with individual noise events rather than the equivalent continuous sound level, L_{eq}.

A number of difficulties arise when considering L_{eq} to compare noise between transport modes. Firstly, L_{eq} applies to a set time-period and not a single transport movement. Secondly, in terms of air-noise, L_{eq} contours for the study airports will be dominated by medium/long-haul traffic so the effects of short-haul traffic are likely to be very small. For this reason the Sound Exposure Level (SEL) was used. This takes into account the peak noise level and the duration of a noise event, so incorporating the total ‘energy’ of a single noise event. It is also the fundamental ‘building block’ of the L_{eq} metric. The downside is that SEL does not take into account the number of events over a given time period, unlike L_{eq}. This is not an issue, however, for a comparison of a particular rail vehicle vs. an aircraft.

The number of events is important when considering the transfer of passengers from one transport mode to another. For this scenario, L_{eq} is the only viable indicator. For air-noise the effects of any transfer are likely to be very small, since short-haul air travel to and from London is a very small fraction of the total air transport operations at the study airports. However, L_{eq} may be used to determine the impact of marginal change.

4.4.1 SEL contours

The air-noise modelling used was based on analysis conducted using the UK Aircraft Noise Contour Model (ANCON) version 2 (Ollerhead et al 1998). This model closely follows international guidance published by SAE (1986), ECAC (1986) and ICAO (1988). The main differences between ANCON version 2 and published guidance lie in the use of local databases for aircraft performance (flight profiles) and noise data, both of which have been developed over many years through the regular collection of operational data.

Noise calculations are performed over a grid surrounding each of the study airports. At each grid point the SEL is calculated, based on the aircraft source characteristics and propagation of the noise source to the receiver grid points on the ground. In most cases, the grid is assumed to cover a ‘flat earth’ but in the case of Leeds/Bradford airport where terrain changes are significant, ground elevation at each grid-point relative to the airport datum is taken into account.

Taking a simplistic approach, the exposure of a flight from Edinburgh to London Heathrow consists of the area and population exposed during the takeoff at Edinburgh and the landing at London Heathrow. Such contours are illustrated in Figure 15.

Figure 15: Example SEL contours for aircraft departure and arrival

In the case of air transport operations, this concept is complicated by the fact that an aircraft may takeoff from Edinburgh's runway in two different directions and use either of two southerly departure routes. Similarly, when landing at Heathrow, two runway directions are available and also two different runways may be used to land. All of these factors are important since they affect the geographical position of the flight track and subsequent population exposed.

To aggregate the numbers in a sensible manner, information was used regarding the typical runway directions used at the study airports. This was based on either a 20-year rolling average or data for the latest year available.

Taking Edinburgh as an example, the split is 78 percent west, 22 percent east. For London Heathrow the split is 77/23. Thus for a trip from Edinburgh to Heathrow the average population exposed is:

$$\begin{aligned}\mathrm{Pop}_{\mathrm{EDI-LHR}} &= 0.78 \times \mathrm{Pop}_{\mathrm{EDI(wd)}} + 0.22 \times \mathrm{Pop}_{\mathrm{EDI(ed)}} + \\ &\quad 0.77 \times \mathrm{Pop}_{\mathrm{LHR(wa)}} + 0.23 \times \mathrm{Pop}_{\mathrm{LHR(ea)}}\end{aligned}$$

Where 'wd' signifies a west departure, and 'wa' a west arrival etc.

Similarly the process is repeated for the reverse direction

$$\begin{aligned}\mathrm{Pop}_{\mathrm{LHR-EDI}} &= 0.77 \times \mathrm{Pop}_{\mathrm{LHR(wd)}} + 0.23 \times \mathrm{Pop}_{\mathrm{LHR(ed)}} + \\ &\quad 0.78 \times \mathrm{Pop}_{\mathrm{EDI(wa)}} + 0.22 \times \mathrm{Pop}_{\mathrm{EDI(ea)}}\end{aligned}$$

Finally, to aggregate both directions, since all flights are scheduled to depart and return:

$$\mathrm{Pop}_{\mathrm{EDI}\leftrightarrow\mathrm{LHR}} = \frac{\mathrm{Pop}_{\mathrm{EDI-LHR}} + \mathrm{Pop}_{\mathrm{LHR-EDI}}}{2}$$

The contour area and affected population is highly dependent on the contour level. A level of 90 dB(A) SEL was chosen for a number of reasons. Firstly, the level is high enough to be within the normal working of air noise models. Lower SEL levels would produce much larger contours, extending further from runways, reducing confidence in model accuracy. Conversely, higher contour levels produce very small population counts, which may not accurately reflect the differences between transport modes. Secondly, 90dB(A) has been found, for air-noise at least, to relate to single event noise disturbance, and in particular sleep disturbance (Ollerhead et al 1992).

As with rail trips, the noise burdens were normalised to the population exposed per passenger carried. The results were normalised in terms of available seats (maximum capacity) and then average load factors on specific routes were used to estimate noise levels per actual passenger carried.

4.4.2 Marginal Effects of Domestic Aircraft

As discussed above, SEL contours or 'footprints' do not take into account the number of aircraft movements during a specific time period. Since the frequency of services by different transport modes may be quite different, it is necessary to supplement the SEL based analysis. For this reason the study has undertaken a marginal analysis based on the proposed L_{den} indicator. The weighting used in this metric has the effect that a single night operation is equivalent to 10 daytime operations and a single evening operation is equivalent to 3.16 daytime operations.

L_{den} contours were calculated for one route to give an example of the likely effects. These were produced for the baseline traffic operating on all routes at a study airport. Then, for the route of interest the passenger numbers were increased or decreased by a set amount and the marginal change in L_{den} contour area and the population exposed estimated. These differences in population (dPopn) along with the change in passenger numbers (dPax) can be used to calculate the change in population affected per increase in passengers (dPopn/dPax) at a given L_{den} contour level.

The changes in L_{den} contours from changes in passenger numbers between Manchester and London Heathrow were examined. Two approaches to this have been adopted, in that changing passenger numbers on the Manchester – Heathrow route are reflected by:

i) Changes in the number of aircraft flying the route.
ii) Changes in the type of aircraft flying the route.

The first examines the aircraft types operating and increases/decreases the number flown according to the change in passenger numbers and seating numbers of each type. The second keeps the number of aircraft operating on the route the same, but increases/decreases the size of aircraft to accommodate more or less passengers. It could be argued that the latter is the more realistic scenario given the crowded nature of airspace and limited availability of slots for extra landings and takeoffs at London airports.

The seat numbers available on each type of aircraft for the Manchester-Heathrow were shown in Chapter 2. As more than one type of aircraft operates on this route, any changes were proportioned across the aircraft types according to the initial distribution of traffic. The table below also shows the order in which aircraft types were up/downgraded by size.

	Aircraft Type	Number of seats
Smallest size	FK10	106
↓	B733	128
↓	EA32	149
↓	B757R	195
↓	B763	252
Largest size	B777	281

The study looked at both trip directions, i.e. providing an extra 1000 seats from Manchester to Heathrow and for Heathrow to Manchester, in light of the potential differences between the two journeys from noise contour distributions . Additional analysis, showing the difference for 57 and 63 L_{den} for aircraft are shown in Appendix 2.

4.5 Surface Access

In addition to the noise from aircraft or high-speed rail, there will be noise from surface access, i.e. from journeys to and from the airport or railway station. As discussed in the previous chapter, there is not currently enough data to accurately assess surface access distance or mode for the regional journeys of interest here. It is likely that noise from surface access will be less important than from the regional trip, though further work to confirm this is recommended.

4.6 Results

The results for noise are shown below. Additional data on aircraft are shown in Appendix 2.

Table 13 shows the SEL evaluation for high-speed rail noise for the five routes for the 90 dB(A) and 100 dB(A) SEL. Two sets of values are presented, adjusted for the actual current situation (average occupancy) and maximum or full occupancy (assuming all seats are full). Both current (2000) and future (2006 – 2020) scenarios are shown. For one rail route (Manchester) the sensitivity of building screening is included. Possible changes in passenger occupancy in future years, as might be expected from implementation of the 10 year transport plan, have not been taken into account.

Table 13. High Speed Rail Noise. The number of people exposed to an SEL of 90 dB(A) and 100 dB(A) and above per passenger carried, assuming no building shielding except for "Manchester – Current", where * = all route screened by properties, ** = typical level of property screening. Inclusion of property shielding would reduce values for other routes by 50% or more).

	Population exposed per passenger journey (average occupancy)			
	90 dB SEL		**100 dB SEL**	
Route	**2000**	**2006-2020**	**2000**	**2006-2020**
Edinburgh - London	173	215	15	18
Glasgow - London	261	276	27	30
Leeds/Bradford - London	258	288	9	12
Manchester – London	545	197	85	21
Manchester (sensitivity)	(55*, 273**)	-	-	-
Newcastle	148	188	12	15

	Population exposed per passenger journey (maximum occupancy)			
	90 dB SEL		**100 dB SEL**	
Route	**2000**	**2006-2020**	**2000**	**2006-2020**
Edinburgh - London	57	71	5	6
Glasgow - London	86	91	9	10
Leeds/Bradford - London	85	95	3	4
Manchester - London	180	65	28	7
Manchester (sensitivity)	(18*, 90**)			
Newcastle	49	62	4	5

These results are interesting. It would be expected that longer routes (i.e. Edinburgh and Glasgow) would have a higher noise burden, as more people would be exposed along the track distance. There is no apparent trend with distance for the 90 dB(A)+ SEL scenario and it is apparent that the specific route conditions (and population distribution) have a much greater influence on the noise burden.

The West Coast route to Manchester currently has the highest noise burden. This is because the trains on this route are predominantly cast-iron tread-braked, while on the other routes the trains are currently predominantly disc-braked. The wheel roughness from tread-braking leads to rolling noise that is around 8 to 10 dB(A) higher than that of disc-braked trains, the latter having smoother wheel rolling surfaces. It can be seen that future exposure levels for the Manchester route are likely to be significantly reduced, despite increased speeds, as a result of the substitution of disc-braked Pendolino Britannico trains for the current stock. On the Glasgow route, stock that is currently predominantly disc-braked will be replaced with fully disc-braked Pendolino trains, at increased speeds, leading to a small increase in the numbers exposed. On the East Coast Route, there is a slight increase from the current situation to the future (e.g. Edinburgh goes from 173 - 215 90 dB(A)+ SEL, because of the increased speeds from upgrades to the line.

The results are very sensitive to building screening (i.e. properties that are adjacent to the track shielding and therefore reducing noise at properties behind them – note, additional screening effects from barrier effects such as cuttings or other future mitigation measures). The building screening analysis on the Manchester route shows that the numbers of people exposed to SEL values of 90 dB(A) are considerably lower if a detailed analysis of building screening effects is included, reducing the noise burden by 50% or more.

The comparable results for domestic air are shown below in Table 14. The tables show the SEL evaluation for aircraft noise for the five routes for the 90 dB(A) SEL for each of the main London airports. Two sets of values are presented, adjusted for the actual current situation (average occupancy) and maximum or full occupancy (assuming all seats are full). Both current (2000) and future (2006 – 2020) scenarios are shown. Full results, by aircraft type, are presented in Appendix 2. Note, air noise prediction does not take into account screening affects associated with buildings because, in general, the source is elevated well above ground level. Where aircraft operate on the ground during landing and takeoff, screening associated with airport buildings may be more significant. However, this is also not considered since its effects are very localised and would therefore not be expected to significantly affect noise levels well outside the airport boundary, i.e. in local communities where noise burdens from airborne operations are important.

Table 14. Domestic Aircraft Noise. The number of people exposed to an SEL of 90dB(A) and above per passenger carried by type and route for year 2000 and future fleet (2006-2020) for Heathrow, Gatwick and Stansted.

	Population exposed per passenger journey at 90dB(A) SEL (average aircraft occupancy)					
	Heathrow		**Gatwick**		**Stansted**	
Route	2000	2006-2020	2000	2006-2020	2000	2006-2020
Edinburgh - London	16.3	13.8	44.4	3.6	7.5	6.3
Glasgow - London	13.3	11.9	212.5	2.8	-	4.7
Leeds/Bradford - London	32.3	37.9	-	-	-	-
Manchester - London	14.9	12.9	15.9	1.6	2.4	2.0
Newcastle	10.0	12.1	1.2	0.4	0.4	0.4

	Population exposed per passenger journey at 90dB(A) SEL (maximum aircraft occupancy)					
	Heathrow		**Gatwick**		**Stansted**	

Route	2000	2006-2020	2000	2006-2020	2000	2006-2020
Edinburgh - London	11.3	9.6	35.1	2.8	4.9	4.1
Glasgow - London	8.7	7.8	161.3	2.1	-	3.3
Leeds/Bradford - London	20.8	24.4	-	-	-	-
Manchester - London	9.8	8.3	12.5	1.2	1.3	1.1
Newcastle	6.9	8.3	0.8	0.3	0.2	0.2

The results show that the noise burden is extremely site-specific. This can be seen clearly in Figure 16 below which shows the noise burden per passenger (average occupancy) for current flights from the various London airports to regional cities.

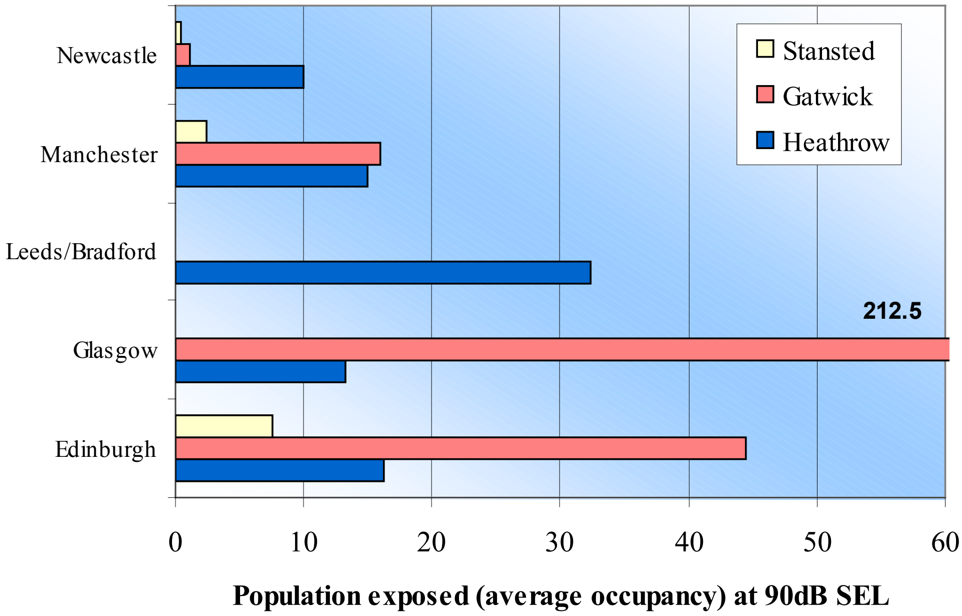

Figure 16: Average population exposed per passenger journey at 90dBA SEL by route for 2000, assuming typical type/route occupancy levels.

The domestic aircraft noise burden is site and route specific. Values differ between routes and airports because of the different aircraft in operation on each route and because of the local population distribution around each airport.

Analysis of the more detailed results (Appendix 2) shows that the same aircraft may have significantly different noise burdens (measured in terms of the number of people affected by a certain noise level) for take-off/landing at different airports or even from different runways at the same airport. The particularly high noise burden for Glasgow arises because of the specific take-off route assumed and population density within the noise contour.

There are large differences (up to an order of magnitude) between aircraft types. Smaller aircraft generally have a lower noise burden (per passenger carried), due to the smaller size of their noise footprint, i.e. because the noise contour from these aircraft does not extend out so far.

Older aircraft (e.g. 737-200) have much a higher noise burden. The removal of these aircraft from the domestic fleet will reduce the noise burden in future years (i.e. for the period 2006-

2020). Nonetheless, there will remain large differences (up to an order of magnitude) in the noise burdens of different aircraft.

The result tables can be compared to assess the relative noise burden from high-speed rail and domestic short-haul aircraft. The results for the current comparison are summarised in Figure 17, adjusted to noise burden per passenger carried for actual (average) occupancy.

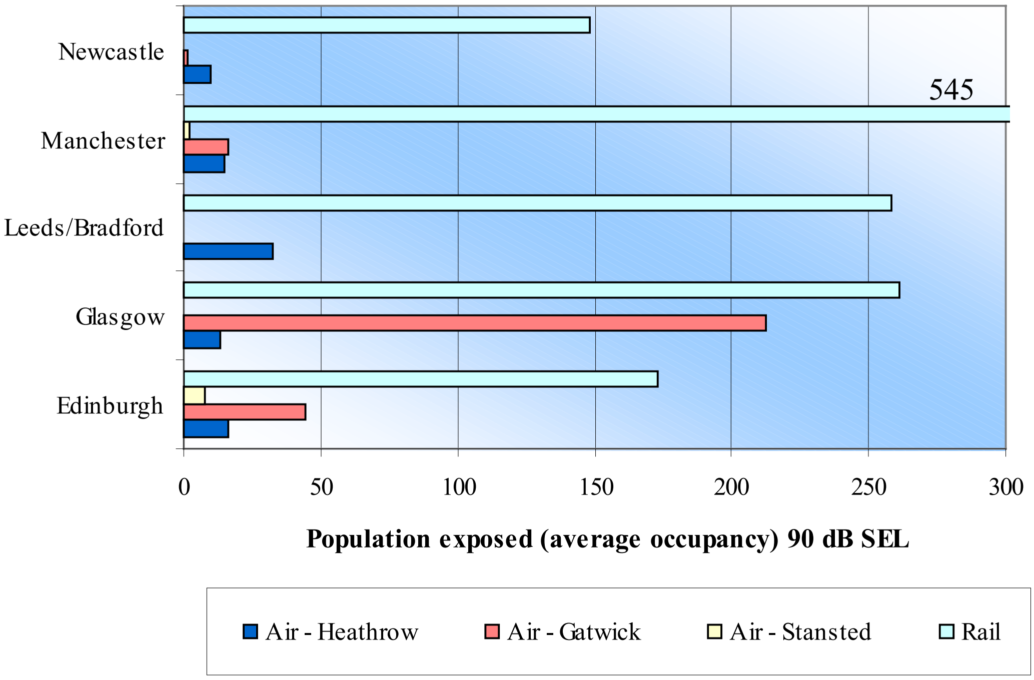

Figure 17: Average population exposed per passenger journey by route, assuming average route occupancy levels.

The analysis of SEL 90dB(A) indicates that high-speed rail has a greater population weighted noise burden than domestic air, per passenger carried (assuming average occupancy), when no screening effects from buildings adjacent to the track are taken into account. Only one air route (Gatwick – Glasgow) has a similar noise burden to high-speed rail. The relative burdens between domestic air and high-speed rail are closer if screening effects from buildings are added for the rail analysis,). They will also change if the relative load factors are changed..

The analysis of future noise levels indicates that changes will occur in the relative comparison between high-speed rail and domestic air. In general, the noise burdens on high-speed rail routes will increase slightly as trains travel at higher speeds after line upgrades (with the exception of the London-Manchester route, which sees very large reductions due to the use of different vehicles). This excludes possible increases in passenger occupancy, as might be expected from the 10 year transport plan. In contrast, the future noise burdens from domestic aircraft will decrease (per average journey) at most airports, as older aircraft are retired. For some airports, e.g. Glasgow and Gatwick, these decreases will be significant and will dramatically reduce the future noise burden for domestic aircraft per journey.

Although the SEL analysis provides an indication of the sound exposure from a single high-speed rail or domestic aircraft journey, it is also important to evaluate the burden in the context of other noise sources for each route. This involves taking into account all train activity along a rail route or all international and domestic landings/take-offs at any airport. This is a more involved analysis and, as an example, has been undertaken for one route (London to Manchester) for both modes.

The analysis has looked at the increase in noise burdens from additional journeys for a thousand additional seats for both modes. For high-speed rail this involved two additional trains. For domestic aircraft, the study assessed the difference for additional capacity provided by additional planes. The results are presented below in Tables 15 and 16. Note the values for aircraft noise are the additive values for Heathrow and Manchester airports. Two sets of values are reported because noise levels will potentially vary according to the trip direction due to the shape of the noise contour and the local distribution of receptors. Additional results for aircraft are presented in Appendix 2.

Table 15. Marginal High-Speed Rail Noise. The number of people exposed to an L_{den} of 68 dB(A) and above from rail on a typical week day for current traffic levels and for an additional 1040 seats (2 trains) carried during the daytime, for a single trip for the Manchester - London route assuming no shielding (inclusion of property shielding could reduce these by 50% or more).

	Number of people exposed to an L_{den} of 68 dB(A)+
Current traffic	100,674
Current traffic with two extra trains	100,926
Additional people exposed	252
% increase in number of people exposed	0.25%

Table 16. Marginal Domestic Aircraft Noise. The number of people exposed to an L_{den} of 68 dB(A) and above on a typical day for additional 1000 seats, over the Manchester to Heathrow route. Values shown are the sum of the additional noise burden from increases in daily movements (average aircraft size remaining unchanged). Analysis of both the Manchester – Heathrow route, and the Heathrow – Manchester route have been assessed.

	Number of people exposed to an L_{den} of 68 dB(A)+	
	Trip direction	
	From Manchester to Heathrow	From Heathrow to Manchester
Current traffic	36,382	36,382
Current traffic + 1000 seats	36,550	36,560
Additional people exposed	168	178
% increase in number of people exposed	0.46%	0.49%

The comparison between domestic aircraft and high-speed rail shows that the additional noise burden is similar per available seat[6]. This is in sharp contrast to the SEL values for the same Manchester – London route above. In the SEL analysis high-speed rail noise for the London

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[6] The addition of screening effects for high-speed rail would lead to a 50% or more reduction in the burden. However, these reductions would be offset by the relative load factors for the two modes, as aircraft have a higher average load.

– Manchester route was very much higher than aircraft (545 people exposed compared to 15 people exposed per passenger journey at 90 dB SEL). The marginal analysis shows that noise burdens from the two modes are determined by background levels and site characteristics for each route. It is not possible to make a clear statement as to whether one mode has a noise advantage without a more detailed analysis of different routes.

Additional analysis has been undertaken for domestic aircraft to investigate if the way additional capacity is added makes a difference (because there is greater flexibility to add capacity for aircraft: for rail only additional services can add significant capacity). There are two ways to respond to increases or decreases in passenger numbers: to change the numbers of planes (as above) or to run the same services with larger or smaller aircraft.

The results are shown in Table 17. These also assess the nature of different levels of changes (e.g. if adding 1000 seats produces a lower impact per passenger carried than adding 2000).

Table 17. Marginal Domestic Aircraft Noise. The number of people exposed to an L_{den} of 68 dB(A) and above on a typical day for additional seats, over the Manchester to Heathrow route. Values shown are the sum of the additional noise burden from increases in daily movements (average aircraft size remaining unchanged) and from changes in aircraft size (movements remaining unchanged). Analysis of both the Manchester – Heathrow route, and the Heathrow – Manchester route have been assessed, as well as an average value for a return trip.

Increase movements, aircraft size unchanged

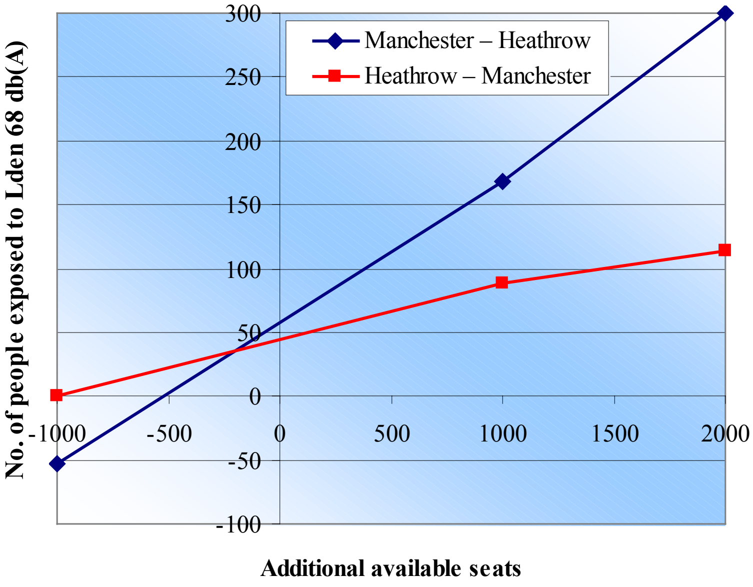
	Number of people exposed to an L_{den} of 68 dB(A)+ (Sum of Manchester & Heathrow Airports)	
Number of	**Trip direction**	
additional seats (Pax)	Manchester – Heathrow	Heathrow – Manchester
-1000	-53	0
+1000	168	89
+2000	300	114

Increase aircraft size, movements unchanged

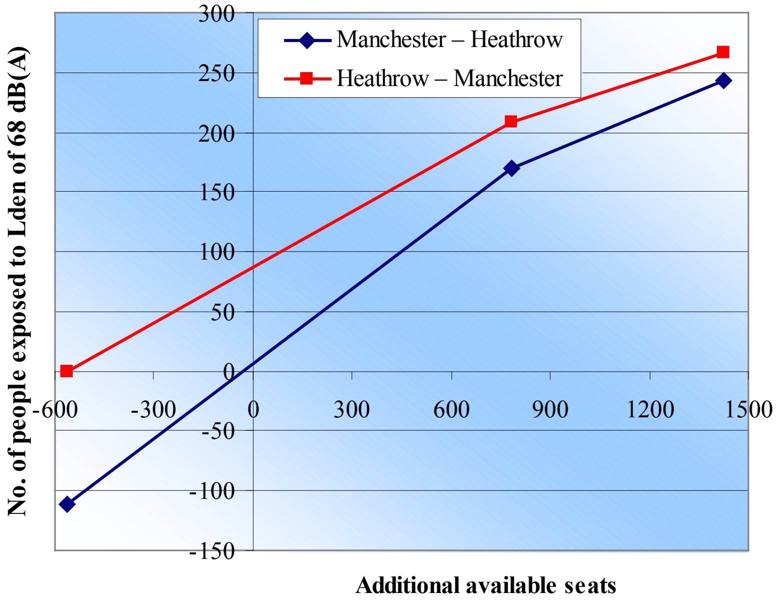
	Number of people exposed to an L_{den} of 68 dB(A)+ (Sum of Manchester & Heathrow Airports)	
Number of	**Trip direction**	
additional seats (Pax)	Manchester – Heathrow	Heathrow – Manchester
-563	-111	0
+784	170	208
+1425	243	266

These tables show that the way changes in capacity are added make a large difference to the noise burden. For example, increasing the number of movements on the Manchester – Heathrow route leads to lower increased noise burdens than increasing aircraft size. This reflects the fact that smaller aircraft have lower noise footprints. Similarly, decreasing the size of aircraft leads to a greater reduction in noise exposure than decreasing the number of movements.

When plotted (Figure 18), it is also clear that marginal noise burdens is strongly non-linear (i.e. the burden per plane, and per additional passenger, varies non-linearly according to the overall change in movements or aircraft). This is very important with respect to potential substitution between the two modes.



Changes from additional services.



Changes from different aircraft size.

Figure 18. The number of people exposed to an L_{den} of 68 dB(A) per additional seat provided

A number of research areas are also identified. It would be useful to undertake an additional marginal analysis for another route, and to investigate the changes in noise burdens for different numbers of marginal trips (both increases and decreases). Furthermore, the analysis here has looked at noise burdens assuming a threshold for moderate annoyance (68 dB L_{den}). There will be noise burdens below this level and it would be useful to evaluate whether a lower threshold changes the noise burdens of the two modes. Finally, the analysis of the total household weighted noise increase (cumulative increase in dB(A)) above a threshold would be useful, as it would allow an evaluation of the relative noise burden in economic terms.

Overall, the noise burden, for both existing and additional journeys, is extremely site and route specific. The results here indicate that aircraft in use on domestic routes may have a small advantage in terms of the absolute noise burden. We stress, however, that this does not translate to a higher noise impact because background noise levels determine the relative burden of a regional journey (due to the logarithmic nature of noise). Our conclusion is that without more detailed analysis, on a route by route basis, it is not possible to say categorically that one mode has a lower noise burden than the other.

5 Land-Use and Other Environmental Effects

Atmospheric emissions and noise comprise the two main environmental burdens from rail and aviation. However, there are a large number of other potential environmental burdens from the two modes. Details are presented in Appendix 3 and summarised below.

5.1 Land-Use

One of the major issues in comparing the environmental effects of rail and air is from land-take. An assessment of the land used for airports and railways has been investigated. In order for the comparison of land take between the two modes to be fair, it is important to be comprehensive in the land-take for both modes, such as to include:

- Comparing runway and track area:
- Comparing airfield and total line area:
- Comparing total airport area with stations, ancillary infrastructure and depots.

For the five rail journeys, the length of each route was taken from a GIS. The land-taken from the routes was estimated, based on assumption about the track width along the ECML and WCML. The width of a four track line (shown in the figure below) is approximately 27m, whilst that of a two track line is 20m.

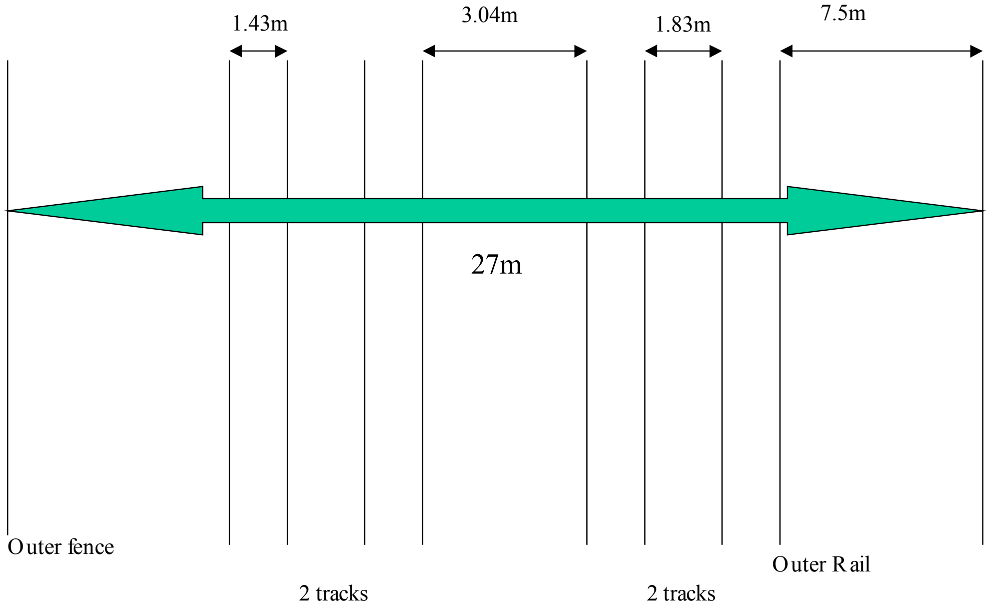


Figure 19. Land-use from Rail Lines.

In both cases, the land includes the area between the outer rail and the boundary fence. This land is either covered in ballast or will be managed vegetation. For the best estimate, it is assumed that 40% of each route is four-line track. This gives a total land area of 56km^2 for the specific routes (connecting the five cities with London). The low and high values (assuming all 2 track or all 4 track) give a range of 49 km^2 to 67 km^2. These values will rise further with the inclusion of railway stations, maintenance depots, and other areas. There are

2500 national railway stations (TSGB, 2000) and around 50 freight depots (1995 value, TSGB, 2000)

Some data has been collected on airport land-take. The total area of an airport includes land that the airport operator owns and also the service buildings for the airport such as airport shops. The land-take for the airports of relevance for this study is presented below.

Table 18. Land-take for UK Airports.

Airport and information source	Total Area	Airfield (runway, taxiing area etc.)	Buildings and ancillary infrastructure
Newcastle (Surveyor, Newcastle airport, Personal Communication 2001)	4.94 km^2	*1.5km^2* (~30% of total based on plan area)	*0.74 km^2* (buildings ~15% plan area)
Leeds Bradford (Transport planning adviser, Leeds Airport 2001)	1.58km^2	1.33 km^2	0.25 km^2
Glasgow (Environmental Manager, Scottish Airports 2001)	3.29km^2		
Edinburgh (Environmental Manager, Scottish Airports 2001)	3.75km^2		
Manchester (Land use planning manager, Manchester Airport 2001)	6.25 km^2 (airport operational area)	3.9 km^2 (runways, taxiways and apron)	1.78 km^2 (excludes airfield and 0.57 km^2 greenfield within operational area)
Heathrow (BAA, 2000)	12 km^2	-	-
Stansted	-	-	-
Gatwick	6.7 km^2.		

This initial analysis shows that aviation requires less land than rail transport. However, it is difficult to separate out the land attributable to regional journeys against the background of overall transport activity for both modes. This means it is not possible to compare the relative land-take for high-speed rail and domestic aviation.

Although land-take, and the environmental impacts from this, e.g. habitat loss, fragmentation, community severance, etc are important, the key issue is the comparison of future land-take for the two modes, i.e. how close are both modes to capacity limits, when and how much additional land-take might be required. The analysis of future land take required is highlighted for further investigation should a second phase of the study be undertaken.

5.2 Other Effects

There are other potential environmental effects from rail and air that have not been considered in detail, but are presented for completeness in the Table below. More details are presented in Appendix 3.

Table 19. Other Potential Effects.

Effect	Rail	Air
Fuel spills	Diesel leakage from trains at stations leading to groundwater and land contamination. Leakage from underground pipes. General diesel spills during refuelling	Fuel spills of kerosene. Drainage contamination with fire fighting foam
Releases during terminal operations, cleaning and maintenance	Maintenance of train tracks requires grit spraying trains to prevent slippage on leafy tracks	CFCs in use or in stock at airports Other terminal operations.
De-icing	De-icing trains spray de-icer over track	Glycol used on aircraft. Also runway de-icer (but often glycol alternative)
Herbicides, pesticides and insecticides applied	Vegetation often allowed to grow beside rail tracks and can potentially act as a wildlife corridor through built up areas, though vegetation managed. Use of herbicides, pesticides and insecticides in certain areas.	Use of herbicides, pesticides and insecticides.
Habitat disruption from land-take, fragmentation	52% of wetland areas have rail infrastructure close to their centres 44% of special bird areas have rail infrastructure close to their centres (TERM 2000)	Birds are discouraged from flying over runways to reduce accidents 7% of wetland areas have air infrastructure close to their centres 4% of special bird areas have air infrastructure close to their centres (TERM 2000)
Waste generation and disposal	Waste from station. Direct release of toilet effluent and detergent onto train tracks The majority of contaminated ballast and sleepers are recycled or re-used	Waste from airport and aircraft.
Other life-cycle effects	Others environmental effects from electricity generation (e.g. risk of accidents and waste disposal from nuclear plant),	Other environmental effects from oil extraction, transportation and processing (e.g. emissions, oil spills, etc.)
Other social effects	Community severance (urban areas)	

6 Conclusions and Research Recommendations

High-speed rail has much lower greenhouse gas emissions than domestic aircraft for regional journeys. For other atmospheric pollutants, it is difficult to conclude if aircraft or high-speed rail currently has an environmental advantage because of the different emissions of different pollutants for the two modes. High-speed rail has lower emissions of NOx, CO and VOCs, whilst domestic aircraft have lower emissions of SO_2. Emissions of PM_{10} are currently similar. In future years, high-speed rail is likely to have benefits for all pollutants except SO_2 due to changes in the electricity generation mix. These benefits will be greatest on shorter trips.

The study has also investigated emissions from surface access trips to airports and railway stations. It is clear that the choice of surface access mode is extremely important in the relative comparison of the two modes. Unfortunately the lack of data means it is not possible to include emissions from surface access for the two modes.

The noise burden from high-speed rail and aircraft is highly dependent on the specific routes involved. High-speed rail has a greater population weighted noise burden than air, per passenger carried, when no screening effects of buildings adjacent to the track are taken into account. The relative burdens between air and rail are closer if screening effects from buildings are added for the rail analysis. However, the relative noise burden changes when other noise sources for each journey are added. An analysis of marginal trips (additional vehicles), on one route, shows that the additional noise burden is similar per passenger carried.

A number of research priorities have been identified in the study. The most important are:

- To compare the environmental *impacts* of atmospheric emissions from domestic aircraft and high-speed trains, assessing the different locations of various emissions (and effects on receptors) and the relative damage of different pollutants. We highlight this evaluation as a priority for future research. One way to undertake this comparison would be through the analysis of the relative external costs of the two modes.
- To investigate surface access emissions from the two modes in more detail. It is clear that the choice of surface access mode is extremely important in the relative comparison of the two modes. Unfortunately the lack of data means it is not possible to include these emissions.
- To further assess the noise burdens and impacts of the two modes. It would be useful to undertake an additional marginal analysis for another route, and to investigate the changes in noise burdens for different numbers of marginal trips (both increases and decreases). Furthermore, the analysis here has looked at noise burdens assuming a threshold for moderate annoyance (68 dB L_{den}). There will be noise burdens below this level and it would be useful to evaluate whether a lower threshold changes the noise burdens of the two modes. Finally, the analysis of the total household weighted noise increase (cumulative increase in dB(A)) above a threshold would be useful, as it would allow an evaluation of the relative noise burden in economic terms.

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Appendices

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Appendix 2	Additional Information Noise
Appendix 3	Other Environmental Burdens and Literature Review

Appendix 1. Additional Information on Atmospheric Emissions

This Appendix presents the additional information to the chapter on atmospheric emissions for rail and short-haul air travel.

High-speed trains in Europe

High-speed trains were introduced into Europe with the TGV (Train de Grande Vitesse) link between Paris and Lyon in 1981. It was followed by other TGV lines, and in the early 1990s, high-speed trains between Stockholm and Goteborg in Sweden (X-2000), and the German ICE trains (InterCity Express) from Stuttgart to Mannheim and Hamburg to Munich/Frankfurt (Jorgensen and Sorenson, 1997). TGV trains are capable of top speeds of 270 and 320 km/hour. The ICE train has top speeds of around 250 km/hour, though it operates on dedicated track. The X-2000 has a top speed of 200 km/hour and operates on shared track.

Nearly all high-speeds trains in operation are electric powered. They usually operate at speeds of around 250 km/hour. Details on calculating energy consumption for electric trains have been produced in the European MEET project - Methodologies for Estimating Air Pollutant Emissions from Transport. (Jorgensen and Sorenson, 1997). This report recognises that data on energy consumption for high-speeds train is generally scarce. Data is shown below for the German ICE train along one route. Variations occur because of different gradients, stopping distances, and maximum speeds.

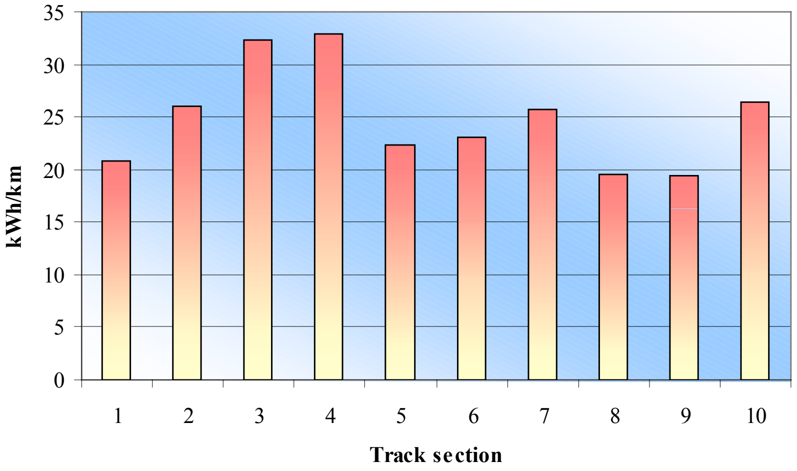

Figure A1. Electricity consumption for German ICE High Speed Trains along one route by section.

The differences between the highest and lowest energy consumption (averages for track sections) vary from around 20 kWh/km to 33 kWh/km. Average electricity consumption on a few ICE lines and TGV lines are shown below – the TGV trains having lower consumption. When averaged over a line, most of these high-speed trains have broadly similar energy consumption.

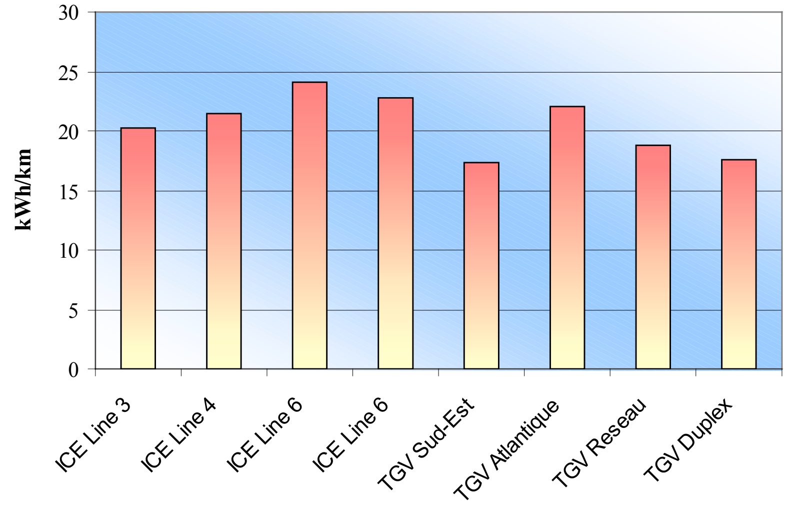

Figure A2. Average electricity consumption on ICE lines and TGV lines.
Source: MEET (1997).

Future Generation Mixes

Details of the future UK electricity supply mix, in TWh of electricity supplied by generation technology, are shown below under the DTI central low and central high scenarios (DTI, 2000). These forecasts are needed to calculate future emissions from electric trains.

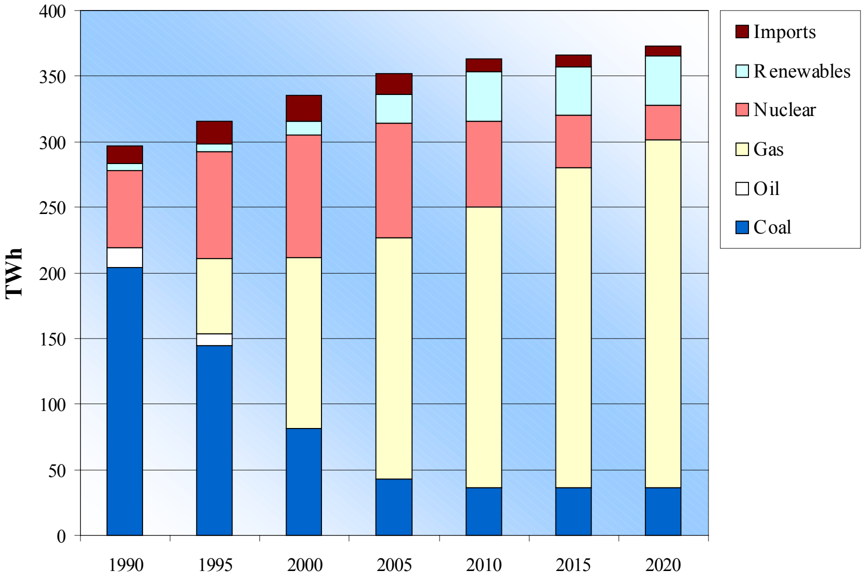

Figure A3. UK Future Generating Mix – Central Growth, High Energy Price Scenario.

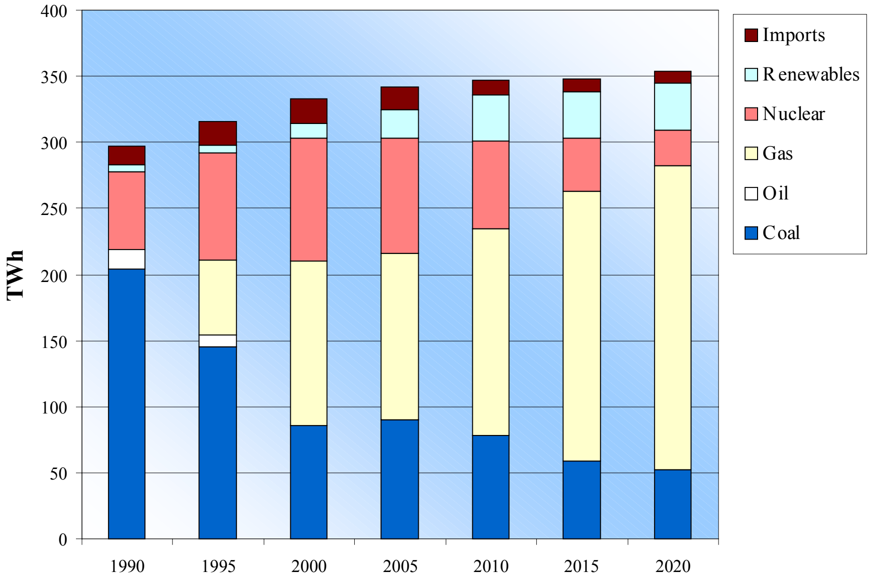

Figure A4. UK Future Generating Mix – Central Growth, Low Energy Price Scenario .

Under the low energy price scenario, even the best coal plants find it difficult to compete against gas, and coal generation declines. Post 2010, the proportion of gas used still rises as nuclear capacity declines. By 2020, gas is the dominant generating plant in the electricity supply mix. Under a scenario where energy prices are higher, coal capacity is better placed, and continues to generate a significant proportion of total energy. Post 2010, coal does decline slightly and the decline in nuclear means that by 2020, gas again becomes the major generation supply plant. Recent trends in oil prices suggest that the 'high' energy price scenario is more likely. Based on the projections, this would mean coal is better able to compete in the short term. The changes in the generation mix feed through to changes in the average electricity generation mix, and so, future emissions from high-speed electric trains in the UK.

Results Tables (Maximum Occupancy)

Table A1. Current Emissions from Domestic Air and High-Speed Trains, Maximum Occupancy.[7]

	grammes per passenger km (maximum occupancy)					
	Total	**Surface Emissions**				
	CO_2	**NOx**	**PM_{10}**	**CO**	**HC**	**SO_2**
London – Edinburgh						
Rail (electric + diesel)	31.6	0.24	0.02	0.062	0.029	0.17
Rail (sensitivity - electric only)	12.6	0.03	0.0017	0.005	0.0007	0.069
Air (weighted average)	135	0.11	0.0041	0.15	0.021	0.010
London – Glasgow						
Rail	12.4	0.030	0.0016	0.005	0.0007	0.068
Air (weighted average)	143	0.12	0.0046	0.09	0.006	0.011
London – Leeds						
Rail (electric + diesel)	12.5	0.046	0.0031	0.010	0.0036	0.066
Rail (sensitivity - electric only)	12.0	0.029	0.0016	0.005	0.0007	0.066
Air (weighted average)	229	0.21	0.0059	0.39	0.026	0.022
London – Manchester						
Rail	14.4	0.035	0.0019	0.0062	0.0008	0.079
Air (weighted average)	225	0.23	0.0067	0.28	0.027	0.021
London – Newcastle						
Rail (electric + diesel)	14.2	0.084	0.006	0.021	0.010	0.068
Rail (sensitivity – electric only)	12.6	0.030	0.0017	0.0054	0.0007	0.069
Air (weighted average)	153	0.11	0.0040	0.29	0.052	0.013

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[7] Care must be taken in using the maximum occupancy value with respect to actual situations. Maximum occupancy for air is less than 100%, as capacity is added before 100% is reached. Maximum occupancy for rail could conceivably exceed 100%

Table A2. Future Emissions from Domestic Air and High-Speed Trains, Maximum Occupancy, (2006-2020).[8]

	grammes per passenger km (maximum occupancy)					
	Total	**Surface Emissions**				
	CO_2	**NOx**	**PM_{10}**	**CO**	**HC**	**SO_2**
London – Edinburgh						
Rail (2006 central high)	11.5	0.024	0.0014	0.004	0.0003	0.023
Rail (2020 central high)	10.4	0.016	0.0006	0.0029	0.0003	0.007
Air (2006-2020 weighted average)	119	0.11	0.0021	0.12	0.017	0.009
London – Glasgow						
Rail (2006 central high)	11.8	0.025	0.0015	0.0041	0.0003	0.024
Rail (2020 central high)	10.7	0.016	0.0006	0.0029	0.0003	0.007
Air (2006-2020 weighted average)	117	0.12	0.0018	0.07	0.003	0.009
London – Leeds						
Rail (2006 central high)	12.4	0.026	0.0015	0.0043	0.0003	0.025
Rail (2020 central high)	11.2	0.017	0.0006	0.0031	0.0003	0.008
Air (2006-2020 weighted average)	207	0.26	0.0032	0.23	0.011	0.020
London – Manchester						
Rail (2006 central high)	12.2	0.026	0.0015	0.0042	0.0003	0.024
Rail (2020 central high)	11.0	0.017	0.0006	0.003	0.0003	0.008
Air (2006-2020 weighted average)	203	0.23	0.0039	0.21	0.021	0.019
London – Newcastle						
Rail (2006 central high)	11.5	0.024	0.0014	0.004	0.0003	0.023
Rail (2020 central high)	10.4	0.016	0.0006	0.003	0.0003	0.007
Air (2006-2020 weighted average)	163	0.14	0.0025	0.27	0.046	0.014

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[8] Care must be taken in using the maximum occupancy value with respect to actual situations. Maximum occupancy for air is less than 100%, as capacity is added before 100% is reached. Maximum occupancy for rail could conceivably exceed 100%

Surface Access Data

Table A3. Mode of transport (%) for UK and non-UK residents to or from UK airports.

		Private car	Hire car	Taxi/ Minicab	*(Total car)*	Under-ground	Rail	Bus/coach
Heathrow	UK	44	2	25	*71*	11	6	11
	Non-UK	22	6	27	*55*	18	8	19
Gatwick	UK	58	1	17	*76*	0	16	7
	Non-UK	20	6	11	*37*	0	37	24
Manchester	UK	64	1	27	*92*	0	6	2
	Non-UK	45	12	26	*83*	0	11	5

Source: how do passengers travel to and from UK airports? DETR.

References

Jorgensen. M., and Sorenson, S., (1997). Report for the Project MEET: Methodologies for Estimating Air Pollutant Emissions from Transport. Estimating Emissions from Railway Traffic. Deliverable Number 17. DG-VII. European Commission.

Appendix 2: Additional Information for Noise

SEL Analysis

Table A4 shows populations exposed by aircraft type for those types operating in year 2000. Additionally the population exposed is expressed as the number of people exposed per available seat (i.e. assuming 100 percent load factor) and based on actual load factors obtained from CAA statistical data.

Marginal Analysis

Marginal aircraft noise has been assessed by examining the number of people exposed to an L_{den} of 68 dB(A) and above on a typical day for current traffic levels and for an alternative number of people (as indicated), over the Manchester to Heathrow route, with both increases in daily movements average aircraft size remaining unchanged, and with changes in aircraft size.

Table A5.
Marginal Change on MAN-LHR at Manchester Airport
(i) increase movements, aircraft size unchanged

Direction	**Manchester – Heathrow**			**Heathrow – Manchester**			**Average**		
Pax change	-1000	+1000	+2000	-1000	+1000	+2000	-1000	+1000	+2000
57 Lden	-189	282	383	-397	136	414	-292	209	399
63 Lden	-28	185	275	-73	14	139	-51	100	207
68 Lden	0	42	170	0	63	63	0	97	117

(ii) increase aircraft size, movements unchanged

Direction	**Manchester – Heathrow**			**Heathrow – Manchester**			**Average**		
Pax change	-563	+784	+1425	-563	+784	+1425	-563	+784	+1425
57 Lden	-104	502	532	-359	226	1470	-232	364	1001
63 Lden	-28	275	275	-70	14	580	-49	145	428
68 Lden	0	170	171	0	152	190	0	161	181

Marginal Change on MAN-LHR at Heathrow Airport
(iii) increase movements, aircraft size unchanged

Direction	**Manchester – Heathrow**			**Heathrow – Manchester**			**Average**		
Pax change	-1000	+2000	+5000	-1000	+2000	+5000	-1000	+2000	+5000
57 Lden	-789	2418	5090	-434	2192	3173	-612	2305	4132
63 Lden	-156	705	1399	47	394	1997	-55	550	1698
68 Lden	-53	251	324	0	52	128	-27	152	226

(iv) increase aircraft size, movements unchanged

Direction	**Manchester – Heathrow**			**Heathrow – Manchester**			**Average**		
Pax change	-563	+784	+1425	-563	+784	+1425	-563	+784	+1425
57 Lden	-1079	-97	2412	-258	1726	2109	-669	815	2261
63 Lden	-177	-90	391	116	349	349	-31	130	370
68 Lden	-111	0	72	0	56	76	-56	28	74

Table A4. Aircraft types operating in year 2000 to London routes.

		Based on 90dB(A) SEL Footprints											
		TO/FROM HEATHROW				TO/FROM GATWICK				TO/FROM STANSTED			
Type	Pax	LF	Pop	Exp/pax	Exp/apax	LF	Pop	Exp/pax	Exp/apax	LF	Pop	Exp/pax	Exp/apax
EDINBURGH													
Large twin-turboprop	50		-	-	-		-	-	-	26.1	118	2.36	9.06
Avro RJ	95		-	-	-		-	-	-		-	-	-
Fokker 100	106	68.6	309	2.91	4.24		-	-	-		-	-	-
Boeing 737-200	116		-	-	-	79.1	6811	58.72	74.27	70.1	5522	47.60	67.89
Boeing 737-300/400/500	128	69.1	1811	14.15	20.47	79.1	525	4.10	5.19	70.1	530	4.14	5.90
Airbus A319/320/321	149	69.1	850	5.70	8.25		-	-	-		-	-	-
Boeing 757-200	195	69.4	2235	11.46	16.51		-	-	-		-	-	-
Boeing 767-300	252	69.4	5101	20.24	29.16		-	-	-		-	-	-
GLASGOW													
Large twin-turboprop	50		-	-	-		-	-	-		-	-	-
Avro RJ	95		-	-	-		-	-	-		-	-	-
Fokker 100	106	68.2	145	1.37	2.01		-	-	-		-	-	-
Boeing 737-200	116		-	-	-	75.9	23107	199.20	262.44		-	-	-
Boeing 737-300/400/500	128	65.8	1821	14.22	21.62	75.9	535	4.18	5.50		-	-	-
Airbus A319/320/321	149	65.8	673	4.52	6.86		-	-	-		-	-	-
Boeing 757-200	195	64.4	2137	10.96	17.02		-	-	-		-	-	-
Boeing 767-300	252	64.4	6725	26.69	41.44		-	-	-		-	-	-

LF = load factor
Pop = population
Pax = passenger numbers

Table A4. (continued)

		Based on 90dB(A) SEL Footprints											
		TO/FROM HEATHROW				TO/FROM GATWICK				TO/FROM STANSTED			
Type	Pax	LF	Pop	Exp/pax	Exp/apax	LF	Pop	Exp/pax	Exp/apax	LF	Pop	Exp/pax	Exp/apax
LEEDS													
Large twin-turboprop	50		-	-	-		-	-	-		-	-	-
Avro RJ	95		-	-	-		-	-	-		-	-	-
Fokker 100	106	64.4	663	6.25	9.71		-	-	-		-	-	-
Boeing 737-200	116		-	-	-		-	-	-		-	-	-
Boeing 737-300/400/500	128	64.4	2803	21.90	34.01		-	-	-		-	-	-
Airbus A319/320/321	149		-	-	-		-	-	-		-	-	-
Boeing 757-200	195		-	-	-		-	-	-		-	-	-
Boeing 767-300	252		-	-	-		-	-	-		-	-	-
MANCHESTER													
Large twin-turboprop	50		-	-	-		-	-	-	55.9	59	1.17	2.10
Avro RJ	95		-	-	-		-	-	-	55.9	0	0.00	0.00
Fokker 100	106	57.4	208	1.96	3.41		-	-	-		-	-	-
Boeing 737-200	116		-	-	-	78.7	6406	55.22	70.19		-	-	-
Boeing 737-300/400/500	128	64.7	1500	11.72	18.11	78.7	214	1.67	2.13		-	-	-
Airbus A319/320/321	149	64.7	665	4.47	6.90		-	-	-		-	-	-
Boeing 757-200	195	68.7	2254	11.56	16.82		-	-	-		-	-	-
Boeing 767-300	252	68.7	5419	21.50	31.30		-	-	-		-	-	-

Table A4. (continued)

		Based on 90dB(A) SEL Footprints											
		TO/FROM HEATHROW				TO/FROM GATWICK				TO/FROM STANSTED			
Type	Pax	LF	Pop	Exp/pax	Exp/apax	LF	Pop	Exp/pax	Exp/apax	LF	Pop	Exp/pax	Exp/apax
NEWCASTLE													
Large twin-turboprop	50		-	-	-	68.3	5	0.10	0.15	56.2	0.4	0.01	0.01
Avro RJ	95		-	-	-	68.3	114	1.20	1.76		-	-	-
Fokker 100	106	69.0	167	1.57	2.28		-	-	-		-	-	-
Boeing 737-200	116		-	-	-		-	-	-		-	-	-
Boeing 737-300/400/500	128	69.0	1552	12.13	17.58		-	-	-		-	-	-
Airbus A319/320/321	149	69.0	620	4.16	6.04		-	-	-		-	-	-
Boeing 757-200	195	69.0	2020	10.36	15.02		-	-	-		-	-	-
Boeing 767-300	252	69.0	5080	20.16	29.23		-	-	-		-	-	-

Appendix 3: Other Burdens and Literature Review

Land-take and Ecosystems

The land take within the EU due to railways shows that the majority of the infrastructure is built in agricultural areas.

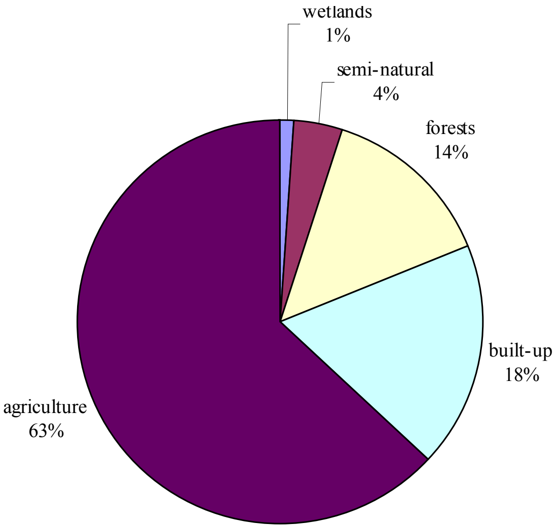

Figure A5. Land take by railways in the EU-15 (including their immediate surroundings) according to land-cover type in 1997

Source: EEA (TERM 2000)

Information for the distribution of railway land-take in the UK is not currently available, though the percentages for built up and wetland areas are likely to be higher than for the EU as a whole, and the forest land take much lower. From the TERM report it can be estimated that the total UK land take of railways is under 0.2% of the total country area. Fragmentation impacts are a serious consideration for rail track stretching across natural habitat.

The number of Ramsar (wetland) sites in the UK affected by rail infrastructure has been analysed in the TERM report (2000). Approximately 52% of wetland sites had rail infrastructure within 5km of their centre, the highest percentage in the EU. The report also concluded that 44% of special bird areas have major rail infrastructure within 5km of their centre (TERM 2000).

The land take of train tracks is significant and thus the impact of developing new infrastructure in the UK may be high. The use of trains, as opposed to HGVs, to transport aggregates and construction materials is likely to minimise disruption to the environment.

However, new rail infrastructure construction might be likely to cause habitat disruption and further severance.

Similar issues arise for airports. The expansion of airports is often in Green Belt land (Gavin 1999). Developments to existing runways and airport terminals may increase habitat fragmentation. In cases where local habitats are close to airports, there is the additional risk from water pollution. Although land-take is smaller from airports, habitat issues are important - at the recent Runway 2 extension at Manchester Airport the relocation of over 30,000 amphibians (including 4000 newts to local ponds) was required.

Safety requirements at airports result in the need to discourage the presence of birds to minimise the risk of 'bird-strike' incidents. Discouraging birds across a long strip of land can have some fragmentation affects, by restricting the movement of birds in the surrounding areas. Landscaping has been used at Glasgow and Edinburgh airports (Scottish Airports 1998/99) in order to minimise bird hits.

As with rail, the number of wetland sites with major airport infrastructure within 5km of their centre was analysed by the TERM report (2000). Approximately 7% of Ramsar (wetland) areas had airport infrastructure within 5km of their centre, the highest percentage in the EU-15. 4% of special bird areas in the UK have major airport infrastructure within 5km of their centre.

Other potential environmental burdens - Air

The other potential environmental burdens are summarised and discussed below. For air, these are:

- Fuel spills from aircraft refuelling
- Releases during terminal operations, cleaning and maintenance;
- De-icing chemicals from airports (and contamination of surface and ground water)
- Herbicides, pesticides and insecticides used along side the runway
- Waste generation and disposal

Fuel spills from aircraft refuelling

Fuel spills do occasionally occur from aircraft refuelling. Volumes are generally low and infrequent. Overloading of the drainage system by foam used in fire fighting activities is a potentially more common environmental incident.

Releases during terminal operations (cleaning, maintenance etc.)

The extreme environmental conditions that aircraft are exposed to at high altitudes mean that their components demand high levels of protection. A number of solvents are used in aircraft maintenance such as halons, CFCs, chlorinated solvents, toluene and xylene which have a variety of environmental impacts from ozone depletion to toxicity (BA 1996). The practices where chemicals are used in maintenance and cleaning are shown below.

The volumes of chemicals used are significant, and thus pose a potential risk to the environment through spillages and fugitive emissions. In 1997/98 Heathrow Airport had

16,499 kg of CFCs in use or in stock and Gatwick had 16,444 kg of CFCs. The seven UK BAA airports have a total of 37,597 kg of CFCs in use or in stock.

Environmentally sensitive chemicals used for aviation

Washing / Cleaning	*Aircraft production and component maintenance*	*Aircraft maintenance*
Exterior cleaner: Solvent based and water based	Dyes, additives and fluorescent ink	Plating strippers
Solvents for washing spray guns	Construction: Acids Cadmium Sodium hypochlorite solution Caustic soda Sodium bisulphate Lead plating Nickel metal plating Nickel compounds Chromic acid Cyanide	Paint strippers: Phenolic and non-phenolic Paint thinners Aircraft and non-aircraft paint: 50% solvent
		Hydraulic fluids: Mineral based Phosphate ester based Silicate ester based
		Corrosion inhibitor

Source: Environmental sustainability in the aerospace industry 1997 (British Airways, Aviation and the environment, 1996)

There can be some additional chemicals used in-flight such as chlorine for on board water purification and bactericides for sanitising aircraft lavatories.

De-icing chemicals

De-icing fluid is applied to runways and aircraft during cold weather only, it is the most significant potential risk to water quality from airport activity (BAA 1997/8). The majority of de-icing fluid is based on polypropylene glycol, which is non-toxic and biodegradable (BA 1996). The fluid is sprayed onto aircraft and approximately 80% of the glycol runs off the aircraft when it is applied, and seeps into the ground if it is not collected. An additional 15% is emitted to the air. Although glycol is biodegradable, large emissions could impact on groundwater and waterways as glycol has a significant biochemical oxygen demand (BAA 1997/8).

Steps can be taken to reduce the run off of glycol by using vacuum trucks and a drainage system to collect the glycol for re-use. Consumption can also be minimised by more effective application techniques (SAS 1995). SAS airports have managed to collect 80-90% of the glycol used in 1994/1995. BAA currently use an improved acetate formation of glycol which has one third of the BOD of glycol (0.3 kg BOD per kg product) (BAA 1997/98). Heathrow has developed a code of best practice for using de-icing chemicals.

BOD kg load applied from de-icing chemicals.

Airport	**96/97 BOD kg from de-icing chemicals**	**97/98 BOD kg from de-icing chemicals**
Heathrow	339,000	345,000
Gatwick	218,540	114,450
Stansted	155,571	50,002
Glasgow	195,000	85,083
Edinburgh	192,000	138,387

Source: BAA 1997/98

For new runways under construction, a waterproof layer one metre below ground level can be used to trap the glycol with a layer of gravel above it containing enough bacteria to naturally degrade the glycol. This method has successfully been used at Munich Airport.

There are also large amounts of de-icer applied to runways in the UK. Non-polluting alternatives to glycol exist, though some airports still use glycol based de-icing agent on their runways, for example, during 1998/99, 163,400 litres of anti-icer was applied to airfield pavements at Manchester Airport. To prevent pollution, contaminated runoff is diverted to a foul sewer - in 1998/99 780,000 m^3 of contaminated runoff was diverted from watercourses into this system (Manchester Airport 2000).

Herbicides, fertilisers, pesticides and insecticides used along side the runway

The boundaries of the runway and land in use at the UK airports will need considerable amounts of herbicides, pesticides and insecticides to control vegetation and pests. Fertilisers are also used to maintain grass condition etc. At Manchester Airport, the use of herbicides has been reduced by 20% from 1997/98 levels and no residual herbicides are used. Vegetable hydraulic oils have been used in all mowers since 1998 in order to reduce soil contamination with oil. Mulch mowers are used which return the nutrients to the soil and reduce the need for application of fertilisers and chemicals (Manchester Airport 2000).

Waste Generation

There are sources of waste generation in the aviation industry, though many will arise from the waste generated by passengers. The waste to landfill per passenger and the percentage of waste recycled at the BAA airports is as follows:

Quantities of airport waste that are recycled or sent to landfill

Airport	**Waste to landfill per passenger (kg) (97/98)**	**Percentage of waste recycled out of total waste arising (97/98)**
Heathrow	0.32	17.0%
Gatwick	0.36	13.7%
Stansted	0.44	5.7%
Glasgow	0.31	3.1%
Edinburgh	0.19	7.2%

The sources of waste are many and varied, some are listed below (BAA 1997/98):

- Aircraft (newspapers, plastic, cans, glass, food waste)
- Terminals (retail delivery packaging, food wrapping etc)
- Vehicle and aircraft maintenance operations (oil, chemical residues, cans, plastic)
- Construction (concrete, metal, wood, soils)
- Hazardous wastes (fluorescent tubes, batteries, anti-freeze, chemicals)

Other Environmental Burdens - Rail

The other potential environmental burdens are summarised and discussed below. For rail, these are:

- Fuel spills from train refuelling
- De-icing chemicals applied to train tracks and leaf removal
- Releases during operations such as cleaning and maintenance
- Waste generation and disposal

Fuel spills

Fuel spills from re-fuelling diesel engines are a problematic source of contamination both of ground water and soil. The main problems arise from the storage of diesel for refuelling locomotives (Railtrack 2000). As with air, spills do occur, though they are generally small in volume and infrequent.

De-icing train tracks and removing leaves

De-icing is necessary along train tracks, especially for electric trains. Railtrack's main de-icing strategy is to spray de-icing fluid on the tracks by using de-icing trains (Railtrack 2001). Trains are also run during the night to keep the tracks clear.

Leaves on the line are a significant problem for the railways of the UK, hence Railtrack undertake trackside vegetation management. This involves felling trees and thinning branches. Railtrack has a fleet of special 'sandite' trains which spread a gritty paste on the track to give trains a better grip and they also clean the rails using high-pressure water jets to remove crushed leaves before they form a hard coating (Railtrack 2000).

Waste generation and disposal

In addition to wastes generated at stations, solid waste from Railtrack activities includes end of life rails, sleepers, ballast and construction waste. The ballast supporting the rails becomes compacted and contaminated and thus needs replacing, over 800,000 tonnes of ballast were removed in 1999 of which 95% is recycled.

Literature Review: Existing Studies of Rail and Air

The literature review has covered significant and recent publications on the environmental impacts of air and rail. The review focuses on comparative studies, i.e. those that directly compare the two modes – a much wider body of literature exists on each separate mode, and for specific areas, e.g. aviation and climate change, this has been included.

The various findings are brought together in the tables, summarising noise emissions, carbon emissions, NO_x emissions and other environmental pollutants of concern.

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(DG TREN 2001)- European Commission web-site, DG Transport and Energy:
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Summary of literature

Report	**Energy**		**CO_2**		**Other pollutant emissions**		**Noise**	
	Rail	Air	Rail	Air	Rail	Air	Rail	Air
BAA 1997/98		11.3 KWh energy consumption per passenger		4.51 kg per passenger				0.0009 noise infringements per departure – day (London airports) 0.027 infringements per departure - night
TERM 2000	1 MJ per passenger km (8 EU countries 1995)	3 MJ per passenger km (8 EU countries 1995)			NMVOC 0.011 g/passenger km (Austria 1996)	NMVOC 0.060 g/passenger km (Austria 1996)	10% of EU population are exposed to noise above 55 L Aeq dB (Based on France, Germany and Netherlands data, Lambert 1998)	10% of EU population are highly annoyed by air transport noise (INRETS 1994)
	1 Mtoe (UK 1997)	9 Mtoe (UK 1997)			NOx 0.075 g/passenger km (Austria 1996)	NOx 0.675 g/passenger km (Austria 1996)		
	0.4 MJ per tonne km (EU 1995)	2.8 MJ per tonne km (EU 1995)			NOx 0.21-1.5 g/passenger km Diesel train (Eurostat)	NOx 0.30–1.52 g/passenger km (Eurostat)		

Report	Energy		CO_2		Other pollutant emission		Noise effect	
	Rail	**Air**	**Rail**	**Air**	**Rail**	**Air**	**Rail**	**Air**
IPCC 1999		1000km flight Boeing B747-400 2.1MJ per seat-km (262 seats) (Japan Airlines)	High speed train coal fired electricity 48g C per passenger-km	Short Haul 99g C per passenger-km (Hofstetter 1992) Short haul 56 g C per passenger (1992 European average)		12.0g NO_2 kg^{-1} fuel, NASA (139.4Tg fuel burnt 1992)		
		1000km flight Boeing 747-400D 1.0MJ per seat km (568 seats) (Japan Airlines)	High speed train using non-fossil fuel electricity: 2g C per passenger km	3160 g/kg CO_2 cruise		Typical cruising emissions: 1.0 g/kg SO_x 7.9 – 11.9 g/kg NO_x 1-3.5g/kg CO <0.5 g/kg CH_4		Not covered by study

Report	**Energy**		**CO$_2$**		**Other pollutant emission**		**Noise effect**		**Land take**	
	Rail	Air	Rail	Air	Rail	Air	Rail	Air	Rail	Air
From Planes to Trains 2000 (FOE/AEF)	Rail: 2.3 litres per 100 passenger km High speed rail: 3.0 litres per 100 passenger km (European Commission)	500 km flight: 10.5 litres per 100 passenger km (European Commission)			NOx g/km 500km journey: 0.11 (IFEU) 0.10 – 0.30 (Hofstetter) 0.02 – 0.03 4.5% electricity fossil fuel based (SAS 1995) 1.67 diesel train (SAS 1995)	NOx g/km 500km journey: 0.6 – 1.63 (SAS 1995) 0.8 – 3.6 (T & E 1993)	Not covered by study	Not covered by study		
INTEGRA / EURO-CONTROL 2000				3150g/kg CO$_2$ (Schumann 1994)		g/kg fuel burnt: Water vapour 1260 NOx 18 (17-20) Hydrocarbons 0.6 (0.2-3) CO 1(0.02-6) Soot 0.015+/-0.014 (Schumann 1994)		10 L_{AEQ} (Airborne) 13.3 L_{AMAX} (Airborne) 10 L_{AEQ} (Ground)		

Report	**Energy**		**CO_2**		**Other pollutant emission**		**Noise effect**		**Land take**	
	Rail	Air	Rail	Air	Rail	Air	Rail	Air	Rail	Air
Boeing 1997							Diesel train (200 feet from rails) 85dBA	Boeing 737-600 takeoff (2 miles from end of runway) 69dBA Boeing 727-200 takeoff (2 miles from end of runway) 94dBA		
SAS 1995			CO_2 g/passenger km): Swedish Intercity 3.4 (1993)	CO_2 g/passenger km): 200km flight 196 (1993)	NOx g/passenger km : Swedish Intercity 0.01(1993) CO g/passenger km: Swedish Intercity 0.001 (1993)	NOx g/passenger km : 200km flight 0.60 (1993) CO g/passenger km: 200km flight 0.56 (1993)	Swedish conditions: 500,000 people exposed to noise above 55dB(A) 70 people per 1,000,000 passenger km	Swedish conditions: 60,000 people exposed to noise above 55 dB(A) 15 people per 1,000,000 passenger km	Land use (German conditions) hectares of land per 1,000,000 passenger km 1989 2.6	Land use (German conditions) hectares of land per 1,000,000 passenger km 1989 0.4