Factsheets

UK transport greenhouse gas emissions

Department for Transport

These factsheets present latest available information on greenhouse gas emissions from transport and are intended to provide a guide to sources of data. All information and analysis in these factsheets is based on information which has been published previously or is publically available upon request.

There are 5 factsheets in this set:

1. **Overview of transport greenhouse gas emissions**
2. **Road transport**
3. **Rail**
4. **Shipping**
5. **Aviation**

These factsheets have been produced by Transport Statistics, DfT

Factsheet 1
Overview of transport greenhouse gas emissions

Introduction

Reported greenhouse gas (GHG) emissions estimates are based on an internationally agreed basket of gases covered by the Kyoto protocol: carbon dioxide (CO_2), methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

Some gases have a greater impact global warming potential than an equivalent amount of others, so greenhouse gas emissions are expressed in terms of the equivalent million tonnes of carbon dioxide ($MtCO_2e$). On this basis carbon dioxide makes up over 98% of UK greenhouse gas emissions from transport.

Emissions targets are usually based on domestic GHG emissions, which exclude emissions from international aviation and international shipping. There is no internationally agreed way of allocating these international transport emissions to individual nation states.

International emissions are not included in the national totals submitted to the United Nations Framework Convention on Climate Change (UNFCCC) but are reported separately as ‘memo items’. However GHG emissions from international shipping and international aviation, which are based on estimated fuel sold from UK fuel supplies, can be added to the domestic emissions to give a UK total.

In these factsheets we present figures for both:
- Domestic UK GHG emissions (which exclude international aviation/shipping)
- Total UK GHG emissions (domestic emissions + international aviation/shipping)

The UK GHG emissions figures in these factsheets are the ‘by source’ (direct emissions) figures published by DECC (Department for Energy and Climate Change), unless stated otherwise (see background to data sources on page 4). These figures include crown dependencies and exclude overseas territories.

UK domestic greenhouse gas emissions

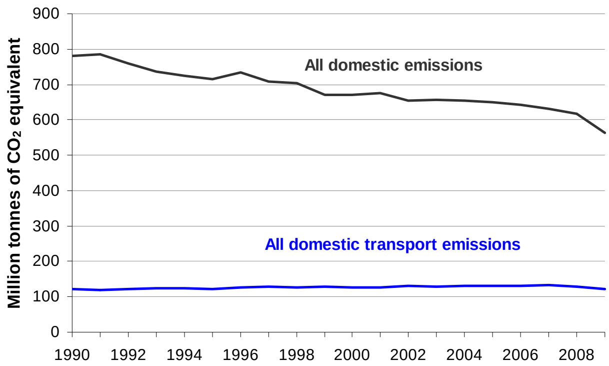
- In 2009 UK domestic greenhouse gas (GHG) emissions were 563.6 million tonnes of carbon dioxide equivalent ($MtCO_2e$), 28% lower than in 1990.

- Domestic GHG emissions fell by 9% between 2008 and 2009. In 2009, emissions were affected by reduced economic activity during the recession.

- Domestic GHG emissions from transport were around the same level as in 2009 (122.2$MtCO_2e$) as in 1990 (122.1$MtCO_2e$).

- As a proportion of all domestic GHG emissions, transport emissions have increased from 16% in 1990, to 22% in 2009.

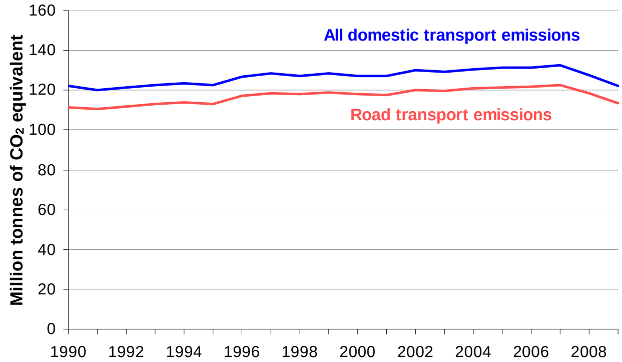
Figure 1.1:
UK domestic greenhouse gas emissions, 1990-2009



Source: National Atmospheric Emissions Inventory (NAEI)

- Domestic GHG emissions from transport increased by 8% between 1990 and 2007, and the fell by 8% between 2007 and 2009.

Figure 1.2:
UK domestic transport greenhouse gas emissions, 1990-2009



Source: National Atmospheric Emissions Inventory (NAEI)

- Road transport emissions (which account for just over 90% of domestic transport GHG emissions) were 2% higher in 2009 than in 1990.

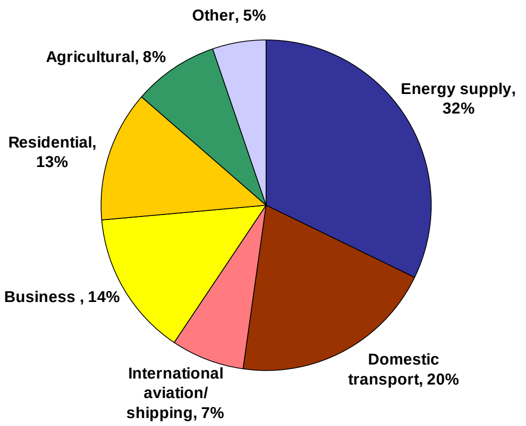
- Road transport GHG emissions rose by 10% between 1990 and 2007, with improvements in new car fuel economy offset by rising road traffic levels. This was followed by a 7% fall between 2007 and 2009.

- Falling traffic levels during the recession is likely to have been a key factor behind the fall in road transport GHG emissions between 2007 and 2009, however there were other factors which contributed to the fall (see factsheet 2).

GHG emissions from transport

- In 2009 total GHG emissions from transport (including international transport) were 165.8 $MtCO_2e$, accounting for 27% of total UK GHG emissions (607.2 $MtCO_2e$).

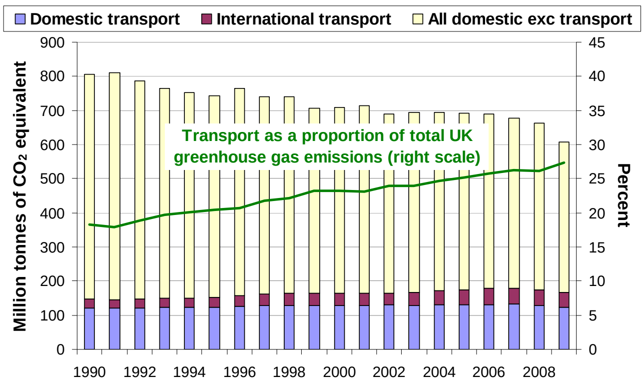
Figure 1.3:
Total UK greenhouse gas emissions by source sector, 2009



Total UK GHG emissions in 2009 = 607.2 $MtCO_2e$
Other: Public, Industrial processes, Waste management and Land Use and land use change and forestry (LULUCF)
Source: National Atmospheric Emissions Inventory (NAEI)

- Domestic transport accounted for 20% of total UK GHG emissions in 2009, with international transport accounting for 7%.

Figure 1.4:
Total UK greenhouse gas emissions, 1990-2009

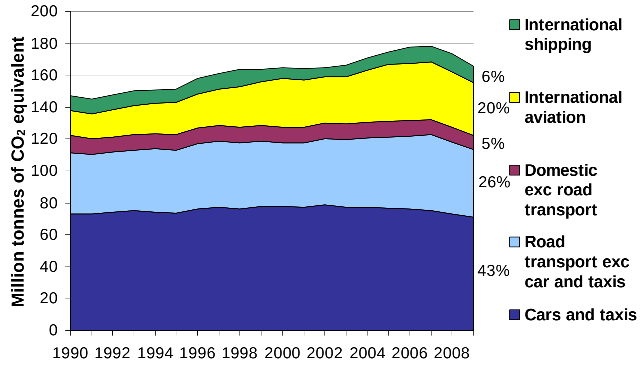


Source: National Atmospheric Emissions Inventory (NAEI)

- Total GHG emissions from transport have increased by 13% between 1990 and 2009, with a 21% increase from 1990 to 2007, followed by a 7% fall between 2007 and 2009.

- As a proportion of total UK GHG emissions transport emissions (both domestic and international) have increased from 18% in 1990 to 27% in 2009.

Figure 1.5:
Total UK transport greenhouse gas emissions, 1990-2009

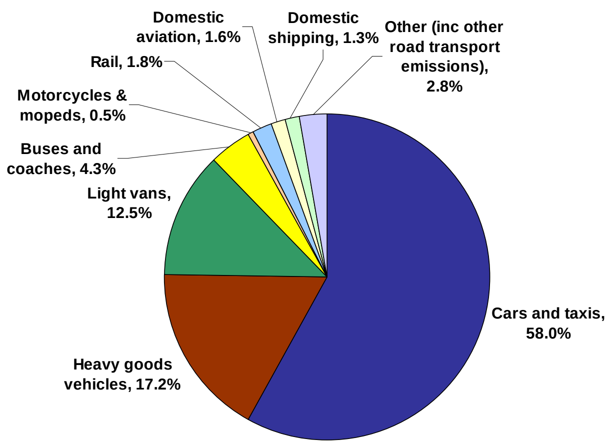


Source: National Atmospheric Emissions Inventory (NAEI)

- Road transport accounted for 68% of total transport GHG emissions, with cars and taxis accounting for 43% and other road vehicles accounting for 26%.

- Most of the growth in total transport GHG emissions since 1990 is attributable to growth in international air travel. Emissions from international aviation in 2009 were more than double 1990 levels (a 110% increase).

Figure 1.6:
UK domestic transport greenhouse gas emissions, 2009



Total UK domestic transport GHG emissions in 2009 = 122.2 $MtCO_2e$
Other' is mostly 'military aircraft and shipping', and also includes emissions from 'aircraft support vehicles' and from road vehicles running on liquefied petroleum gas (LPG).
Source: National Atmospheric Emissions Inventory (NAEI)

- In 2009 cars and taxis accounted for 58% of UK domestic transport greenhouse gas emissions with light vans and heavy goods vehicles making up around 30%.

- Although transport emits 22% of domestic greenhouse gas emissions, the 'by final user' figures show that if emissions from the processing of transport fuels (e.g. petrol or electricity) are included then transport accounts for 24% of domestic GHG emissions.

The UK transport greenhouse gas emissions figures can be found in figure 1.11, page 6. The full UK figures can be found on DECC's [2009 final UK emissions figures page].

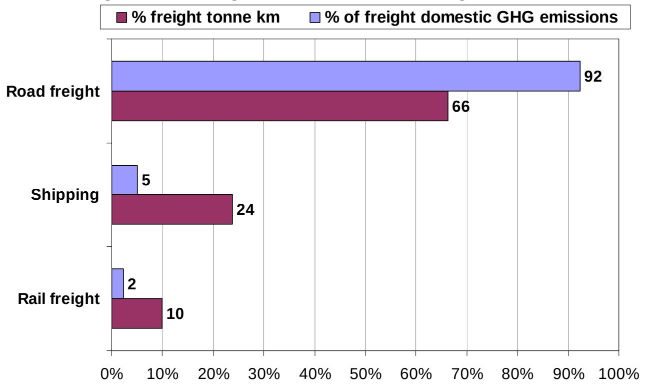
GHG emissions from the transport of freight within the UK

In what follows the transport of freight by pipeline is not included.

- The transport of freight within the UK is estimated to account for 21% of domestic transport GHG emissions and 5% of all UK domestic GHG emissions.

- Road freight is estimated to account for 20% of domestic transport GHG emissions and 4% of all UK domestic GHG emissions.

Figure 1.7:
Domestic greenhouse gas emission from freight, 2009



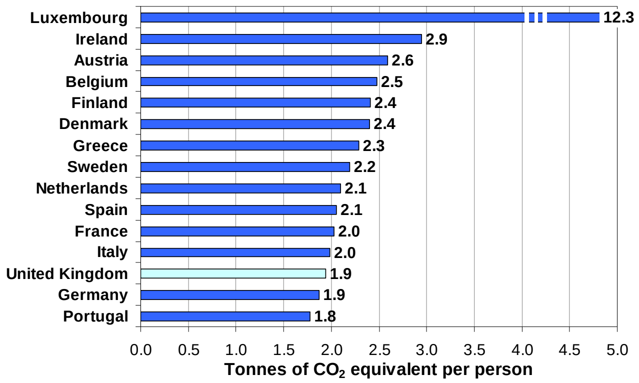
Source: DfT Analysis, National Atmospheric Emissions Inventory (NAEI)

- In 2009 shipping accounted for 24% of tonne km moved but only 5% of freight emissions. Rail accounted for 10% of tonne km moved but only 2% of freight emissions (see figure 1.7 above).

International comparisons

- On a per person basis the UK's domestic transport greenhouse gas emissions are comparable to those of other EU-15 countries.

Figure 1.8:
Domestic transport GHG emissions per person, EU-15, 2009



Source: United Nations Framework Convention on Climate Change

- Transport GHG emissions are in principle based on the amount of fuel sold. Luxembourg's disproportionately high domestic transport emissions reflect the purchasing of road transport fuels in Luxembourg by non-residents as a result of comparatively low fuel prices there.

Background on the UK GHG emissions inventory

The UK's national GHG emissions inventory is compiled in line with international guidance from the International Panel on Climate Change (IPCC).

- In line with the IPCC guidance the emissions from transport are in principle based on fuel sold in the UK. So for example:
  - the emissions from a lorry being driven abroad using diesel purchased in the UK would be included in the UK inventory, while
  - the emissions from a lorry being driven in the UK using fuel purchased abroad, would not be included in the UK inventory.

  This is to avoid the double counting of GHG emissions between different nation states.

- The GHG emissions are usually reported on a '**by source**' basis, i.e split by the sector emitting the greenhouse gases.

- On the '**by end user**' (also referred to as 'by final user') basis emissions from power stations and fuel processing facilities in the UK are reallocated to the final user of the fuel on an approximate basis, according to their use of the fuel. So for example:
  - emissions from the processing of fuels used by road vehicles are reallocated to road transport;
  - emissions from the production of the electricity used by electric trains are reallocated to rail.

- Carbon dioxide is reported in terms of net emissions, which means total emissions minus total removals of CO_2 from the atmosphere by carbon sinks. Carbon sinks are incorporated within the Land Use, Land Use Change and Forestry (LULUCF) sector, which includes afforestation, reforestation and deforestation.

- The UK emissions inventory is subject to continual methodological improvement. There are also revisions to the data sources used in compilation of the inventory. The emissions are therefore revised back to 1990 each year to ensure a consistent time series, meeting international obligations under the UNFCCC.

- DECC reports GHG emissions on the National communications (NC) categories. GHG emissions are reported to the UNFCCC using the IPCC categories. For transport the main difference is that under NC categories emissions from military aircraft and shipping are subsumed into the transport sector.

- The UK GHG emissions reported to different bodies and used for different targets are from the same data but vary in their geographical coverage as shown in figure 1.9. The differences in overall UK totals are less than 1%.

Figure 1.9:
Geographical coverage of UK GHG emissions reporting

	Geographical coverage
Reported to the UN (UNFCCC) and used for **Kyoto Protocol**	UK including inc both CDs and OTs
Reported by DECC as **UK National Statistics** (and are the figures used in these factsheets)	UK including CDs and excluding OTs
UK Climate Change Act	UK excluding both CDs and OTs
Reported to the EU (EEA) and included in the EU GHG emissions inventory reported to the UNFCCC. Included in the **EU-15** total for the **Kyoto Protocol**	UK including Gibraltar but excluding all other CDs and OTs

UNFCCC = United Nations Framework Convention on Climate Change
EEA = European Environment Agency (an agency of the EU)
DECC = UK Department for Energy and Climate Change
CDs = Crown Dependencies (Jersey, Guernsey, and the Isle of Man).
OTs = Overseas Territories that are party to the UK ratification of the Kyoto Protocol (Bermuda, Cayman Islands, Falkland Islands, Gibraltar and Montserrat).

- The basic principle in estimating emissions is: Emissions = Activity × Emissions per unit activity

  Examples of activity include fuel consumed or distance driven. The exact methodology varies between different sectors and different gases.

UK GHG emissions targets

- Greenhouse gas (GHG) emissions targets are based on domestic greenhouse gas emissions only as there is no internationally agreed way of allocating emissions for international aviation and international shipping to individual nation states.

- The **"1990" baseline** for the Kyoto protocol is made up of 1990 levels of carbon dioxide, methane and nitrous oxide; added to the 1995 levels of hydro-fluorocarbons, per-fluorocarbons and sulphur hexafluoride. The UK climate change act also follows this convention.

- The **Kyoto Protocol**: The UK has agreed a legally binding target to reduce its domestic GHG emissions so that the annual average over the period 2008-2012 is 12.5% below the "1990" baseline.

- The **UK Climate Change Act** includes legally binding targets for the UK to reduce its GHG emissions by at least 80 per cent by 2050, and by at least 34 per cent by 2020, both below base year levels. It also establishes a system of binding five-year **UK carbon budgets** to set the trajectory towards these targets.

- UK emissions targets have differences in geographical coverage (see figure 1.9). In addition to this the Kyoto Protocol uses a narrower definition of Land Use, Land Use Change and Forestry (LULUCF) sector than the reported UK GHG emissions.

- The baseline for the Kyoto Protocol is not updated each year when the emissions figures are revised back to 1990. Instead the baseline is fixed and based on the 1990–2006 version of the emissions inventory.

Figure 1.10:
UK performance against GHG emissions targets

	Emissions figures ($MtCO_2e$)					Target ($MtCO_2e$)
	"1990" Baseline	1999	2007	2008	2009	
Kyoto Protocol	779.9	670.2	634.7	620.5	566.3	682.4 (2008-2012 average)
UK Carbon Budgets	783.1	669.5	630.3	616.0	561.8	603.6 (2008-2012 average) 556.4 (2013-2017) 508.8 (2018-2022)

Environmental accounts

The ONS Environmental Accounts report greenhouse gas emissions (GHG) produced by UK residents and UK-registered companies, broken down by the industry emitting the gases. The resulting emissions are on the same basis as the UK National Accounts, and can therefore be used to look at emissions per unit of economic output.

- Environmental Accounts GHG figures are based on the National Atmospheric Emissions Inventory (NAEI) data – 'by source', but apply a cross-boundary adjustment to remove purchases by overseas residents of UK fuel, and add purchases by UK residents of foreign fuel.

- While the NAEI data is broken down according to the activity which produces the emissions, the Environmental accounts provides a breakdown of GHG emissions by the economic sector producing them regardless of what activity that produces them. For example for heavy goods vehicles:

  - HGV emissions are taken from the NAEI data (these are in principle based on the fuel bought from the UK, regardless of who purchased the fuel or where it was used).
  - Cross boundary adjustments are applied to remove estimated fuel bought by foreign HGVs in the UK and include estimated fuel purchased by UK HGVs abroad.
  - The resulting HGV emissions are allocated to a range of industries including "transport of freight by road" (the road haulage industry), and parts of the retail & wholesale, manufacturing and construction sectors.

- In terms of geographical coverage, the environmental accounts exclude all crown dependencies and overseas territories. Emissions from the LULUCF sector are excluded and emissions from the combustion of biomass are added in.

Environmental Accounts GHG data for transport industries is shown in figure 1.12. The full UK figures can be found in ONS's UK Environmental Accounts, 2011.

Figure 1.11: Transport contribution to UK greenhouse gas emissions

United Kingdom	Million tonnes of CO_2 equivalent					% of 2009 …			
	1990	1999	2007	2008	2009	… domestic transport GHG emissions	… all UK domestic GHG emissions	… total transport GHG emissions (inc international transport)	… total UK GHG emission (inc international transport)
Road Transport	**111.2**	**118.7**	**122.8**	**118.3**	**113.6**	***93***	***20***	***68***	***19***
Cars and taxis	73.1	77.9	75.4	73.0	70.9	*58*	*13*	*43*	*12*
Heavy goods vehicles	24.0	22.9	24.6	23.1	21.0	*17*	*4*	*13*	*3*
Light vans	9.4	12.7	16.2	15.8	15.3	*12*	*3*	*9*	*3*
Buses and coaches	3.8	4.5	5.4	5.4	5.3	*4*	*1*	*3*	*1*
Mopeds & motorcycles	0.6	0.6	0.7	0.6	0.6	*1*	-	-	-
Other road vehicle emissions[1]	0.3	0.2	0.5	0.5	0.4	-	-	-	-
Other domestic transport	**10.8**	**9.7**	**9.6**	**9.3**	**8.6**	***7***	***2***	***5***	***1***
Rail	1.6	1.8	2.1	2.1	2.1	*2*	-	*1*	-
Domestic aviation	1.4	1.9	2.3	2.2	2.0	*2*	-	*1*	-
Domestic shipping	1.8	1.9	1.7	1.6	1.5	*1*	-	*1*	-
Other[2]	6.1	4.1	3.5	3.3	3.0	*2*	*1*	*2*	-
Total domestic transport	**122.1**	**128.4**	**132.4**	**127.6**	**122.2**	***100***	***22***	***74***	***20***
Total UK domestic emissions	**781.6**	**671.6**	**632.2**	**617.7**	**563.6**		***100***		***93***
International transport	**24.9**	**35.5**	**45.8**	**45.9**	**43.6**			***26***	***7***
International Aviation	15.8	27.6	35.8	34.5	33.0			*20*	*5*
International Shipping	9.1	7.9	10.1	11.4	10.6			*6*	*2*
Total transport (domestic and international)	**146.9**	**163.9**	**178.2**	**173.5**	**165.8**			***100***	***27***
Total UK emissions (inc international transport)	**806.5**	**707.1**	**678.0**	**663.6**	**607.2**				***100***

1. 'Other road transport emissions' consist of emissions from road vehicles running on liquefied petroleum gas (LPG) and emissions from the evaporation of engine lubricants.
2. 'Other' is mainly 'military aircraft and shipping' and also includes 'aircraft support vehicles', and emissions from London Underground's natural gas power generator.
Source: National Atmospheric Emissions Inventory (NAEI)

Figure 1.12: UK greenhouse gas emissions by industry – transport industries

	1990	1999	2007	2008	2009	2009 % of all sectors
All transport and storage industries industries	**64.0**	**80.1**	**94.2**	**92.4**	**85.1**	***13***
Rail transport (national rail inc freight)	1.9	2.2	2.6	2.6	2.6	-
Buses & coaches, taxis, trams, metro, underground and other urban rail services	6.5	8.1	9.1	9.0	8.9	*1*
Freight transport by road, removal postal and courier services[1]	16.4	17.0	17.2	16.0	13.6	*2*
Water transport services	17.2	17.3	19.6	20.1	17.1	*3*
Air transport services	20.4	34.1	44.3	43.2	41.5	*7*
Other transport and storage industries	1.6	1.4	1.5	1.5	1.4	-
Household use of private vehicles	**60.8**	**65.6**	**68.3**	**66.1**	**64.9**	***10***
Total UK GHG emissions – all sectors	**815.2**	**725.4**	**708.0**	**694.6**	**636.5**	***100***

1. Freight transport by road only includes freight transport by the road haulage industry, other the emissions from other road freight activities are allocated to the sector that carries out these activities, e.g. parts of the retail, wholesale, manufacturing and construction sectors.

Source: Environmental Accounts – Office for National Statistics (ONS)

Factsheet 2
Road transport greenhouse gas emissions

Department for Transport

Introduction

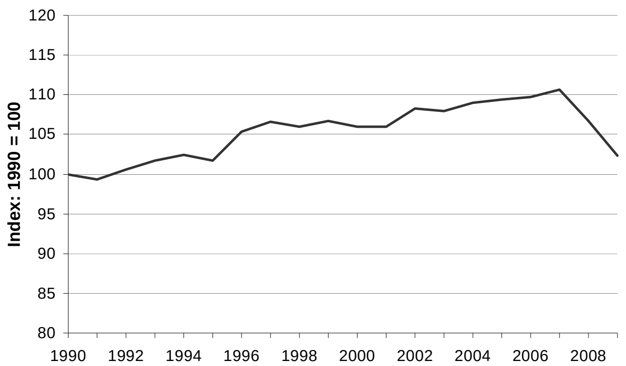
This factsheet looks at UK greenhouse gas (GHG) from road transport. Road transport accounts for the majority of GHG emissions from transport and around a fifth of all UK greenhouse gas emissions.

Following an overall rising trend from 1990 to 2007, road transport GHG emissions have been falling since 2007. This factsheets also looks at possible reasons for this apparent change in trend.

Overview of road transport GHG emissions

- Road transport greenhouse gas (GHG) emissions have increased by 2% since 1990 to 113.6 $MtCO_2e$ in 2009. This compares with a 28% fall in all UK domestic GHG emissions over the same period.
- GHG emissions from road transport rose by 10% between 1990 and 2007, driven by growth in road traffic volumes.

Figure 2.1:
UK road transport greenhouse gas emissions, 1990-2009

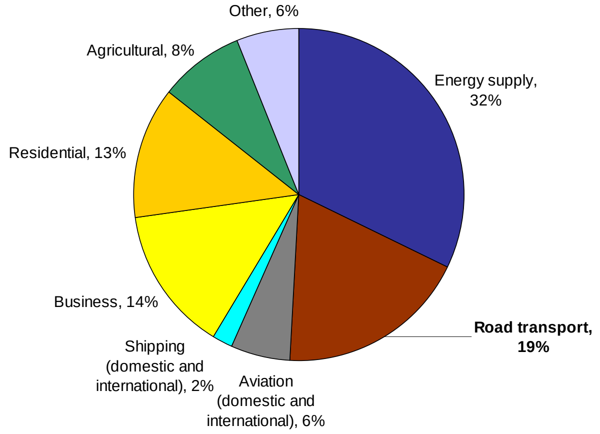


Source: National Atmospheric Emissions Inventory (NAEI)

- There was a 7% fall in road transport GHG emissions between 2007 and 2009. Reduced road traffic volumes as a result of the recession, is likely to be a key factor behind this recent fall. However there are also other factors involved as discussed in *Background to recent trends* (pages 9-11).
- In 2009, road transport accounted for 93% of all domestic transport GHG emissions, with 58% for car & taxis, 17% for heavy goods vehicles, 12% for light vans and 4% for buses & coaches.
- As a proportion of all domestic GHG emissions, emissions from road transport have increased from 14% to 20% between 1990 and 2009.

- Although road transport accounts for 20% of UK domestic greenhouse gas emissions, the 'by final user' figures show that if emissions from the processing of road transport fuels used that takes place within the UK are included, then road transport accounts for 22% of UK domestic GHG emissions.
- Road transport is one of the largest contributors to total UK GHG emissions (both domestic and international) as shown by figure 2.2 below.

Figure 2.2:
The contribution of road transport to total UK greenhouse gas emissions, 2009

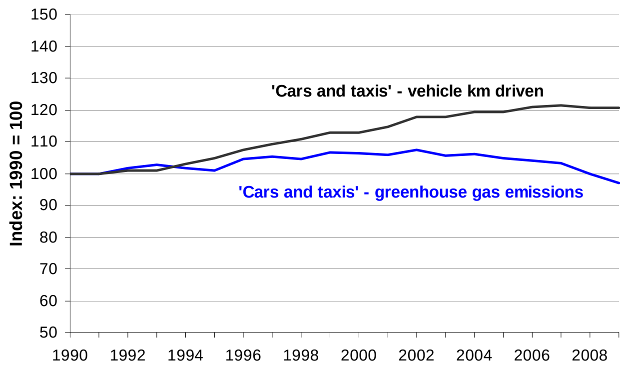


Source: National Atmospheric Emissions Inventory (NAEI)

Road transport emissions by vehicle type

- Cars and taxis accounted for 62% of road transport GHG emissions in 2009. GHG emissions from cars and taxis were 70.9 $mtCO_2e$ in 2009, 3% lower than in 1990 and 10% lower than in 2002.

Figure 2.3:
Greenhouse gas emissions from car & taxis, 1990-2009

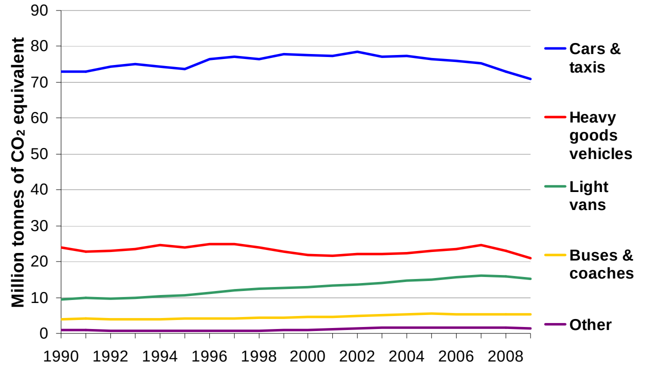


Source: National Atmospheric Emissions Inventory (NAEI)

- There has been a downward trend in GHG emissions from cars and taxis since 2002. Continual improvements in new car fuel economy is likely to be a key reason along with slower car traffic growth over this period.

- GHG emissions from heavy goods vehicles were 21.0 $MtCO_2e$ in 2009 down 13 per cent from 1990. A 15% fall in GHG emissions heavy goods emissions between 2007 and 2009 is mainly attributable to a large fall in heavy goods vehicles traffic volumes during the recession.

Figure 2.4:
UK road transport greenhouse gas emissions by mode, 1990-2009



Source: National Atmospheric Emissions Inventory (NAEI)

- The increase in road transport GHG emissions since 1990 is mainly attributable to light vans. GHG emissions from light vans increased by 62% between 1990 and 2009, alongside a 68% increase in light van traffic over the same period.

Background on the road transport emissions estimates

The exact methodology for calculating greenhouse gas emissions from road transport is fairly complex and is subject to continual methodological improvement. An outline of the overall approach is provided below.

Main sources of data used

The main sources of data for estimating greenhouse gas emissions from transport are:

a. Total UK consumption of road fuels (based on inland deliveries of road fuels)
b. Carbon content of road transport fuels (g C /g fuel)
c. UK road traffic volumes by road type and vehicle type (total vehicle kilometres travelled)
d. Composition of the UK road vehicle fleet, by the characteristics mentioned above (DVLA database of licensed vehicles)
e. Free flowing speeds by road type of vehicle type
f. Emissions factor equations (g emitted/km) – these estimate how emissions of different gases per km vary according to vehicle speed for different vehicle types/ fuel type/ year of first registration (used as a proxy for Euro emissions class)/ engine size/ etc…
g. Fuel consumed per vehicle km for registered good vehicles and for local bus services - based on real annual fuel consumption data.

Carbon dioxide emissions

CO_2 emissions make up over 96% of total greenhouse gas emissions from road transport

- Road transport petrol consumption in 2009
  = total petrol consumed – estimated petrol consumption from off road vehicles/machinery
  = 15.75 mt – 0.26 mt = 15.50 mt (million tonnes)

  Road transport diesel consumption in 2009
  = 20.06 mt – 0.01 mt = 20.05 mt

  Total petrol/diesel consumption does not include blended in biofuels. Emissions from the consumption of biofuels are not included in the UK CO_2 emissions total, as discussed in *The increased use of biofuels* section (page 10).

- Fuel consumption can be converted directly into CO_2 emissions using (b), e.g:
  2009 total emissions from road transport petrol consumption
  = tonnes of petrol consumed by road transport
  × tonnes of carbon per tonne of petrol
  × carbon to CO_2 conversion factor
  = 15.50 mt × 0.855 × 44/12
  = 48.6 $mtCO_2$

- It is not possible to trace which exactly which vehicles are using petrol and diesel sold. UK petrol and diesel consumption figures, therefore have to be modelled, mainly using data sources (c) – (g) above:
  - Using information/assumptions on the petrol/ diesel ratio of car traffic and of van traffic on different types of road. The number of electric cars/vans remains negligible.
  - These ratios are then applied to (c) giving estimated road traffic volumes by vehicle type, road type and fuel type.
  - Data on the composition of fleet (d) together with information/assumptions on the relative mileage of different sorts of vehicles (e,g different engine sizes/ ages) on different types of roads, is used to estimates the characteristics of vehicles actually on the road.
  - Other data including (e) – (g) are applied to give model based estimates of fuel consumption by road type, vehicle type and fuel type.

- The model based estimates of fuel consumption are adjusted to add up to the petrol and diesel road transport consumption totals. The difference between the two set of consumption figures has never been greater than 7%.

Other greenhouse gases

- Other greenhouse gases are not directly related to the amount of fuel consumed and so are derived using (c) – (g).
- Additional factors also need to be taken into account such as failure of catalytic converters and excess emissions that occur when a vehicle is started with its engines below its normal operating temperature.

More details of the methodology used for the road transport greenhouse gas emissions (1990-2009) can be found in the Annex to the 2010 UK submission to the UNFCCC which can be found at: http://naei.defra.gov.uk/report_link.php?report_id=650

Background to recent trends

Following an overall rising trend since 1990, the 7.5% fall between 2007 and 2009 reduced GHG emissions from road transport to pre-2000 levels. This section looks at likely reasons for this fall.

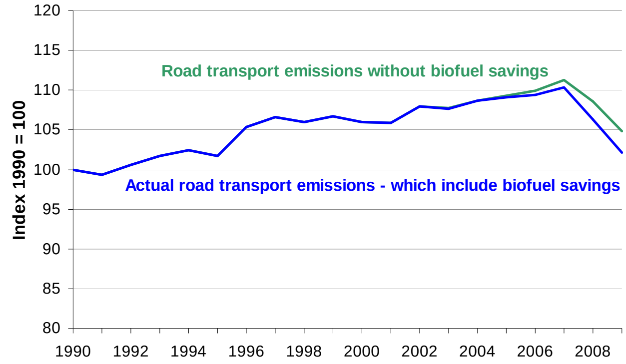
Falling road traffic volumes during the recession

- Falling road traffic volumes during the recession was probably the key factor behind the 7.5% fall in road transport emissions between 2007 and 2009 (see figure 2.3 below). We estimate that…
  - If traffic had continued to grow at the same rate between 2007 and 2009, as it had done for the previous 5 years, GHG emissions would have fallen by up to 2%.
  - If there had been no change in road traffic volumes between 2007 and 2009 then GHG emissions from road transport would have fallen up to 4%.

Increased use of biofuels

- The nature of the fuel used by road vehicles has been changing. The biofuels, bioethanol and biodiesel are produced from a range of agricultural crops. These fuels are blended into the fossil fuels, petrol and diesel.
- Unlike fossil fuels (e.g. petrol and diesel), the CO_2 emissions from the combustion of biofuels are not included in the UK emissions figures in line with international guidelines. This is because these CO_2 emissions are offset by absorption of CO_2 in the growth of the feedstock used to produce the biofuels.

Figure 2.5:
The estimated impact on UK road transport GHG from the consumption of biofuels



Source: DfT Analysis, National Atmospheric Emissions Inventory (NAEI)

- Biofuels have been increasing as a proportion of all road transport energy fuels. The consumption of biofuels in 2009 resulted in an estimated 2.6% saving in road transport GHG emissions, compared with a saving of only 0.9% for road transport in 2007.
- The increase in biofuels as a proportion of all road transport fuel consumption between 2007 and 2009 is estimated to have contributed around 1.6 percentage points to the 7.5% fall in road transport GHG emissions over this period.
- The **Renewable Transport Fuels Obligation (RTFO)**, introduced in 2008, places an obligation on owners of liquid fossil fuel intended for road transport use to ensure that either a certain amount of biofuel is supplied or that a substitute amount of money is paid, providing a potential revenue stream to support the production of biofuel. Only those organisations that supply more than 450,000 litres of fossil fuel in a given year are obligated by the Order. More details on how the RTFO works can be found at: www.dft.gov.uk/topics/sustainable/biofuels/rtfo/
- The obligation in 2009/10 was for biofuels to make up 3.25% the road transport fuels supplied by volume, and this will increase to 5% in the financial year 2013/14. The **EU renewable energy directive** sets a target of 10% of land transport energy to be from renewable sources by 2020. This can include power sources such as hydrogen fuels cells and electric cars, but the bulk of the target is likely to be met with increased use of biofuels.
- As discussed earlier the **consumption of bioethanol and biodiesel has no net CO_2 emissions** in the sense that the CO_2 emitted in the combustion of these biofuels, returns to the atmosphere the CO_2 absorbed in the growth of the feedstock used to produce the biofuels.

However **when emissions associated with** the **production** of biofuels (e.g the cultivation of the crops used as feedstock, transportation of the feedstock, processing the feedstock to produce the final fuel, etc.) are **also taken into account** the **GHG saving** from the use biofuels in place of fossil fuels is **much less than 100%**.

The RTFO enables the DfT to gather information on the GHG emissions savings and sustainability of the biofuels being used in the UK. It is estimated that that for the 2009-10 financial year, on average:

- One joule of biodiesel resulted in an overall GHG emissions saving of 45% relative to one joule of diesel fossil fuel.
- One joule of bioethanol resulted in an overall GHG emissions saving of 63% relative to one joule of petrol fossil fuel.

These estimates do not account for the indirect GHG emissions resulting from land use change driven by the use of biofuels, over which there is considerable uncertainty.

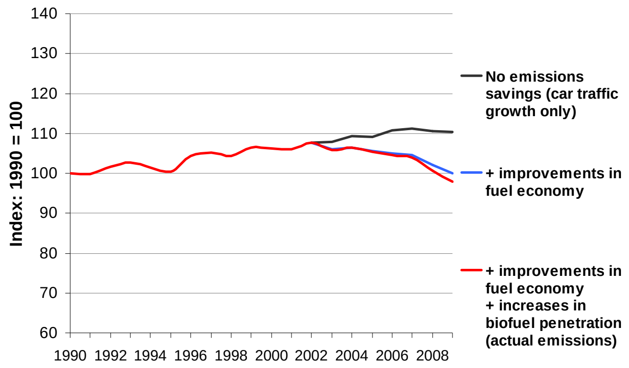
- Looking at where UK road transport biofuels came from in 2009:
    - In terms of feedstocks used, soy made (30%), sugar cane (20%), oil seed rape (16%) and tallow (12%) made up the majority of road transport biofuels.
    - Argentina (20%), Brazil (19%), US (11%) and UK (11%) were the main countries of origin.
    - 56% of biofuels were known to have been produced from feedstocks grown on land which was previously used for growing crops.

- The *Gallagher Review (2008)* looks at the evidence of **adverse effects from biofuels** including the potential GHG emissions from indirect land use change effects, rising food commodity prices and impacts on biodiversity. It also looks at potential polices to mitigate these adverse effects including the possible use of more sustainable '**second generation' biofuels** which could avoid indirect land use change and have greater potential GHG emissions savings relative to fossil fuel. The *Gallagher Review* and subsequent research can be found at: www.dft.gov.uk/topics/sustainable/biofuels/research/

Improvements in new car fuel economy

As mentioned earlier in the factsheet there has been a downward trend greenhouse gas (GHG) emissions from cars since 2002, despite growth in car traffic volumes. Carbon dioxide makes almost all (99%) of car GHG emissions. Figure 2.6 shows an estimated breakdown of where the savings in car CO_2 emissions since 2002 have occurred.

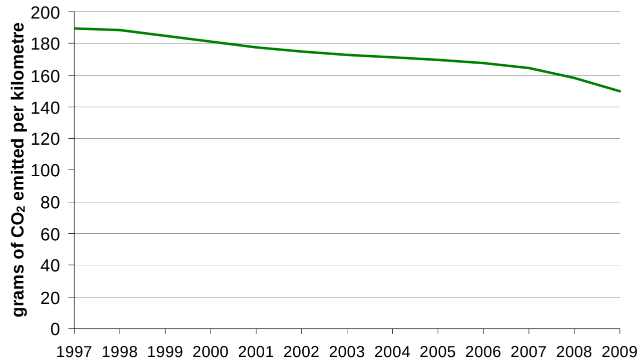
Figure 2.6:
Savings in car CO_2 emissions from changes since 2002



Source: DfT analysis; National Atmospheric Emissions Inventory (NAEI)

- Improvements in fuel economy have been the main factor behind the falls in car CO_2 emissions as shown in figure 2.6 above. New increasingly more efficient cars entering the fleet with older less efficient cars leaving the fleet is likely to be the main driver of the increase in overall fuel efficiency.

Figure 2.7:
Fleet averaged new car CO_2 emissions per kilometre 1997-2010



Source: DVLA/DfT

- The CO_2 emissions per kilometre (figure 2.7) are based on a standard drive cycle carried out under test conditions. The fleet averaged new car CO_2 data does not reflect changing driving conditions or changing driver behaviour but provides a measure of how the intrinsic fuel efficiency of new cars is changing over time. More details about the drive cycle can be found at: http://carfueldata.direct.gov.uk/downloads/default.aspx

- In 1998/1999 the EU signed **voluntary agreements** on reducing fleet averaged new car CO_2 emissions **with** the **automobile manufacturer associations** for Europe, Japan and Korea respectively.

- In March 2005**, graduated vehicle exercise duty** (VED) was introduced in the UK, with a higher tax rate for cars with higher CO_2 emissions, to encourage drivers to purchase more fuel efficient cars. For the details of the latest VED bands go to: www.direct.gov.uk/en/Motoring/OwningAVehicle/HowToTaxYourVehicle/DG_10012524

- In April 2009 the EU introduced **mandatory targets for manufacturers** for the CO_2 emissions of each new car sold in the EU. The EU regulation establishes a “limit curve” which specifies a gCO_2/km limit which varies according to car weight. The limit curve is set up to achieve a new car fleet average of 130gCO_2/km.

  The target will be phased in from 2012 to 2015. 65% of each manufacturer's newly registered cars must comply on average with the limit value in 2012, rising to 75% in 2013, 80% in 2014, and 100% from 2015 onwards. The regulation sets out financial penalties for non-compliance. The details of the regulation can be found at: http://ec.europa.eu/clima/policies/transport/vehicles/cars_en.htm

  There is a longer term target of 95gCO_2/km by 2020, but the details of how this is to be achieved are yet to be set out.

- Ways in which new cars have been made more efficient include:
  - Aerodynamic improvements
  - Light weighting
  - Improved lubrication in engines

- Hybrid electric cars most of which run on petrol, have both a conventional combustion engine and an electric propulsion system; and they tend to have much higher fuel economy than conventional cars. Uptake of hybrid electric cars has been increasing; however they still made up only 1% of new cars in 2010.

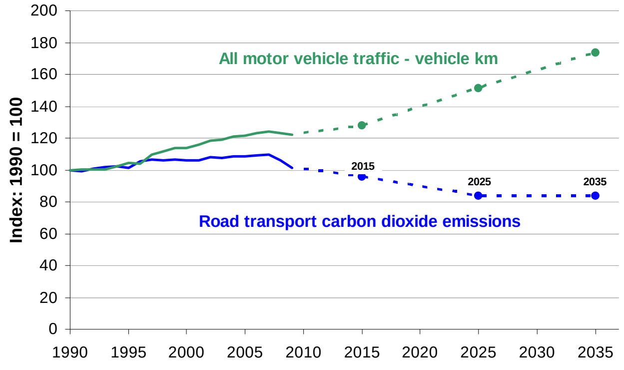
- The uptake of plug in electric/hybrid cars which can be plugged into the electricity supply has been risen since the introduction of the DfT’s Plug in car grant, in January 2011, but remains negligible as a proportion of all new cars.

DfT forecast for road transport CO_2 emissions

The DfT produces forecasts for road transport (road traffic volume, emissions, congestion) using the DfT’s National Transport Model (NTM), a strategic multi-modal model of land-based transport in Great Britain (although results are usually published at the England level only.

- The central forecast for emissions (shown in figure 2.8) is, based on a ‘baseline scenario’ that represents a continuation of existing policies up to 2035. The model currently produces forecasts for the years 2015, 2025 and 2035.

Figure 2.8:
Historic and forecast Road traffic and CO_2 emissions, England, 1990-2035



Source: DfT National Transport Model (2009)

- The central CO_2 forecast suggests that emissions will fall a little then stabilise slightly below current levels. The reduction in emissions from 2010 onwards reflects more stringent targets on vehicle fuel efficiency and biofuels, including the EU New Car CO_2 Regulation, and the Renewable Energy Directive.

- The levelling off in CO_2 emissions at the end of the forecast period is explained by there being no targets currently in place for on vehicle efficiency or biofuels post 2020, combined with continued growth in road traffic levels. At present the possible role of electric vehicles in reducing emissions has is not accounted for in the model.

Emissions per passenger km

To estimate total GHG emissions associated with an average journey, Defra/DECC emission factors intended for voluntary company reporting, can be used:

Average car[1,2]:	151.0g CO_2e per passenger km
Average motorcycle[2]:	139.8g CO_2e per passenger km
Average London bus:	102.8g CO_2e per passenger km
Average bus – other:	221.3g CO_2e per passenger km
Average coach:	36.4g CO_2e per passenger km

1. The factors for cars are estimates averages across the UK car feet and assume and average occupancy rate of 1.6.

Source: Defra/DECC’s greenhouse gas conversion factors 2011

- The factor for cars does not reflect the fact that lower CO_2 emitting cars, such as newer cars and diesel cars, tend to be driven more driven more than higher CO_2 emitting cars

- The relatively high emissions per passenger km figures for non-London buses reflects much lower bus occupancy rates (buses running emptier) outside London.

More information can be found at: www.defra.gov.uk/environment/economy/business-efficiency/reporting/

Factsheet 3
Rail greenhouse gas emissions

Introduction

This factsheet details the latest statistics and information on greenhouse gas (GHG) emissions from rail.

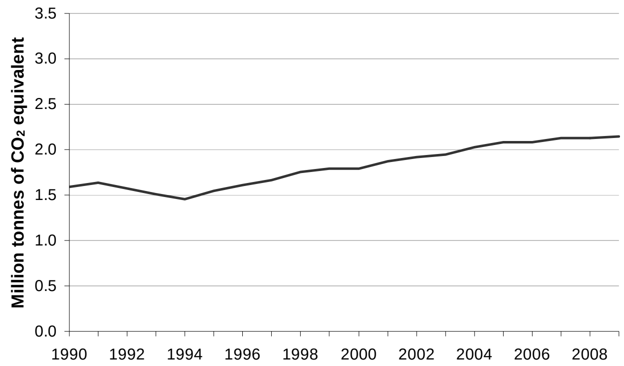
Unless otherwise stated the rail emissions figures in this factsheet are on a 'by source' basis which means than they do not include indirect emissions resulting from the processing of the gas oil consumed or resulting from the production of the electricity used. These indirect emissions are mostly allocated to the energy sector.

There are no direct GHG emissions from electric trains, so on the 'by source' basis, they make no contribution to rail GHG emissions.

Overview of railway GHG emissions

Rail greenhouse gas (GHG) emissions have increased by 35% since 1990 to 2.1MtCO_2e in 2009. This compares with a 28% fall in all UK domestic GHG emissions over the same period.

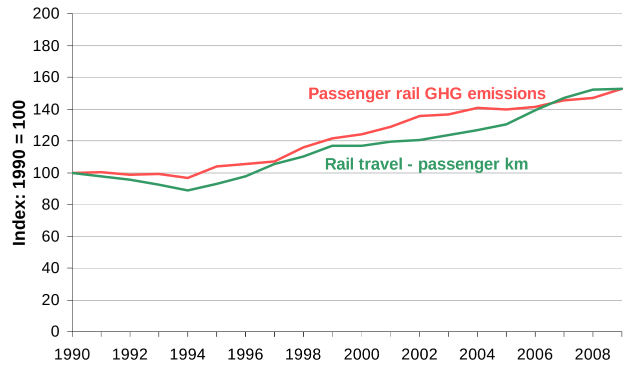
Figure 3.1:
UK rail greenhouse gas emissions 1990-2009



Source: National Atmospheric Emissions Inventory (NAEI)

- In 2009, rail GHG emissions accounted for 1.8% of all domestic transport GHG emissions and 0.4% of all domestic GHG emissions.
- If GHG emissions resulting from the processing of the gas oil used by rail and the generation of the electricity used to power electric trains is included then rail makes up around 0.7% of all domestic GHG emissions
- Rail freight accounts for 27% of rail GHG emissions. Passenger rail travel accounts for the remaining 73% (intercity (38%), regional (33%) and coal trains (1%)).

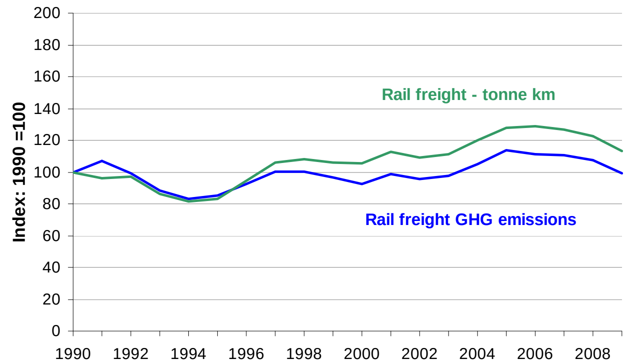
Figure 3.2:
Passenger rail greenhouse gas emissions 1990-2009



Source: National Atmospheric Emissions Inventory (NAEI); Office of Rail Regulation (ORR)

- Passenger rail GHG emissions have increased broadly in line with rail travel as shown in figure 3.2 above.

Figure 3.3:
Rail freight greenhouse gas emissions 1990-2009



Source: National Atmospheric Emissions Inventory (NAEI); Office of Rail Regulation (ORR)

- The rail freight GHG emission figures show a slight improvement in efficiency during the late 1990s. This reflects a shift from class 50 and class 60 freight trains to the more fuel efficient class 66 trains.

Background to the rail emissions estimates

Main sources of data used

The main sources of data for estimating greenhouse gas emissions from rail are:

a. Rail gas oil consumption in Great Britain, broken down by passenger and freight.
b. Coal consumed by coal trains.
c. Train km and freight km data for diesel trains
d. Industry information on the mix of locomotives used
e. Fuel consumption factors and emissions factors for different types of locomotive.

Carbon dioxide emissions from diesel trains

CO_2 emissions from diesel trains make up almost 90% of rail GHG emissions. Gas oil consumption can be converted directly into CO_2 emissions using information about the carbon content of gas oil.

Rail gas oil consumption cannot be estimated from information provided by oil refineries, in the same way as the fuel consumption for other transport sectors. This because gas oil used by rail is indistinguishable from other uses of gas oil, and refiners sell the gas oil for rail use on to resellers rather than direct to rail companies.

- In previously years, rail gas oil consumption has been estimated by the NAEI as a part of their work in producing the UK rail estimates, based on:
  - train km and freight km data
  - assumed mix of locomotives
  - fuel consumption factors for different locomotives

- The most recent UK rail emissions estimates made use of gas oil consumption figures from ATOC (Association of Train Operating Companies)/ORR (Office of Rail Regulation) which are available broken down by passenger rail/freight rail for years 2005/06 onwards. Adjustment factors for freight rail and passenger rail gas oil consumption separately, have been applied to the back-series to produce consistent time series.

Other rail emissions

- The emissions of methane and nitrous oxide from diesel trains cannot be derived directly from fuel consumption and so are modelled using (c) to (e).

- Emissions of carbon dioxide, methane and nitrous oxide from coal trains are derived from (b) using information about the quantities of these gases that are emitted when coal is burned.

Emission per passenger km

To estimate total GHG emissions associated with an average rail journey, the Defra/DECC emission factors intended for voluntary company reporting, can be used:

National rail:	65.1g CO_2e per passenger km
Light rail and trams:	80.9g CO_2e per passenger km
London underground:	83.3g CO_2e per passenger km

Source: Defra/DECC's greenhouse gas conversion factors 2011

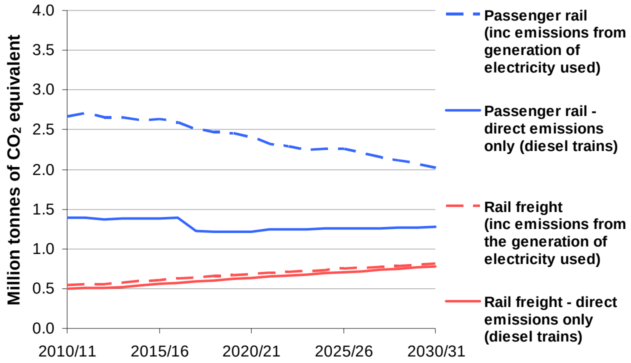
- These emissions include emissions from the processing of the gas oil by diesel trains and the emissions from the generation of the electricity used by electric trains (regardless of the country in which the emissions occurred).

More information can be found at:
www.defra.gov.uk/environment/economy/business-efficiency/reporting/

DfT forecasts of railway CO_2 emissions

The DfT rail CO_2 forecast model produces forecasts for CO_2 emissions for National Rail in Great Britain. It produces estimates for both passenger and freight diesel trains. Electric trains do not emit any carbon dioxide however the forecast model provides forecasts of the CO_2 emissions resulting from generation of the electricity used by electric trains.

Figure 3.3:
Rail CO_2 forecasts, National Rail, GB, 2010/11-2030/31



Source: DfT Rail forecast model, 2011

- Looking at CO2 emission directly from passenger trains (i.e diesel trains only) the fall between 2016/17 and 2017/18 reflects the DfTt's rail electrification program

- When the CO_2 emissions from the generation of the electricity used by electric trains is included, the CO_2 emissions from passenger rail are expected to fall sharply due to the expected de-carbonisation of electricity generation, through increasing use of renewable energy sources.

- Rail freight emissions are expected to increase driven by rising rail fright activity.

Factsheet 4
Shipping greenhouse gas emissions

Department for Transport

Introduction

This factsheet looks at UK greenhouse gas (GHG) from both domestic and international shipping.

There is no internationally agreed way of allocating emissions from international shipping to individual nation states. Reported UK international shipping emissions are in principle based on marine fuels purchased (used to represent fuel consumed) from UK supplies. Naval emissions are reported under “Military aircraft and shipping”.

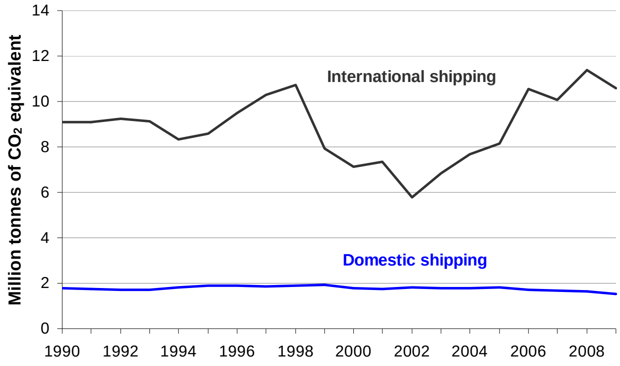
Overview of UK shipping GHG emissions

Figure 4.1:
UK domestic and international shipping GHG emissions, 1990 and 2009

	Greenhouse gas emissions ($MtCO_2e$)		Share of UK total (including international)	
	1990	**2009**	**1990**	**2009**
Domestic	1.8	1.5	0.2%	0.3%
International	9.1	10.6	1.1%	1.7%
Total shipping	10.9	12.1	1.3%	2.0%

Source: National Atmospheric Emissions Inventory

Figure 4.1:
UK greenhouse gas emissions from shipping, 1990-2009

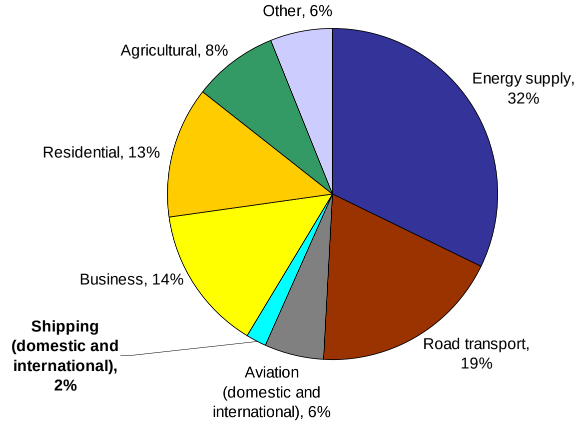


Source: National Atmospheric Emissions Inventory

- The international shipping GHG emissions are based on marine fuel consumed from UK supplies. UK ships may refuel abroad and foreign ships may refuel in the UK. Unlike aircraft, marine vessel do not need to refuel at their origin and destination, marine vessels may also refuel on route. The volatility of marine fuel consumption is not well understood and may be related to fluctuations in the price of marine fuel in the UK relative to the prices of marine fuel abroad.

- Shipping is responsible for around 2% of total UK GHG emissions. Shipping does not make as large a contribution to total UK GHG emissions as either road transport or aviation.

Figure 4.2:
The contribution of shipping total UK greenhouse gas emissions, 2009



Source: National Atmospheric Emissions Inventory

Background on the UK shipping GHG emissions estimates

Total shipping emissions estimates are based on total fuel sold from UK marine fuel supplies (used as a proxy for fuel consumed) in line with international guidelines. For each of the gases CO_2, CH_4 and N_2O, an emission factor (grams of gas emitted per kg of fuel) is applied to convert fuel consumption into gas emitted.

Marine fuel consumption figures

The marine fuel consumption figures are based on refiner’s declared fuel (gas oil and fuel oil) sales to maritime users. Whether the fuel sold is used for domestic shipping or international shipping is not traceable. This is because marine fuels are often sold through third parties and a marine vessel can operate domestically and then internationally on the same tank of fuel.

- In the past the maritime fuel consumption domestic/international split has been based on the refiner’s best estimates of how the fuel they sold was used.

- The most recent (1990-2009) version of the emissions inventory made use of estimates of the fuel consumed by domestic shipping in 2007 – by vessel type, taken from a detailed shipping study carried out by Entec on behalf of DEFRA. The Entec study was based on detailed data on shipping movements.

- Domestic shipping fuel consumption was taken directly from the Entec/DEFRA study and the remaining marine fuel (after subtraction of naval consumption) is allocated to international shipping, ensuring that the resulting figures add up to DECC totals for marine fuels in line with international guidelines.

The Entec Study

The Entec study covered a 50km by 50km area including waters within 200 miles of the baseline and extended eastwards to include more complete coverage of the North Sea. The study produced estimates of fuel consumed and emissions of certain air pollutants for 2007, using the following information about marine vessel movements.

a. Time spent at port
b. Vessel speed and distance travelled
c. Type of fuel used by the vessel
d. Engine power
e. Emissions abatement technologies installed

The Entec/Defra study estimated 2007 fuel consumption from domestic and international shipping, by vessel type. These estimates for 2007 were forward- and back-cast to for the full time series using DfT maritime statistics as proxies for changes in marine vessel activity for each vessel type over time

Further details about the Entec/Defra study can be found in the UK Ship Emissions Inventory Report.

Factsheet 5
Aviation greenhouse gas emissions

Introduction

This factsheet looks at UK greenhouse gas (GHG) from aviation. Total GHG emissions from transport have increased since 1990 while emissions from other sectors have fallen. Most of the increase in total transport GHG emissions is from aviation emissions.

There is no internationally agreed way of allocating emissions from international aviation to individual nation states. Reported UK international aviation emissions are in principle based on aviation fuel purchased (used to represent fuel consumed) from UK fuel bunkers. This roughly corresponds to emissions from international flight departing from the UK and ensures that there is no double counting globally. Emissions from military aircraft are reported under "Military aircraft and shipping".

The global warming effect of aviation is thought to be higher than suggested by the reported aviation GHG emissions alone (see the section on *The global warming effects of aviation*, page 18).

Overview of UK aviation GHG emissions

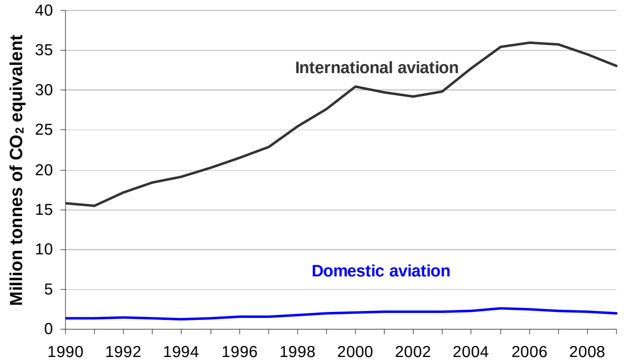
Figure 5.1:
UK domestic and international aviation GHG emissions, 1990 and 2009

	Greenhouse gas emissions ($MtCO_2e$)		Share of UK total (including international)	
	1990	**2009**	**1990**	**2009**
Domestic	1.4	2.0	0.2%	0.3%
International	15.8	33.0	2.0%	5.4%
Total aviation	17.1	35.0	2.1%	5.8%

Source**:** National Atmospheric Emissions Inventory

- Greenhouse gas (GHG) emissions from domestic aviation increased by 43% from 1990 to 2.0 $MtCO_2e$ in 2009. GHG emissions from domestic aviation have doubled over the same period (a 110% increase), to 33.0 $MtCO_2e$.

Figure 5.2:
UK greenhouse gas emissions from aviation, 1990-2009

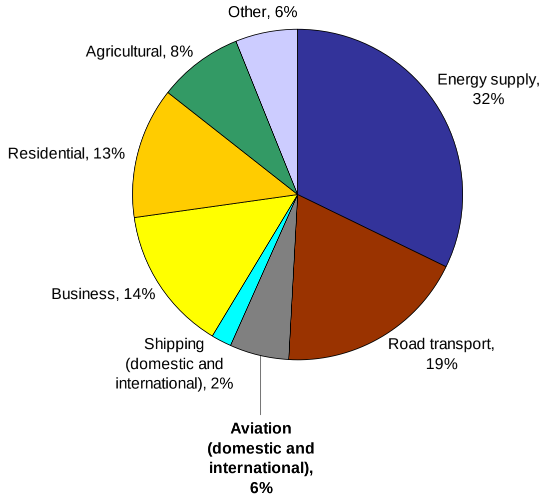


Source**:** National Atmospheric Emissions Inventory

- The contribution of aviation to total UK GHG emissions (including international transport) is not as large as other sectors such as energy and road transport.

  However total aviation emissions have doubled (a 104% increase) since 1990, while emissions from road transport have increased by only 2% and emissions from the other large contributors have fallen. As a result aviation's share of total UK GHG emissions has tripled from 2% in 1990 to 6% in 2009.

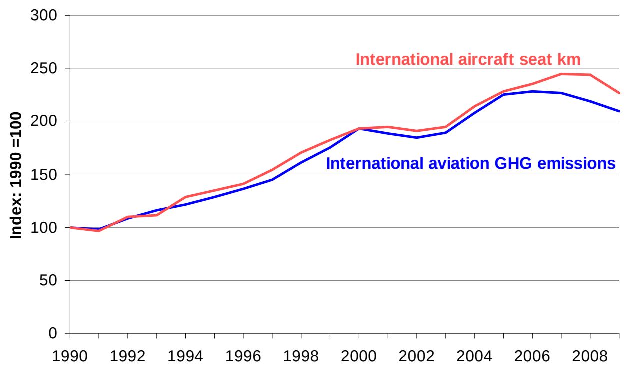
Figure 5.3:
The contribution of aviation to total UK greenhouse gas emissions, 2009



Source**:** National Atmospheric Emissions Inventory

- International aviation emissions have been increasing in line with growth in international aircraft kilometres up until 2005 (see figure 5.4 below).

Figure 5.4:
UK greenhouse gas emissions from international aviation, 1990-2009



Source**:** National Atmospheric Emissions Inventory; Civil Aviation Authority

- The propagation of more modern and fuel efficient aircraft into the fleet was behind the levelling off in international aviation emissions since 2005, along with a levelling off in international air travel during the economic downturn.

Background on the UK aviation emissions estimates

Main sources of data used

The main sources of data for estimating greenhouse gas emissions from aviation are:

a. Total UK consumption of aviation fuel and aviation turbine fuel. Military consumption of aviation turbine fuel from UK supplies.
b. Carbon content (g C /g fuel) of aviation spirit and of aviation turbine fuel
c. Detailed data on aircraft movements: LTOs (landings and takeoffs), distances flown, broken down by airport, the type of aircraft used for the flight and whether the fight was domestic or international
d. Information on the rate of emission of different gases/ rate of fuel consumption at different phases of landing and takeoff.
e. Information on the amount of time spent in different phases of landing/takeoff for different types of aircraft and and airport.
f. Data on cruise (the level part of the flight) emissions/fuel consumption for different types of aircraft for a number of standard flight distances

Carbon dioxide emissions

CO_2 emissions make up over 98% of GHG emissions from aviation.

- Aviation turbine fuel from UK supplies used for used for military purposes is subtracted form total aviation turbine fuel. Emissions from military aircraft are allocated to "military aircraft and shipping" which is included under the "Other" in figure 1.11 (page 6). The figures on consumption of aviation fuels can be converted directly into CO_2 emissions using (b).

- It is not possible to track how much fuel was used for domestic aviation and how much for international. However we do have information of aircraft movements broken down by domestic and international. These can be used to produce model based estimates of the consumption of aviation fuels for domestic aviation and international aviation:

  - Emissions from landings and takeoffs are modelled using data in the numbers of landings and takeoffs of different types of aircraft from different types of airport together with (d) and (e).

  - Cruise (flying level) emissions are based on data on the distances flown by different types of aircraft together with (f).

- The model based estimates for the consumption of aviation fuels, from LTOs and from cruise for domestic aviation and international aviation are adjusted to add up to the total UK consumption aviation spirit and aviation turbine fuel (excluding military consumption).

Other greenhouse gases

- The emissions of other greenhouse gases are not directly related to the amount of fuel consumed. They are produced in a similar way to the model based estimates of fuel consumption.

Emission per passenger km

To estimate total GHG emissions associated with an average fight, the Defra/DECC emission factors intended for voluntary company reporting, can be used:

Domestic	195.2g CO_2e per pkm
Short haul	114.7g CO_2e per pkm
Long haul	132.0g CO_2e per pkm

Source: Defra/DECC's greenhouse gas conversion factors 2011

When multiplying by distance, a 9% uplift factor should be applied to take into account non-direct routes (i.e. not along the straight line great circle distances between destinations) and delays/circling.

- These figures include emissions from the processing of the aviation fuels used (regardless of the country in which the emissions occurred).

- Actual emissions per passenger will vary significantly according to the type of aircraft in use, the load, cabin class, flight route, etc.

More information can be found at: www.defra.gov.uk/environment/economy/business-efficiency/reporting/

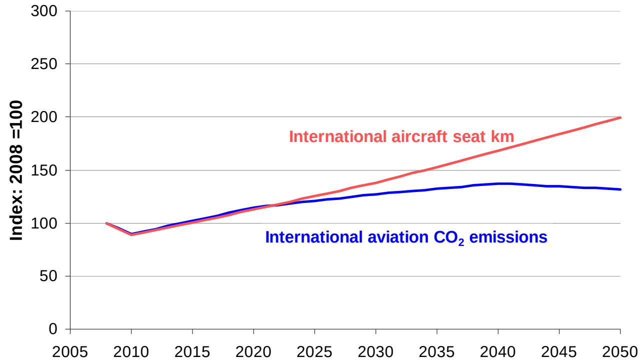
Aviation and meeting emissions targets

In 2012 aviation will join the EU Emissions Trading Scheme (EU ETS). This means that the total annual CO_2 emissions from regulation flights arriving at and departing from airports in the EU will be capped at 97% of average 2004-06 levels in 2010, with the cap tightening to 95% of average 2004-06 levels from 2013 onwards. Emissions above the level of this cap will need to be offset by aircraft operators purchasing EU emissions allowances from other sectors of the EU ETS or project credits from the wider carbon market. This means that emissions can only increase above the level of the cap if aircraft operators pay for emissions reductions in other sectors.

DfT forecasts of GHG emissions

The DfT aviation forecast model provides forecasts of UK aviation activity and CO_2 emissions up to 2050.

Figure 5.5
Forecasts for UK aviation CO_2 emissions, 2008-2050



Source: UK Aviation Forecasts 2011, DfT

- The forecast reflects, for example, aviation joining the EU Emissions Trading System from January 2012, and an assumed improvement in the fuel efficiency of the aircraft fleet, with older aircraft being replaced by newer, more fuel efficient aircraft.
- Post 2030, the assumed improvements in fuel efficiency are expected to outweigh the growth in aviation activity which is also forecast to slow as demand get closer to saturation point and capacity constraints start to have an impact. This causes aviation CO_2 emissions to stabilise and start to fall.

Further information can be found in the DfT's UK aviation forecasts 2011 report.

The global warming effects of aviation

As with GHG emissions figures in general, aviation GHG emissions figures are based on the on the internationally agreed basket of gases covered by the Kyoto protocol. Carbon dioxide accounts for almost all of the reported greenhouse gas emissions from aviation.

The global warming effect of aviation is thought to be higher than suggested by the reported aviation GHG emissions alone. Other global warming effects of aviation include:

- Emissions of nitrogen oxides resulting in the formation of ozone in the troposphere, which has a warming effect.
- The flight of aircraft can (depending on weather conditions) result in the formation of linear ice clouds and can lead to further subsequent induced cirrus cloudiness. These cloud effects have a warming effect.

There is a low level of understanding about these effects and other warming effects of aviation which are not accounted for in the reported GHG emissions.

Recent research (Lee et al 2009) suggests that aviation's total climate change impact is equivalent to between 1.3 and 2.0 times the impact implied by aviation carbon dioxide emissions alone.

Further information can be found in the UK Climate Change Committee report, *Meeting the UK aviation target – options for reducing emissions to 2050*, see Chapter 6 (pages 120 -132).