ESTIMATING EMISSIONS FROM RAIL TRAFFIC

Summary

Base Year: 2008
Up-to-date 2008 rail traffic and energy consumption datasets were obtained from DeltaRail and were used to comprehensively estimate emissions from rail traffic in the LAEI 2008.

Projection Years: 2011 and 2015
Up-to-date 2008 rail traffic and energy consumption datasets were obtained from DeltaRail and were used as the base year dataset to project rail traffic emissions to 2011 and 2015.

Emission estimation methodology: 2008

This section presents the methodology used for the estimation of atmospheric emissions (specifically, carbon dioxide, CO_2; carbon monoxide, CO; oxides of nitrogen, NO_X; hydrocarbons, HC; particulate matters with aerodynamic diameter less than 10 microns, PM_{10}; and sulphur dioxide, SO_2) from railway traffic in 2008 within the Greater London area with the aim of updating the LAEI.

Undoubtedly, estimating atmospheric emissions from railway traffic is a complicated task because several factors play significant roles in the definition of emission parameters, namely: type of train (electric or diesel); average train speed service; fuel (sulphur contents in diesel fuels); number of passengers per seat (0-100%); topography of the distance travelled, slopes and hills; wind speed; number of cold starts (for diesel powered trains); average distance between train stations; and degree of reuse of braking energy. In addition, the estimation of atmospheric emissions from railway traffic in the Greater London area is further complicated by the fact that London's rail traffic is characterised by diversity: a national railway system with a series of railways owned by private companies with a variety of applications; a passenger rail traffic that varies from smaller electric and diesel urban trains, with regular stops and starts, to high-speed passenger trains with infrequent stops; both diesel-powered passenger and freight trains operating on electrified lines used by electrically powered passenger and freight trains; both electrically powered passenger and freight trains operating on the same line, making it difficult to distinguish between electricity (kWh) used for a passenger train or that for a freight train on the same line at the same time; and the use of a given locomotive type for both freight traffic and for different types of passenger operation, making it difficult to attribute energy consumption to a given type of train traffic.

Railway traffic atmospheric emissions are dependent on the source of power (electricity or diesel fuel) used in the train. In the Greater London area, electrically powered trains undertake a significant proportion (about 70%) of high-speed journeys from London to regional cities. When electricity is used to power trains, their emissions are attributed to the power generation plants, and not to the location of the trains themselves as is the case for diesel-powered trains, where emissions are local as a result of the combustion. Therefore, the extensive use of electrically powered trains in London makes it difficult to attribute emissions directly to trains, further complicating the allocation of emissions to rail source in the LAEI. To do this, the distribution of electrical power generation sources and the fuel used (e.g., coal, gas, nuclear energy etc.) for the generation of the electric power in the Greater London area must be known. However, further difficulties arise because the electrical power used to operate most trains in London is actually produced by power stations located outside the Greater London area. Unfortunately, the type of fuel used by these power stations for the generation of the electric power is not known.

Prior to the LAEI 2002 (released in 2005), railway traffic emissions were estimated using a very simplified methodology – emission factors were multiplied by the total amount of passenger-kilometre regardless of the train speed service and average distances between stops. Variables such as occupancy and rail technology were implicitly incorporated into these emission factors, which were typically evaluated for one particular train speed and driving pattern, thus limiting the usefulness of this simplified methodology.

To overcome several of the difficulties highlighted in the preceding paragraphs, an improved methodology, largely based on the methods described in greater detail by Hickman (1999) and Jorgensen & Sorenson (1997), was used in estimating the atmospheric emissions generated by rail traffic in the Greater London area. A fundamental prerequisite in the improved methodology is the availability of the energy consumption (in particular, the specific energy consumptions, expressed as kWh/tonne-km[1]) of a given type of train. This energy consumption is the energy required to move the train and is for all extents and purposes independent of the type of locomotion used, allowing the same methodology to be used for both electric and diesel trains. Therefore, train weight is an important parameter in this improved methodology, since it is the most significant parameter determining the energy consumption and emission rates. However, there are some minor differences in train weights due to differences between the weights of electrical and diesel powered locomotive, but in general these differences are minute in relation to other uncertainties. The differences in emissions arise primarily through the differences in emissions factors for diesel engines and for electrical power generation.

In order to successfully use the improved methodology with a reasonable degree of confidence, the availability of actual up-to-date rail traffic and energy consumption information for the Greater London area and appropriate energy-specific emissions factor (expressed as g/kWh or kg/GJ) were imperative. In this study, actual rail traffic and energy consumption information were obtained from DeltaRail's "ACTRAFF" (Actual Traffic) database and "TRATIM" program respectively. ACTRAFF uses source data from Network Rail's BIFS (Billing Infrastructure for Freight System) and CCF systems. The results are therefore subject to the same limitations as the source data. Similarly the quality of the results is dependent on the quality of the raw data. ACTRAFF assumes that passenger trains are fully occupied, and assumes an average passenger weight of 0.08 tonnes. This may therefore marginally overestimate the weight, and therefore the energy consumption, of passenger trains. DeltaRail holds large amount of data on actual train movement in the UK, compiled by taking historic train running data from TRUST (Train Running System on TOPS: A computer system

[1] Transportation of one tonne of goods over one kilometre including the weight of the rolling stock.

which records actual train running times against scheduled times) and mapping this back to the rail network. At the end of each four-week period DeltaRail updates the ACTRAFF database, which holds information about the number of trains by type and weight of trains that have passed over each section of the Network Rail network. Furthermore, DeltaRail's Train Performance Service prepares energy consumption data for Network Rail (to assist the evolution of track access charging) and for train operators (for business costing purposes), which is used to produce basic energy consumption tables from its TRATIM program. The energy-specific emission factors for diesel engines per unit of power produced were obtained from Jorgensen & Sorenson (1997) for CO_2, CO, HC and SO_2 and for NOx and PM from National Transport Model (DfT). The emission factors for electric trains, based on the averaged energy-specific emission factors of the electricity generation mix for the UK, were obtained from DUKES (2008).
Emission rates were determined according to the equation below.

$$E_p = EC \times EF_p * 10^{-6}$$

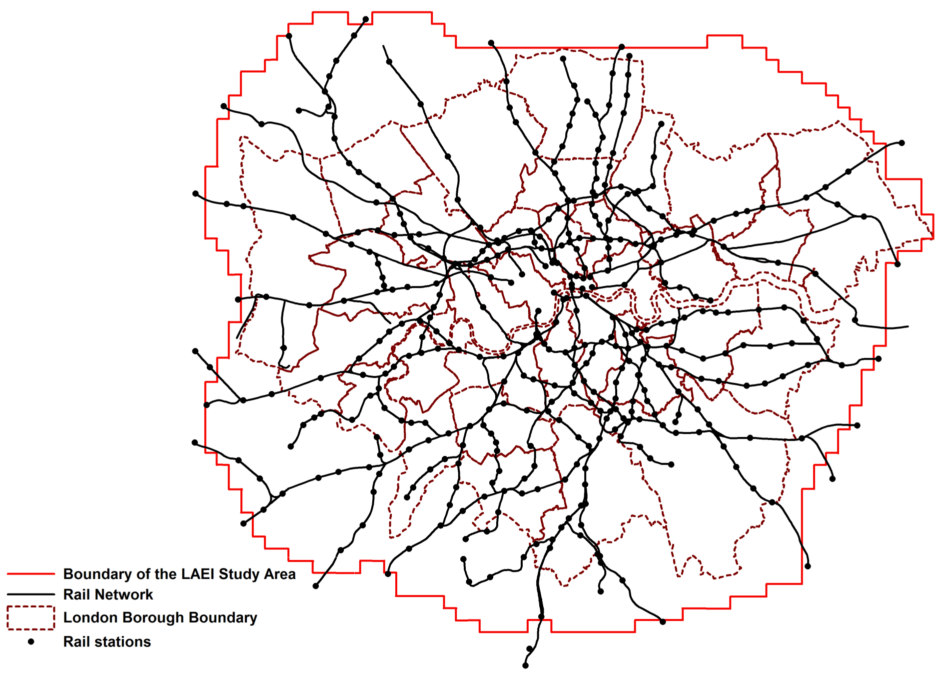
Where:

E_p	= Emission rate of pollutant *p*, tonne/annum
EC	= Energy consumption, kWh
EF_p	= Energy-specific emission factor for pollutant *p*, g/kWh
10^{-6}	= Conversion factor, gramme to tonne

For the purpose of spatially analysing and allocating rail traffic emission estimates across the study area at 1 km x 1km spatial resolutions, the UK Ordnance Survey National Grid Reference System was used as the geographical reference system. A digital geographic layer of the entire railway network (see Figure 1) in the Greater London area was developed, with each railway link represented as a line feature and allocated a unique identification number, and both spatial and non-spatial attributes attached.

Undoubtedly, the finer the temporal resolution the greater becomes the volume of data required for estimating emissions (with mounting accuracy requirements as well). Taking into account the goal of this study, estimating only the average emission of the pertinent pollutants from railway traffic in the Greater London area over the year 2008 was considered sufficient. In terms of the rail traffic data from the ACTRAFF database, there are 13 railway periods every year, each (normally) consisting of four weeks (these do not coincide exactly with the calendar year).

Figure 1. Spatial distribution of the rail network in the LAEI study area



Rail Traffic

In order to obtain a proper spatial distribution, that is how many railway trains are operating within the Greater London area at a given time, proper rail traffic data was crucial. To keep the data collection and analytical process at reasonable levels, a sensible categorisation of train types (see Table 1) was agreed.

Since 2005, a small number of changes have been made to London's railway infrastructure. These include:

- the opening of "High Speed 1" between St Pancras International and the Greater London boundary
- the introduction of services to Heathrow Terminal 5
- closure of the route between Stratford and North Woolwich;

ACTRAFF results are based on infrastructure existing at June 2006, therefore data relating to High Speed 1 and Heathrow Terminal 5 is very limited. Since the 2008 results are based on the same network as 2005, there is no GIS link data for new infrastructure.

Table 1. Train categorisation used in the study

Train Category	Description
D1	Intercity 125 2-Engine
D2	Diesel Multiple Unit (DMU) type
D3	Diesel Multiple Units - 6 coaches
D4	Diesel Multiple Units - 4 coaches
D5	Diesel Multiple Units - 3 coaches
D6	Diesel Multiple Units - 2 coaches
D7	Diesel Multiple Units - 5 coaches
E1	25kV Electric Locomotive & coaches
E2	25kV 8/12-coach Electric Multiple Unit
E3	25kV 4-coach Electric Multiple Unit
E4	750V Electric Multiple Unit (EMU)
E5	750V 8/12-coach Electric Multiple Unit
E6	750V 4-coach Electric Multiple Unit
E7	750V 3-coach Electric Multiple Unit
E8	750V 2-coach Electric Multiple Unit
E9	750V 6-coach Electric Multiple Unit
Ey	750V 5-coach Electric Multiple Unit
F1	Freight - other
M1/M2*	Unknown - missing from "CONSIST"
P1/P2*	Preserved-Locomotive

*M1 and P1 for electric trains and M2 and P2 for diesel trains

The information in Table 2 was extracted from the ACTRAFF database for the calendar year 2008 across the LAEI study area on a link-by-link (a section of track) basis.

Table 2. Rail traffic data extraction from the ACTRAFF database

	Information	**Description**
1	Year	2008 – base year
2	Link	A unique ID for a section of track
3	Type	Passenger or Freight
4	Fuel Type	Electric or Diesel
5	Distance	Distance of link in kilometres
6	Number	Total number of passenger/freight trains
7	Tonnage	Total tonnage of passenger/freight trains
8	Seats	Average number of seats (passenger trains only)
9	Wagons	Average number of wagons (freight trains only)
10	Tare Weight	Average tare weight in tonnes (passenger and freight trains)
11	Gross Weight	Average gross weight in tonnes (passenger and freight trains)

Rail Energy Consumption

In order to determine train energy consumption (i.e., both the average and specific energy consumption values) for a variety of situations, or in cases where it was necessary to make estimates, DeltaRail simulated TRATIM program runs over all the route sections with the identified train types from the ACTRAFF database. Specifically, the energy consumption of great interest is that energy (expressed in kWh/tonne-kilometre) which is required of a locomotive to move the train. By making the energy consumption mass specific, the key factor in determining the energy consumption, the train mass, was normalised out of the calculation. In these terms, energy consumption for different train types became more similar, and correlations based on mass specific energy consumption were applicable to a wider range of trains. Under acceleration, the energy consumption is directly related to the accelerated mass. Hence of great importance was the train weight dataset from the ACTRAFF database.

DeltaRail has substantial infrastructure and traction and rolling stock database that provides Network Rail with point-to-point train timing and energy consumption information via the suite of programs known as "TRATIM". Network Rail owns TRATIM but BR Research and subsequently DeltaRail have agreed exploitation rights. TRATIM calculates Sectional Running Times (SRTs) based on the Runge-Kutta Integration method. It is an event-based single train simulation and is used to compute the running times for single train operation to supply to Network Rail Operational Planning Units and the Train/Freight Operating Companies on request. It is currently recognised by Network Rail, the Train/Freight Operating Companies and other interested parties as the 'industry standard' method of calculating train timings and energy consumption.

The TRATIM simulations in this study utilised the latest railway geographical information comprising distances, station locations, gradients and speed restrictions. The train types and formations operating over the lines of route were identified from the on-line real running time 'TOPS' suite, of operational main frame computer programs, and then allocated train identifiers for evaluation purposes. The lines of route (broken down into route sections) under evaluation were based on the data extracted from ACTRAFF. These routes, uniquely identified as links, all emanated from London's main line terminus stations.

The TRATIM simulations were only carried out for passenger trains, since the freight movements in the central London area were low in number, comprising mainly very short formation trains, spasmodic in operating regularity when compared to the frequent vast numbers of passenger train movements. For this area, TOPS data was also very vague in detail, regarding freight movements and CONSIST makeup details. Line voltages of 600v on the DC electrification system, and 22.5kV on the AC electrification system were used in the simulation to pre-defined inner suburban boundaries. These boundaries were agreed some thirty years by the Electrification Division of the then DM & EE, and subsequently agreed by Network Rail for use in Zonal routine operational timing.

The TRATIM simulations assumed the passenger trains were fully seated operating over the identified lines of route, stopping at the stations as specified. For each line of route, stopping pattern and train formation under evaluation, a forward and reverse direction, and minimum running time simulation were carried out. The average line energy consumption was then derived from the resultant two energy consumption values. A train auxiliary load, for an ambient temperature of 10 degrees C as declared by the manufacturer, was included in the simulation calculations for each traction type and train formation. Regarding the diesel traction units evaluated in the study, the above methodology was also applied, and the following conversion factors were used:

1 gallon of gas oil = 8.34lbs

Calorific value of 1 tonne of gas oil = 45.6GJ

To calculated line energy, the auxiliary energy consumption attributable to station dwell times (typically 30 seconds/station stop) was added and a total energy consumption figures derived. Thereafter, for each link of the route under evaluation, the value of *average energy consumption (kWh/train-km)* and *specific energy consumption (Wh/tonne-km)* were then calculated for each train type and formation. Table 3 shows the information extracted by TRATIM.

Table 3. Energy consumption information from the TRATIM program

Field Name	Description
Year	2008
Link	A unique ID for a section of track
Distance	Distance of link in km
Average Energy Consumption (kWh/train km)	
Specific Energy Consumption (Wh/tonne km)	

Emission Factors

Table 4 below presents the energy-specific emission factors for diesel engines per unit of power produced and were extracted from Jorgensen & Sorenson (1997) and from DfT - Estimation of Rail Environmental Cost Report (2007). In the case of electric trains, emissions are not produced locally, but at remote power plants both within and outside the Greater London area, where the type of emissions is dependent on the fuel used (coal, gas, nuclear energy etc.) for the generation of the electric power. Even for one fuel type, there are variations in the emissions abatement technologies used at most of the power plants. Because the energy–specific emission factors for power generation from within and outside the Greater London area are unknown, we assumed that the electricity used to power electric trains in the Greater London area is supplied from the National Grid and have therefore used emission factors that are based on the averaged energy-specific emission factors of the electricity generation mix for the UK as provided in DUKES (2008). It should be noted that electrical generation and distribution are not uniform throughout the UK, so the emission

factors in Table 4 may not be exactly equal to the general public electricity supply in Greater London. The energy-specific emission factors are given on the basis of primary energy consumption, that is, the energy consumed at the power stations, and not in terms of the amount of electrical energy sent over the electrical net. Ideally, the emission factors should have been divided by a power generation efficiency factor and a transmission loss factor, but the efficiencies of the various processes were not known.
The 2008 energy emission factors have been calculated using Sima Pro life cycle analysis software. This software uses the Ecoinvent data base and allows users to analyse and monitor the full range of environmental impacts of products or processes across the whole life cycle. The Ecoinvent database covers a huge array of pollutants which may be generated over the life cycle of a product or process and includes all the major sources of emissions to air, land and water. Consequently, electricity generation using the UK's generation mix from 2008, sourced from DUKES, has been modelled and the emission factors for CO, NOx, HC SO_2 and PM have been extracted.

Table 4. Energy–specific emission factors for diesel and electric trains, 2008

	CO_2	CO	NO_x	HC	SO_2	PM
Diesel (g/kWh)	640	3.9	8.4	2.0	0.8	0.32
Electricity (g/kWh)	455	0.126	1.04	0.0341	1.28	0.445

Estimating rail traffic emissions

The emission estimation methodology used the actual rail traffic and specific energy consumption data from DeltaRail's ACTRAFF database and TRATIM program respectively, and then applied appropriate energy-specific emissions factors in g/kWh of power produced to determine emission rates, as shown in Equation 1 below.

$$E_p = EC \times EF_p * 10^{-6} \qquad \text{Equation 1}$$

Where:

E_p =Emission rate of pollutant *p*, tonne/annum
EC = Energy consumption, kWh
EF_p =Energy-specific emission factor for pollutant *p*, g/kWh
10^{-6} =Conversion factor, gramme to tonne

The following steps were employed in estimating emissions generated by rail traffic:

1. Calculation of **total tonnage** for train category *t* on link *l*.

$$TT_{t,l} = N_{t,l} * G_{t,l} W_{avg}$$

Where;

$TT_{t,l}$ = Total tonnage in tonnes for train category *t* on link *l*

$N_{t,l}$ = Total number of trains in train category *t* on link *l*

$G_{t,l}W_{avg}$ = Average gross weight in tonnes, for train category *t* on link *l*

2. Calculation of **gross tonne kilometre** (expressed in tonne-kilometre) for train category *t* on link *l*; i.e., the transportation of one tonne of goods over one kilometre by train category *t* on link *l*, including the weight of the rolling stock.

   $$GTK_{t,l} = D_l * TT_{t,l}$$

   Where;

   $GTK_{t,l}$ = Gross tonne kilometre (tonne-kilometre) for train category *t* on link *l*

   D_l = Distance (km) travelled by train category *t* on link *l*

   $TT_{t,l}$ = Total tonnage in tonnes for train category *t* on link *l*

3. Calculation of **primary energy consumption** (kWh) by train category *t* on link *l*, using the specific energy consumption (Wh/tonne-kilometre) data.

   $$PEC_{t,l} = GTK_{t,l} * SEC * 10^{-3}$$

   Where;

   $PEC_{t,l}$ = Primary energy consumption (kWh) by train category *t* on link *l*

   $GTK_{t,l}$ = Gross tonne-kilometre for train category *t* on link *l*

   SEC = Specific energy consumption (Wh/tonne-kilometre) from TRATIM

   10^{-3} = Conversion factor from Wh to kWh

4. Calculation of **emission rate** (tonne/annum) of pollutant *p* by train category *t* on link ***l***, using energy-specific emission factors (expressed in g/kWh).

   $$EM_{p,t,l} = PEC_{t,l} * EF_p * 10^{-6}$$

   Where;

   $EM_{p,t,l}$ = Emission rate (tonne/annum) of pollutant *p* by train category *t* on link *l*

   $PEC_{t,l}$ = Primary energy consumption (kWh) by train category *t* on link *l*

   EF_p = Energy-specific emission factor (g/kWh) for pollutant *p*

   10^{-6} = Conversion factor from grammes (g) to tonne

Atmospheric emissions from rail traffic depend on the source of power used in the train, i.e., electricity or diesel fuel. Emissions from electric trains depend on two parameters – the energy consumption for the train and the emissions from the electricity generated to power the train. Hence, the atmospheric emissions from electric trains were attributed to the power generation plants that supply electricity to these electric trains. For diesel trains, atmospheric emissions were spatially and locally allocated because emissions from diesel engines are local as a result of combustion.

Emission projection

As explained in earlier paragraphs, emissions from rail traffic are estimated basically as the product of energy consumption by rail traffic and energy-specific emission factors. Therefore, to undertake any projection, future developments in parameters describing rail traffic activity, energy consumption and emission factors must be scrutinised to estimate what changes in rail transport are likely. Projecting future emissions from rail traffic must be based on several assumptions that cannot be easily authenticated, because changes in socio-political and economic climates can have profound effect on the makeup of rail traffic - passenger and freight trains, diesel and electric trains etc. Therefore, all projections in this study have been based on the assumptions that no calamitous scenarios and no spectacular technological breakthroughs affecting the railway system occur. This allowed future rail traffic emissions to be attributed to annual growth in the passenger and freight traffic, diesel and electric trains, improvements in train operating conditions, and improvements in the emission factors and the emissions characteristics of the power generating units.

To provide a foundation for establishing future developments in passenger and freight rail traffic, past rail traffic trends[2] (expressed as annual growth rates in passenger-kilometre and tonne-kilometre) between 2002 and 2008 were examined. After analysing the trends, a 3.57% and 2.9% annual growth rates were assumed for passenger and freight rail traffics respectively. For passenger traffic, the annual growth rate is based on the assumptions that there will be no change in train occupancy and no widespread restrictions on passenger rail traffic. For freight traffic, the annual growth rate is based on the assumption that there will be no major political incentives (e.g., the Government's 10 Year Plan for Transport sets the target of an 80 percent increase in rail freight over the next 10 years 2000-2010) to promote rail freight transport. These trends provided no indication of the share of rail traffic powered by electricity or diesel. However, it is expected that the share of rail traffic powered by electricity will be 85-90% in 2010.

Table 5 presents the energy-specific emission factors for electric and diesel engines per unit of power produced and were obtained from Bek & Sorenson (1997). To aid future decision-making, the energy-specific emission factors in Table 6 were obtained by statistical interpolation from the emissions factors for electrical power generation and diesel locomotive emissions provided by Bek & Sorenson (1997) for 1998 and 2020. Undoubtedly this approach unfortunately introduced significant uncertainty and provides an area to be targeted for future emission factor studies.

Table 5. Energy–specific emission factors for diesel and electric trains, 2011

	CO_2	CO	NO_x	HC	SO_2	PM
Diesel (g/kWh)	480	2.5	7.75	0.75	0.515	0.165
Electricity (g/kWh)	370	0.06	0.775	0.825	1.75	0.105

[2] National Rail Trends Yearbook 2007-2008, Office of Rail Regulation.

The emissions from electric trains will vary with the electricity generation mix and if operators decide 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 technology employed. Large changes in emissions from electric trains will occur by 2010 regardless of the use of renewable energy, because of the changes in the future UK electricity mix (Watkiss *et al*, 2002). Electricity generation emissions have been estimated for future years, based on forecasts from the DTI – the lower proportion of coal fired generation will have large effects on emissions of CO_2 and SO_2. It has been forecasted that emissions from electric rail journeys will decrease significantly in future years, especially for NO_x, PM_{10} and SO_2, because of the lower proportion of coal in the electricity generation mix and because abatement technology is being fitted on remaining coal fired plants (Watkiss *et al*, 2002).

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