Facts Sheet 5: Fuel and emissions: Trains compared with replacement express coaches and lorries.

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CAVEAT

The abstract of a paper by Mikhail V Chester and Arpad Horvath illustrates how vital it is to have dust to dust estimates of energy consumptions and emissions. There we see the estimates of life cycle energy inputs and emissions in the USA add 63% to the tailpipe values for road vehicles, 31% for air and 155% for rail. **Click here ************.**

Instead of that, nearly all UK emission studies deal with tail pipe emissions. Consequently the conclusions and policies drawn from those studies may turn out to be unsustainable.

Introduction

The following compares the fuel consumption and emission of national rail with that which would arise if the trains were replaced by express coaches with 20 people aboard returning 10 miles per gallon and by lorries returning 8 miles per gallon delivering 30 Tonnes outbound and returning empty. However, with regard to freight, the data base is extraordinarily weak, and relates to 1998, see data section.

Diesel fuel consumptions for diesel trains and road vehicles are increased by 10% to allow for the fuel burnt in refineries and the energy used in transporting the fuel to the user. The energy used by the electric trains is that burnt in the power stations so as to produce the electricity used by the trains. The calculation takes account of the thermal efficiency of the generating stations, the transmission losses and the electricity used by the generating industry itself. Most other analyses do not allocate the latter to the end user, so underestimating the total power attributable to those users. Similarly most other analyses ignore refinery energy use and the energy used transporting the fuel to the end user.

In deference to the UK vernacular, we express fuel consumption in passenger-miles or Tonne-miles per (imperial) gallon of diesel as well as in KWh. Emissions are in terms of carbon dioxide. To convert to carbon divide by 44/12.

Except where stated, the data in this note relates to the year 2005.

Summary results

If the railway function had been carried out by express coaches and lorries using the railway rights of way then the fuel consumption would have been 24% less than by train and carbon dioxide emissions (a) 13% or (b) 37% less depending on whether one takes the generating industry average emission or the coal-fired value.

If data in the paper cited in the caveat applies to the UK then the life cycle energy inputs and emissions for rail would be 2.6 times the tail pipe values and the lifetime cycle values for road vehicles would be 1.6 times the tailpipe values. In that circumstance replacing the trains by lorries and express coaches would reduce energy consumption and carbon emissions by over 100% except that one has to regard the emissions due to construction as a by-gone.

Passenger Rail returned the equivalent of 94 passenger miles per gallon and emitted either (a) 66.4gms or (b) 101.9 gms of carbon per passenger-km according to whether, for electricity, (a) the average emissions or (b) the emissions due to coal-fired generation is used. There were 43.2 billion passenger-km. The system wide fuel consumption was 13,870 GWh, equivalent to 286 million gallons. The system wide carbon dioxide emissions were (a) 2,868 KT or (b) 4,400 KT.

In comparison express coaches with 20 passengers aboard would provide 180 passenger miles per gallon and 41.8gms of carbon dioxide per passenger-km. The system-wide fuel consumption would then have been 7,272 GWh or 150 million gallons. The corresponding emission would have been 1807 KT.

Rail Freight in 1998 returned 160 Tonne-miles per gallon and emitted 46.6 gms carbon dioxide per tonne-km ignoring the drag into and out of rail heads by lorry. In 2005 there were 23.56 billion Tonne-km. Applying the 1998 consumption and emission data to that yields 4,465 GWh equivalent to 91 million gallons, emitting 1,100 KT carbon dioxide.

In comparison lorries with an average load of 30 Tonnes outbound, back empty, would provide 108 Tonne miles per gallon and emit 69.7gms of carbon dioxide per Tonne-km. Applying that to the 2005 Tonne-km yields 6610 GWh equivalent to 136 million gallons, emitting, 1639 KT carbon dioxide.

In combination

Passenger services plus rail freight used 18,335 GWh, equivalent to 377 million gallons of diesel. The corresponding carbon dioxide emission is (a) 3,968 KT (assuming the generating industries average emissions or (b) 5,500 KT assuming emissions from coal generation are the relevant ones.

In comparison, the replacement express coaches and lorries would have required 13,882 GWh or 286 million gallons of diesel and would have emitted 3,446 KT of carbon dioxide.

Data

National data for the fuel consumption of rail is weakly based. For example, Table 3.2 of the 2006 edition of Transport Statistics Great Britain (TSGB) provides an oil equivalent for petroleum consumption of 0.87 million Tonnes for the year 2005. The corresponding number from the 2007 edition is 0.71. The 11% change between the editions is disturbing.

The same table provides the electricity consumption for the transport sector. However, those responsible for the tables were initially unable to say whether that included or excluded London underground and the nation's light rail and tram systems. They now say that it does but are unable to divide the petroleum or the electric consumption of rail between freight and passengers, or between national rail and to the other systems.

Perhaps the most reliable source for passengers is the report series T618 published in July 2007 by the Rail Safety and Standards Board, RSSB. Section 6 provides the electricity and diesel consumption subdivided between freight and passenger services. The primary source for the passenger data is the Association of Train Operating Companies, ATOC, which in turn will have obtained the data from the Train Operating Companies, TOCs. Hence that data is probably correct. However, for freight the source cited is Transport Watch. Our data was from Network Rail and relates to the year 2002. We have since come to distrust the source because:

(a) We were advised by Network Rail that the total diesel was to be divided roughly equally between freight and passenger services. However the RSSB data has 4700 GWh of diesel allocated to passengers and 2700 GWh allocated to freight (the latter being the same as our number from Network Rail).
(b) The Network Rail data provided fuel consumption per passenger-mile that was substantially lower than that available from both RSSB report and from data we had from British Railways in 1990.

In 1999 we had for the year 1998 an estimate of 232 kilo-tonnes of diesel for rail freight from Tim Murrells of NETCEN citing the National Atmospheric Emissions Inventory on behalf for the DETR. Possibly that is the best data available to the nation. At any rate, if we reject the later Network Rail data, cited by the RSSB, there appears to be no other source.

Hence in this note we rely (a) on the RSSB data for passenger rail and (b) the Tim Murrell's data for freight, relating to the year 1998.

Carbon from the generating industry

Two options for the carbon emissions from the generating industry are used here, namely (a) the average and (b) the value for coal-fired generation. The Rail Safety and Standards Board, RSSB, in its report on Traction Energy Metrics, July 2007, points out on page 10 that any large scale increase in electricity demand would extend the life of coal-fired power stations. Hence the latter may be the more appropriate when considering the emission of any large scale user.

The emission rates, see Appendix 1, are (a) 149 and (b) 293 Tonnes of carbon per GWh respectively. That corresponds to (a) 546 and (b) 1074 Tonnes of carbon dioxide per GWh

Units and constants

(a) The gross calorific value if diesel is 45.7 Giga Joules per metric ton (Tonne)
(b) The calorific value of an "oil equivalent" is 41.868 Giga Joules per metric ton (Tonne)
(c) The Specific Gravity of diesel is 0.84
(d) The carbon emission of diesel is 86% by weight providing 3,150 gms of carbon dioxide per Kg of diesel
(e) One gallon = 4.546 litres
(f) One Tonne of diesel = 262 (imperial) gallons
(g) 1000 gallons of diesel equates to 45.7/262/3.6 = 0.04848 GWh
(h) Appendix 1 shows that the energy burnt to generate electricity is 3 times that used by the end users after allowing for (a) transmission losses (b) the electricity used by the generating industry itself.
(i) On 6th December 2007 Stephen Geldert, of the UK Petroleum Industry Association, provided that refineries use 5.7% of their input as fuel. Hence in this note diesel consumptions will be increased by 10% to allow for both refinery use and the fuel used in transporting the fuel to the end users.

Calculations

Passenger Rail

The tables in section 6 of the RSSB source provide 2,900 GWh of electricity at the substations and 4700 GWh of diesel to the traction units.

Hence the total primary burn amounted to (2,900 x 3 + 4,700 x 1.1) = 13,870 GWh, equivalent to: 286 million gallons of diesel.

There were 43.2 billion passenger km. Hence we have:

$(43.2 \times 10^9 \times 0.625) / (286 \times 10^6) = 94.4$ passenger-miles per gallon.

In comparison an express coach returning 10 miles per gallon and with as few as 20 people aboard would return 180 passenger-miles per gallon after allowing for refinery and transport losses of 10%. (Note, the RSSB suggest express coaches have a 60% occupancy ,equivalent to 30 people for a 50-seat coach). The corresponding system wide fuel consumption would then be $(43.2 \times 10^9 \times 0.625)/180 = 150$ million gallons, or 573 KT diesel or 7,272 GWh.

The carbon dioxide dioxide emission attributable to passenger rail is:

(a) (2,900 x 546) + (4,700 x 1.1 x 3,600 x 3.15 / 45.7) = (1,584 + 1,284) KT = 2,868 KT.
(b) (2,900 x 1,074) + (4,700 x 1.1 x 3,600 x 3.15 / 45.7) = (3,116 + 1,284) KT = 4,400 KT.

Equivalent to:

(a) 2,868/43.2 = 66.4 gms per passenger-km
(b) 4,400/43.2 = 101.9 gms per passenger-km

In comparison the express coach cited above would emit (4.546 x 0 .84 x 3150 x 0.625)/180 = 41.8 gms per passenger-km. The corresponding system wide emission is 41.8 x 43.2=1,807 KT.

Rail Freight

Tables 3.1 and 3.2 of National Rail Trends provide for 1998: 18.13 billion Tonne-km moved (including "infrastructure")

From Tim Murrells we had 232 Kilo-tonnes of diesel. If that accounted for 95% of the freight movement and if we add 10% to the fuel consumption to allow for refinery use plus transporting then we have: (232 x 1.1)/0.95 = 268 Kilo Tonnes. That yields:
$(18.13 \times 10^9 \times 0.625) / (268 \times 262 \times 10^3) = 160$ tonne-miles per gallon and the emissions are 268 x 3.15 = 844.2 KT of carbon dioxide. Hence we have:
$(844.2 \times 10^{9)}/ (18.13 \times 10^9) = 46.6$ gms carbon dioxide per tonne-km

Applying those rates to the 23.56 Tonne-km in 2005 yields a system wide fuel consumption of 268 x 23.56/18.13 = 348.3 Kilo Tonnes or 91. 2 million gallons or 4,465 GWh emitting 1,100 KT carbon dioxide.

In comparison a lorry with an average load of 30 Tonnes outbound empty back returning 8 miles per gallon provides 108 tonne-miles per gallon after allowing for refinery losses and transportation. The corresponding emission is (4.546 x 0 .84 x 3150 x 0.625)/108 = 69.7 gms per Tonne-km. Applying those values to the 23.56 Tonne-km in 2005 yields energy of:
$23.56 \times 0.625 \times 10^9 /108 = 136$ million gallons, or 520 KT or 6,610 GWh and emissions of 1,639 KT carbon dioxide.

<u>In combination</u>

From above we have:

For passengers:

By Rail 13,870 GWh, emitting (a) 2,868 or (b) 4,400 KT of carbon dioxide in 2005.

By coach 7,272 GWh emitting 1,807 KT of carbon dioxide.

For freight

By Rail 4,465 GWh and 1,100 KT of carbon dioxide.

By lorry 6,610 GWh emitting 1,639 KT of carbon dioxide.

In total

Rail 18,335 GWh emitting (a) 3,968 or (b) 5,500 KT of carbon dioxide.

Road 13,882 GWh emitting 3,446 KT of carbon dioxide.

So the road option reduces fuel consumption by 24% and emissions by (a) 13% or (b) 37%.

Historic data

Mr Ivor Williams of British Rail writing on 18th May 1990 provided the first three rows in the following table. The other data in the table were calculated using parameters slightly different from the above. The 88 passenger-miles per gallon correspond well with the 94 for the year 2005.

Table 1 Passenger rail data for 1990

	Network South East	Provincial	Intercity	Totals/ average
Passenger miles (millions)	9,400	3,261	8,306	20,967
Diesel fuel (litres, millions)	46	168	213	427
Electricity consumption MKw-h	1,576	217	416	2,209
Equivalent litres of diesel (million)	514	232	337	1,089
Passenger miles per gallon:	**83**	**64**	**112**	**88**

Click here for Appendix 1 **********

Transport-watch

Appendix 1 Emissions from the UK generating industry

Table A1 below and the associated notes provide:

1. Ratios of primary burn to end user consumption of (a) 1024.8/345.2 = 2.97 in 2005 and (b) 1022.9/344.8 = 2.96 in 2006; leading us to use 3.0 in other calculations.
2. A fair estimate of the corresponding carbon emission from industry as a whole is 150 Tonnes per GWh delivered to end users or 50 Tonnes per GWh of primary energy burn. Those numbers correspond to 550 and 183 Tonnes of carbon dioxide. If it is coal-fired emissions that are relevant then these emissions should be doubled.

TABLE A1 Electricity generating industry: Energy burnt and supplied and emissions

Fuel Source	**MtC/Mtoe (a)**	**Mt of oe burnt (b)**		**TWh burnt (d)**		**Carbon emission Gt**		**TWh supplied (b)**		**Tonnes C per GWh consumed (e)**	
		2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
Coal	1.029	32.62	36.12	380.57	421.40	33.56	37.16	128.67	143.54	**293**	**289**
Oil	0.875	1.33	1.62	15.52	18.90	1.16	1.42	4.72	5.20	**277**	**305**
Gas	0.582	28.7	26.51	334.83	309.28	16.71	15.44	149.78	138.57	**125**	**125**
Nuclear	0	18.37	16.92	214.32	197.40	0.00	0.00	75.17	69.24	**0**	**0**
Hydro	0	0.43	0.39	5.02	4.55	0.00	0.00	4.01	3.32	**0**	**0**
Other renew	0	3.6	3.76	42.00	43.87	0.00	0.00	11.91	12.41	**0**	**0**
Other fuels		2.07	1.48	24.15	17.27	0.00	0.00	4.72	4.03	**0**	**0**
Imports		0.72	0.8	8.40	9.33	0.00	0.00	8.32	9.30	**0**	**0**
Totals/mean		87.84	87.6	1024.8	1022	51.44	54.01	387.3	385.61	**149**	**157**
Final consumption TWh (c)								345.241	344.85		

Notes:

(a) These are Mega Tonnes of Carbon per Mega Tonne of Oil Equivalent as provided by Julian Prime of BERR on 5th October 2007.
(b) Table 5.1 of Energy Trends March 2007. The Mt of oe burnt is the oil equivalent burnt by the generators. The TWh supplied is that reaching the grid.
(c) Table 5.2 of Energy Trends March 2007. The TWh consumed is the electricity reaching users after deducting transmission losses and the generating industry use.
(d) The calorific value of an Oil Equivalent is 42 GJ per tonne. Hence TWh here are the oil equivalent values multiplied by 42 and divided by 3.6.
(e) Typical calculation **293** = (33.56 billion)/(128.67 million x 345.24/387.3).
(f) The BERR and others' estimates of emissions treat the generating industry itself and sometimes the grid as end users. That leads to lower emissions per GWh delivered than we have calculated.

Comparison with Energy Trends

Energy Trends, March 2007, provides 131 Tonnes of Carbon per GWh generated i.e. before generating industry use or transmission losses. The electricity generated was 408,500 GWh. The end user consumption amounted to 344.85 GWh. Hence multiplying the carbon emission per GWh generated by the ratio 408.5/344.85 provides the carbon per GWh used by end users. That yields 155 Tonnes which is close to the 157 Tonnes in Table A1.