Guidelines on greenhouse gas emissions for various transport types

Brian Shorter

Winchester Action on Climate Change (WinACC)

(March 2011)

This report was written as a result of a review carried out of currently available data on emissions from various modes of transport. It will enable those who are considering making any journey to decide what means of transport they should use, or indeed whether the journey should be made at all. It will also assist in the calculation of one's carbon footprint.

Summary and recommendations

The report gives estimates of greenhouse gas emissions for various modes of transport. Unsurprisingly air travel and driver only cars are particularly high. For public transport, the occupancy rate, or load factor, is critical in estimating realistic current per passenger emissions; and actual load factor data is difficult to obtain.

It is recommended that, whatever the comparisons may show for any particular journey, every effort should be made to use the transport mode that generally gives rise to the least emissions, in the following orders:-

- For short distances - walk/cycle, bus, car
- For longer distances - coach/train, car, aircraft

Contents

1 Introduction

This report has been prepared by the Science and Technology Advisory Panel (STAP) of WinACC to assist in coming to a “consensus” view of what figures should be used in comparing the emissions of different forms of transport. This was partly as a result of a request from the Transport Group of WinACC.

Cars, buses/coaches, trains and aircraft have been covered. Data have been collected from the internet.

The main outputs are:-

- energy use and CO_2e emissions per seat per km (ie. per passenger if full), and
- energy use and CO_2e emissions per passenger per km, taking account of load factors

For cars and buses/coaches, CO_2e emissions and energy use per vehicle per km have also been calculated.

Two sources of data have been used, as a starting point, followed by a number of other sources, and then a judgment has been made as to how to combine the various sources, depending on how much they conflict. The two main sources used were:-

- “Mackay D (2009) Sustainable Energy – without the hot air”, which, amongst many other good things, calculates transport energy requirements and, to an extent, emissions from first principles.

- “DEFRA (2010) 2010 Guidelines to Defra / DECC’s GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors”, which gives the government’s recommended figures for transport emissions, and also covers emissions from UK electricity generation.

It is recognised that, because of the different sources used, not all of the figures are always totally consistent with each other.

The report considers the existing situation in the UK. It takes no account of future methods of energy production. One extreme corollary to this is that if the majority of electrical energy were to be produced sustainably, then electric car transport would be particularly good from an emissions point of view.

A robust analysis would include the energy embedded in the vehicle, as a result of its construction and its component materials; and also of the associated infrastructure – roads, railway lines, airports etc. This has been considered beyond the scope of this work; with the exception of car construction.

However the report does take account of so called “indirect” transport emissions. These are defined by DEFRA[1] as “emissions emitted prior to the use of a fuel/energy carrier (or in the case of electricity, prior to the point of generation), i.e. as a result of extracting and transforming the primary energy source (e.g. crude oil) into the energy carrier (e.g. petrol)”

The report generally uses as its unit of emission gCO_2e /km (grams of CO_2 equivalent per km). This takes account of the small amounts of two other greenhouse gases that are emitted by the combustion of fossil fuels, methane and nitrous oxide.

To take account of these additional greenhouse gases and the indirect emissions, mentioned above, an additional 19% is added to the figure for CO_2 emissions for the combustion of petrol, diesel and aviation fuel[2]. Hence some of the emissions figures may appear to be larger than those sometimes quoted.

Why are we interested in the emissions from various methods of transport? The two primary reasons are:-

- To help calculate our total carbon footprint, and assist us in prioritising ways of reducing it.
- If we do need to travel, to assist in working out which is the most carbon efficient means.

The latter is primarily of interest within the UK and western Europe. Beyond that, for most people air is the only realistic option. However, websites such as “www.seat61.com” give guidance on booking long distance rail travel.

For long distances, the question for most people is whether to travel or not, rather than how. The main difference between aircraft and other transport modes considered is that aircraft are fast and huge distances can be covered in comparatively short times.

2 Cars

There is general agreement on emissions, as it is fairly simple to obtain the fuel consumption of any one car model, and from that obtain emissions data. However, there are obviously different sizes of car. The 2010 DEFRA report, above, gives data as shown in the table below[3]. This is calculated from their data on size and make up of the national fleet. The conversion from MPG to emissions of CO_2e can be obtained from the calorific value of fuel and quantities of CO_2 and other gases emitted per kg of fuel burnt. It is unlikely that these figures can be improved upon by STAP, so it is suggested that they are accepted.

Table 1 – Emissions for typical cars

Vehicle Type	***Engine size***	***Vehicle size***	***gCO_2e /km***	***MPG***	***Total* gCO_2e per /km[4]***
Petrol car	< 1.4 l	Small	174	37.6	205
	1.4 - 2.0 l	Medium	216	30.3	254
(Includes 4WD)	> 2.0 l	Large	301	21.7	354
Average petrol car			212	30.9	**249**
Diesel car	<1.7 l	Small	147	51.4	174
	1.7 - 2.0 l	Medium	183	41.2	217
(Includes 4WD)	> 2.0 l	Large	247	30.4	294
Average diesel car			197	38.3	**234**
Average car			208	33.5	**246**

* This includes indirect greenhouse gas emissions. See above

These 2010 DEFRA figures are slightly higher than those produced by them previously. This is because they now take account of what they term “real world” effects. These are factors not taken account of in manufacturers' quoted fuel efficiencies. An additional 15% has been added, by DEFRA, to quoted fuel usages to include the use of accessories such as air conditioning, lights, heaters etc; and also vehicle payload (only driver+25kg is considered in tests, no passengers or further luggage), poor maintenance (tyre under inflation, maladjusted tracking, etc), gradients (tests effectively assume a level road)[5]. The higher consumptions are considered to be more realistic.

Rounding the average car emissions to 240 gCO_2e/km, then emissions per passenger (assuming a passenger capacity of four) are as below. Additional columns have been added to the table for cars with emissions of 140, 180 and 220 g CO_2e/km. (Equivalent to petrol fuel consumptions of 55, 43 and 35 mpg, respectively; or diesel consumptions of 64, 50 or 41 mpg respectively)

Table 2 – Car emissions per occupant

	Occupants	Energy kWh/km	Emissions (g CO_2e/km)		Emissions (g CO_2e/km	Emissions (g CO_2e/km	Emissions (g CO_2e/km
Car		0.85	240		140	180	220
Per occupant	1	**0.85**	**240**		140	180	220
Per occupant	2	**0.42**	**120**		70	90	110
Per occupant	3	**0.28**	**80**		47	60	73
Per occupant	4	**0.21**	**60**		35	45	55

However, anyone can assess the emissions from their own car from its actual fuel consumption assessed over a reasonable period of time, not just one long journey, as follows:-

- For a petrol car, total g CO_2e per km emitted is given by the expression "7750 / MPG" (ie if the fuel consumption is 35 mpg, then the emissions are 7750/35 = 221 g CO_2e /km)
- For a diesel car, total g CO_2e emitted is given by the expression "8850 / MPG" - calculated as for petrol.

This is likely to be more accurate than using the generic average car figures.

Speed has an impact on fuel consumption and therefore emissions. The most fuel efficient driving speed for a car is of the order of 40-50 mph. The following table, obtained from Department for Transport data, shows the increases in emissions (by distance) that different steady speeds give rise to[6]. Figures are for an "average" diesel or petrol car. Clearly the amount of stopping and starting, fierceness of acceleration and other factors have a significant effect also.

Table 3 – Effect of car speed on emissions

Speed (mph)	10	20	30	40	50	60	70	80	90
Increase in emissions (%)	55	20	4	0	0	5	12	29	40

Embedded Energy

It has been estimated variously that some 15 – 35 % of the energy used during the lifetime of a car is used in its manufacture[7,8,9]. If it is assumed that this proportion is only 20%, then, if there is the opportunity to obtain a more efficient car after 50% of its average life, it would need to be 50% more efficient to "break even" over the whole of its life.

That is to say, if it is assumed that a car travels 120,000 miles in its life, then, if after 60,000 miles one contemplates a more efficient car purely for fuel efficiency reasons (ignoring likely higher maintenance bills that might be saved, and possible loss of efficiency as the car gets older), then one with half the fuel consumption of the older one would be required in order for that 120,000 miles to be completed in a more overall energy efficient way.

This is a very simplistic scenario, but demonstrates that there is a significant amount of energy embedded in the manufacture of a car. This proportion is likely to increase as fuel efficiency improves.

If, in fact, the energy embedded within the car is at the higher end of the 15 – 35% range, then a car with a fuel consumption even lower than half would be required.

3 Buses and Coaches

Buses

As with other forms of transport, the difficulty in coming up with a simple figure for emissions per passenger km is the load factor, or occupancy. In addition, there appears to be minimal data that distinguishes between rural bus (as opposed to coach) services and urban bus services.

The 2010 DEFRA report suggests that the average occupancy of a London bus is 16.6 passengers, and of a local bus elsewhere is 7.2 passengers[10].

As a result of this, and other data, the following is a guide.

Table 4 – Bus emissions per passenger

		Energy kWh/km	**Emissions (g CO_2e/km)**
London Bus	Per pass if full	0.07	22
	Per pass 23% full	**0.32**	**95**
	Whole bus	5.2	1,600
Other local bus (single decker)	Per pass if full	0.06	18
	Per pass 10% full	0.60	180
	Whole bus	3.0	890
Other local bus (double decker)	Per pass if full	0.06	18
	Per pass 8% full	0.77	225
	Whole bus	4.5	1,350
Average local bus (outside London)	Per pass if full	0.06	18
	Per pass	**0.68**	**200**

Bus usages are notoriously low outside peak hours. Clearly if they were used more, then emissions per passenger would reduce

In general, local buses run on comparatively short routes, for which there may be the alternatives of cycling and walking, as well as a car. Buses are in a slightly odd position in the transport mix, in that, environmentally, it is preferable that they are not, in general, used on short journeys by those fit enough to walk or cycle; but that they should be used to replace car journeys, for longer trips. It is likely that, should this scenario (of reduced use for short journeys and increased use for longer journeys) occur, then bus usage would increase and thus they would become more economically and environmentally sustainable.

Coaches

Again, the difficulty in coming up with a simple figure for emissions per passenger km is the load factor, or occupancy. This is commercially sensitive to coach companies, and is hard to obtain.

The DEFRA figure for emissions is 30 g CO_2 per passenger km (direct emissions only), assuming an occupancy of 16.2 (about 33% load factor)[11]. However the same report states that this occupancy includes rural buses also, and that coach occupancy is likely to be higher than this; and therefore the per passenger emissions would be lower. Using data in the Kemp report[12] emissions of 35 – 42 g CO_2 per passenger km (direct emissions only) are obtained for half full coaches.

It is suggested that the generally accepted DEFRA figure of 30 g CO_2 per passenger km is used, assuming a load factor of 35% (ie 17 passengers), and factored to include indirect emissions. This results in the following.

Table 5 – Coach emissions per passenger

		Energy kWh/km	**Emissions (g CO_2e/km)**
Coach	Per pass if full	0.04	13
	Per pass 35% full	**0.12**	**36**
	Whole coach	1.96	640

4 Trains

UK

There is a wealth of literature on this, and a measure of agreement to within about 20%. Clearly, with the two fuel systems, diesel and electric, and different lengths and design speeds of trains, it is difficult to come to a consensus.

For instance, from 2008 to 2010, the DEFRA reports[13,14] have figures for overall national rail emissions reducing from 60.2 to 53.4 g CO_2 / pass km; while over the same period London Underground emissions increase from 65.0 to 74.1 g CO_2 / pass km. These may be correct or, more likely, are caused by using different methods of assessment. In fact the data below do not, as far as can be seen, take account of London Underground trains.

A particular difficulty is the load factor (proportion of seats used) on a train. A car may change its load on a journey, but generally won't; while an aircraft definitely won't on any one leg! However train load factors are very variable. For instance an early evening train from London to Glasgow is likely to have a load factor well over one (ie standing room only) at the start of the journey, and be virtually empty at the northern end. London commuter services have load factors well over one, only in one direction (and very low in the other direction) for perhaps three hours per day, and have average load factors for the remainder of the day.

Having analysed a number of reports[15,16,17], below is a realistic overall estimate of energy used and CO_2 emissions, assuming an overall load factor of 35%, which is slightly above the 33% quoted in the ATOC report[18], but all agree that it is rising. This relates to trains within the UK.

Table 6 – Train emissions per passenger

		Energy kWh/km	**Emissions (g CO_2e/km)**
Diesel Train	Per pass if full	0.10	29
	Per pass 35% full	0.28	83
Electric Train	Per pass if full	0.04	20*
	Per pass 35% full	0.10	57*
Average Train	Per pass if full	0.05	24
	Per pass 35% full	**0.14**	**68**

* Emissions based on the overall UK electricity generation split

As trains come in many sizes, energy and emissions analyses are generally carried out "per vehicle", meaning carriage/power unit. The average energy use for an electric unit is of the order of 2 kWh per km per unit (so a train of 4 units uses 8 kWh per km). The average energy use for a diesel unit is of the order of 5.2 kWh per km per unit (so a train of 4 units uses 20.8 kWh per km)[19].

It would appear logical to use the above "overall" figures, perhaps only the "average train" figure, to make decisions as to which means of transport is the most energy efficient. If one starts going into too much detail for an individual journey, a can of worms is opened. How much more efficient to drive from Carlisle to Glasgow by car in the late evening, if that mode of transport is compared with the 1% (perhaps) full train. But the train is running anyway, so better to use it; and so might that half empty aircraft be running anyway in another journey comparison……….!

Eurostar

The current (Feb 2011) Eurostar website[20] gives per passenger emissions for a London-Paris return trip. Confusingly it gives 6.6 kg CO_2 in one location and 11 kg CO_2 in another. The two equivalent conflicting figures for London-Brussels are 8.2 and 24.3 kg CO_2, respectively. These figures are lower than those for British trains because of the high proportion of nuclear produced electricity in France.

The conflicting figures may be due to a complication regarding the calculation of emissions. Eurostar say that they calculate emissions using the mix of generation of the power actually purchased by them (Supplier mix). However the UK government requires their emissions to be calculated using the "average" British and French generation mix. This produces quite a large difference, as seen below. Since other UK electric train emissions are calculated using average values, it would seem logical to do the same for Eurostar for comparison purposes.

The tables below are based on data in the Watkiss/Eurostar Emissions report[21].

Table 7 – Eurostar train emissions per passenger

EUROSTAR (London-Paris)		Energy (kWh/km)	Emissions (gCO_2e/km)
Supplier emissions	Per pass if full	0.06	4.8
	Per pass 72% full	0.08	6.7
Average emissions	Per pass if full	0.06	9
	Per pass 72% full	**0.08**	**13**

EUROSTAR (London-Brussels)		Energy (kWh/km)	Emissions (gCO_2e/km)
Supplier emissions	Per pass if full	0.06	19
	Per pass 59% full	0.09	11
Average emissions	Per pass if full	0.06	14
	Per pass 59% full	**0.09**	**24**

The Watkiss Eurostar report gives the emissions on the Eurostar/TGV route from London to Avignon to be 10 gCO_2/pass km for the average mix and 7.4 gCO_2/pass km for the supplier mix; lower than for the London-Paris route as more of the journey is in France.

Europe

The study by Kemp suggests that other high speed European trains have similar energy requirements to Eurostar[22]. CO_2 emissions, though, depend on the method of generating the energy. French electric trains, being supplied by nuclear produced energy, give rise to particularly low emissions. Note that, as for the construction of transport vehicles and its infrastructure, no account has been taken in this report of the likely significant additional embedded energy in a nuclear power station and energy required for its decommissioning.

Emissions due to the production of electrical energy used by trains in most western European countries (with the exception of France) is approximately 75% of that of UK[23]. It is therefore suggested that emissions of high speed trains in France are taken as being 10 g CO_2/pass km, and elsewhere in Europe as being 40 g CO_2/pass km.

It is possible to travel longer distances in Europe, and within UK, overnight in a sleeper carriage. These come in various levels of comfort. The more comfortable they are, in general, the more space is taken up by each passenger, and the higher the emissions per passenger are. Emissions are likely to be some two to six times those for standard seating, depending also upon load factors.

5 Aircraft

There is a lot of data available relating to CO_2 emissions from aircraft; generally in agreement within some 30-40%. This quite wide range is to be expected as aircraft vary a lot in size and design. In particular modern aircraft are more fuel efficient, and it is not easy to obtain the exact sources of data used to obtain emissions. In fact emissions can vary by as much as a factor of two per seat for a given length of flight, depending upon the type of aircraft.

Despite the above, there is reasonable agreement that emissions on all types of flights are of the order of 100 -140 g CO_2e/pass km for flights over about 800 km, but for shorter flights the range is of the order of some 130-200 g CO_2e/pass km; the higher emissions being for the shorter flights, due to the greater significance of the high landing, take-off and taxiing emissions[24,25,26,].

However, there is another issue with aircraft emissions, sometimes known as the Radiative Forcing Index (RFI). Simply - it is known that emissions in the stratosphere, generally above 9,000m (or 29,000 ft), have a far greater warming impact than those emitted at lower levels. Some of this is due to the effects of other gases such as nitrogen oxides, and condensation trails[27]. There appears, though, to be no consensus yet as to the level of this increased impact. Therefore a factor is applied to the CO_2 emissions. The various organisations assessing this do it differently. For instance, DEFRA recommend a 1.9 factor on all flights[28], Kemp recommends a factor of 2 on domestic flights and 2.7 on all others[29], while Ecopassenger recommends a factor increasing with flight length, from 1.27 to 2.5[30]. The logic of this is that shorter flights spend less time, often none, at over 9,000 m. Atmosfair do something similar, using a factor of 3 for those parts of a flight over 9,000m. This means that every flight has a slightly different overall factor, which is always below 3.

Given the above, it can be seen that emissions which take account of an RFI factor may have significant variation! Indeed, though two commonly used websites, Ecopassenger[31] and Atmosfair[32], have reasonable agreement on most flights, the longer domestic flights do not. Southampton-Newcastle and Southampton – Edinburgh are assessed to emit 221 and 226 g CO_2/pass km respectively according to Ecopassenger, but 330 and 314 according to Atmosfair.

It is suggested that the following is used as an overall rule of thumb for flight emissions, taking account of RFI. As explained above, it is logical that RFI increases with flight length, as happens in the Ecopassenger and Atmosfair analyses. The below table simplifies this, using an RFI of 1 for flights of length less than 400 km, 2.5 for short haul flights (between 400 and 3,700km), and 3 for long haul flights. These figures are of a similar order to those calculated by Ecopassenger and Atmosfair.

As is evident from the above, this is not an exact science, so the figures in the table below also use flight times as an indicator of length

Table 8 – Aircraft emissions per passenger

		Energy kWh/km	**Emissions (g CO_2e/km)**
Flights less than 400km, or one hour	Per pass if full	0.51	150
	Per pass 75% full	**0.68**	**200**
Short Haul – flights between 400km (one hour) and 3700km (five hours)	Per pass if full	0.40	240
	Per pass 80% full	**0.50**	**300**
Long Haul – over 3700km (five hours)	Per pass if full	0.40	320
	Per pass 80% full	**0.50**	**400**

Because First and Business class passengers have more space than the majority Economy passengers, they can be said to give rise to a greater proportion of emissions. DEFRA[33] estimate that on short haul flights emissions due to First/Business class passengers are some 40% above those for Economy; while on long haul flights Business class and First class passengers give rise to emissions some three times and four times those for Economy, respectively.

6 Summary

The following table summarises the findings, and can be used as to compare transport types, or to make an assessment of total CO_2 emissions due to travel. As described earlier, these emissions include so called "indirect emissions", those produced by the extraction of oil and the production of petrol or diesel.

Table 9 - Transport emissions summary table

Means of Transport	**Assumed load factor (%)**	**Energy per passenger km (kWh) (Assuming load factor to left)**	**Emissions of CO_2e per passenger km (gm) (Assuming load factor to left)**		**Energy per seat km (kWh) (ie full vehicle)**	**Emissions of CO_2e per seat km (gm) (ie full vehicle)**
Average Car						
One occupant	**25**	**0.85**	**240**			
Two occupants	**50**	**0.42**	**120**			
Three occupants	**75**	**0.28**	**80**			
Four occupants	**100**	**0.21**	**60**		**0.21**	**60**
London Bus	**23**	**0.32**	**95**		**0.07**	**22**
Bus outside London	**9**	**0.68**	**200**		**0.06**	**18**
Coach	**35**	**0.12**	**36**		**0.04**	**13**
Train						
UK	**35**	**0.14**	**68**		**0.05**	**24**
Eurostar (Paris)	**72**	**0.08**	**13**		**0.06**	**9**
Eurostar (Brussels)	**59**	**0.09**	**24**		**0.06**	**14**
Hi speed (France)	**72**	**0.08**	**10**		**0.06**	**7**
Hi speed (W Europe)	**40**	**0.15**	**50**		**0.06**	**20**
Aircraft						
Flights less than 400km	**75**	**0.68**	**200**		**0.51**	**150**
Short haul - between 400km (one hour) and 3700km (5 hours)	**80**	**0.50**	**300**		**0.40**	**240**
Long Haul – over 5 hours	**80**	**0.50**	**400**		**0.40**	**320**

7 Thoughts and Recommendations

Looking at the figures above, it is striking how widely emissions vary between different forms of transport. It is no surprise that aircraft emissions are the highest.

The table may give rise to a few thoughts:-

- A small fuel efficient car with four occupants is likely to emit less per passenger than an average train – perhaps 40 gm CO_2e per km. Is it therefore logical, purely on emissions grounds, to drive instead of taking the train?

- Perhaps a similar argument could be made about the aircraft that is travelling anyway. The addition of four additional passengers to a flight that is not full will give rise to minimal additional emissions. Driving a car would give rise to more. So surely it would be better to fly?

- Unless local buses fill up, it looks better to use the car if more than one occupant is in it. Is it really better for three of us to travel in the car the two miles into Winchester, rather than using the bus?

The answer to the above questions should be “no”.

The argument that “it’s running anyway” is very similar to the argument for buying ivory, that “the elephant is dead anyway”. It probably wouldn’t be if there was no demand for ivory, and similarly there would be fewer flights if there was less demand for flying.

The logical conclusion, therefore, is that the above figures are of limited interest only. Whatever the comparisons say regarding a particular journey, the more carbon fuel efficient modes of transport, which are coaches, trains and well used buses, as well as walking or cycling, should be used; rather than making direct comparisons, that can give rise to possibly illogical answers.

This report has not considered the obvious problems of insufficient rail capacity at peak times on some lines, and other similar issues.

References

[1] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting. Version 1.2.1 Final Updated 06/10/2010 p 5

[2] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting. Version 1.2.1 Final Updated 06/10/2010 p 10.

[3] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors p 19

[4] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting. Version 1.2.1 Final Updated 06/10/2010 p 19

[5] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors p 17-18

[6] Department for Transport.Transport Analysis Guidance, TAG Unit 3.5.6 - Values of Time and Operating Costs p 14

[7] www-materials.eng.cam.ac.uk/energyforschools/D01Cars

[8] www.imeche.org/knowledge/industries/energy-environment-and-sustainability/news/green-cars

[9] Mackay D (2009). Sustainable Energy – without the hot air p 94

[10,11] DEFRA (2010). 2010 Guidelines to DEFRA / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors p 26

[12] Rail Safety and Standards Board (R Kemp 2007). T618, Traction Energy Metrics p 41 *This reference gives fuel consumptions of 0.38 and 0.57 litres/km, which give rise to emissions of 42 and 35 g* CO_2 */ pass km, respectively, at 50% load factor.*

[13] DEFRA (2008). 2008 Guidelines to Defra / DECC's GHG Conversion Factors: Methodology Paper for Transport Emission Factors p 25

[14] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors p 31

[15,19] Rail Safety and Standards Board (2007). T633 Study on further electrification of Britain's railway network (WS Atkins) p 27-28

[16] ATOC (2007). Baseline energy statement – energy consumption and carbon dioxide emissions on the railway p 3

[17] Rail Safety and Standards Board (R Kemp 2007). T618, Traction Energy Metrics p 27

[18] ATOC (2005). Looking Forward. Contribution to Railway Strategy June 2005 p 22

[20] www.eurostar.com/UK/uk/leisure/about_eurostar/environment/greener_than_flying.jsp

[21] Paul Watkiss Associates (2009). Update of Eurostar CO_2 Emissions using Energy Logging Train Data p 4

[22] Rail Safety and Standards Board (R Kemp 2007). T618, Traction Energy Metrics p 34

[23] Institut für Energieund Umweltforschung (IFEU) Heidelberg GmbH (2010). EcoPassenger - Environmental Methodology and Data p 13

[24] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors p 48

[25] Rail Safety and Standards Board (R Kemp 2007). T618, Traction Energy Metrics p 42-47

[26] The EMEP/EEA Air Pollutant Emission Inventory Guidebook, Part B, 1.A.3.a Aviation_annex

[27] www.atmosfair.de/fileadmin/user_upload/Medienecke/Downloadmaterial/Rund_um_atmosfair/Documentation_Calculator_EN_2008.pdf p 4

[28] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors p 55

[29] Rail Safety and Standards Board (R Kemp 2007). T618, Traction Energy Metrics p 47

[30] Institut für Energieund Umweltforschung (IFEU) Heidelberg GmbH (2010). EcoPassenger - Environmental Methodology and Data p 20

[31] www.ecopassenger.org

[32] www.atmosfair.de/en/act-now/contribute-now/offset-your-flight/

[33] DEFRA (2010). 2010 Guidelines to Defra / DECC's GHG Conversion Factors for Company Reporting: Methodology Paper for Emission Factors p 49