Measurement of CO_2 Emissions from Road Freight Transport: A Review of UK Experience

A.C. McKinnon and M.I. Piecyk

Logistics Research Centre
School of Management and Languages
Heriot-Watt University
Edinburgh
EH14 4AS

www.sml.hw.ac.uk/logistics
www.greenlogistics.org

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Executive Summary

Measuring CO_2 emissions from an activity like freight transport is not an exact science. On the contrary, it is possible to estimate CO_2 emissions from road freight transport in different ways with varying degrees of accuracy. Depending on the definition of trucking activity, the degree of reliance on survey, vehicle test-cycle and traffic count data and the geographical scope of the calculation, estimates can vary by as much as 30% for both a single year and a longer term trend.

In recent years differing estimates of CO_2 emissions from heavy goods vehicles (HGV) have emerged from official sources, while the corresponding statistical series have undergone major revisions. This can frustrate the policy-making process and erode the confidence of industry stakeholders in the validity of the figures. For example, between January 2008 and March 2008 the estimated growth in CO_2 emissions form HGVs in the UK between 1990 and 2004-5 was revised downward from 30% to 10%.

Using UK data, this report examines the various methods of carbon auditing road freight transport at the national level and compares the results both for a single year (2006) and over the period 1993-2006. It highlights a series of statistical anomalies and approximations and tries to explain discrepancies that have arisen in the UK data sets. It casts doubt on the accuracy of emission estimates based on the running of lorries under laboratory conditions on roller-beds. Surveys of road haulage operations and road traffic counts appear to yield more accurate estimates, though also have several shortcomings.

A concluding section considers the general lessons that can be learned from efforts in the UK to compile accurate macro-level estimates of CO_2 emissions from road freight transport. It emphasises the need to clarify the scope of CO_2 measurements, publicise revisions to statistical series and find a more accurate means of differentiating aggregate fuel purchases by vehicle type.

1. Introduction

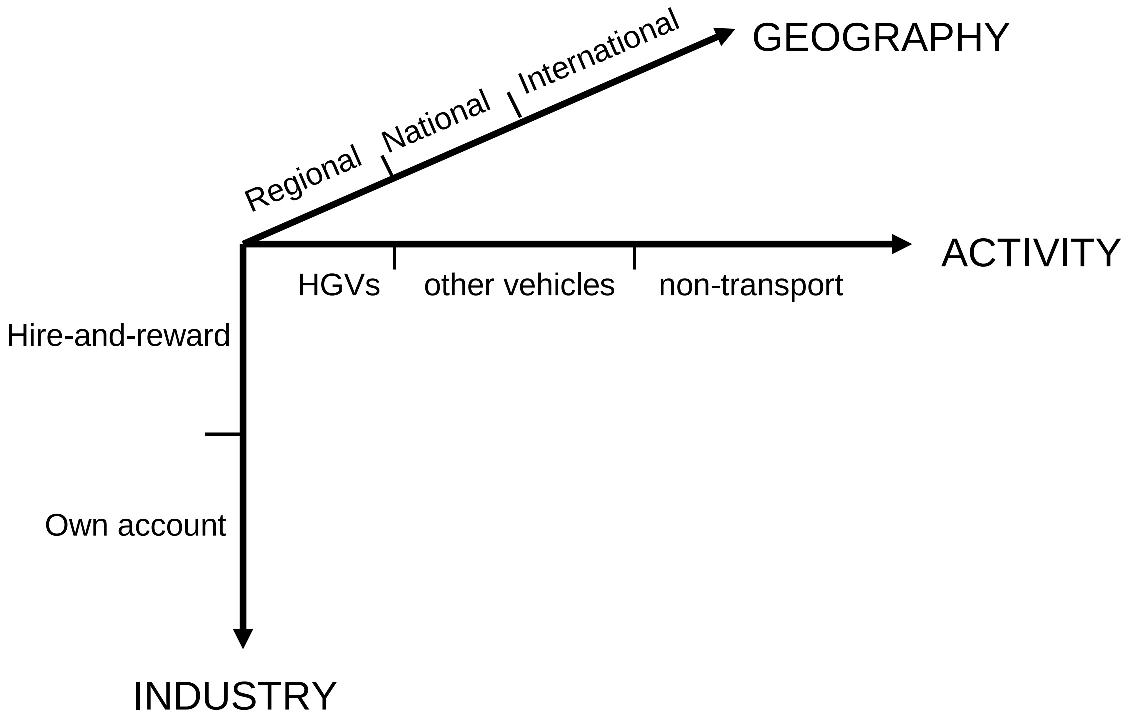
Several governments have been formulating carbon abatement strategies for freight transport. The first stage in the development of these strategies is usually an analysis of greenhouse gas (GHG) / CO_2 emissions from freight operations, disaggregated by transport mode. Attention has tended to focus on road transport, as this is the dominant mode of freight movement, accounting for the largest share of freight-related emissions within countries (Inter-governmental Panel on Climate Change, 2007). Experience in the UK highlights the difficulty of compiling an accurate and consistent set of emissions data for trucking. Emission estimates calculated in different ways and using different base data can yield widely varying aggregate measures and trends. There have also been substantial revisions to official emissions estimates for road freight in recent years, raising doubts about the credibility of the earlier values, some of which are still being quoted in articles and reports. For example, the UK government figure for the growth in GHG emissions from the road freight sector over the period 1990 – 2002, dropped from 59% in the spring of 2004 to 48% in late 2004 to the current estimate of 11% (Department for Transport, 2004a; Department of the Environment, Food and Rural Affairs, 2008). Such radical revisions over a relatively short time period can seriously frustrate the policy-making process and erode business and public confidence in the validity of environmental statistics.

This paper reviews the methods that have been used in the UK to calculate CO_2 emissions from road haulage, tries to explain the discrepancies that have emerged and considers what lessons can be learned from the UK experience.

2. Defining Road Freight Transport

The scope of the emissions calculation for road freight must be defined with respect to activity, industry sector and geography. These three dimensions of variability are illustrated by Figure 1.

Figure 1:
Dimensions of variability in CO_2 estimates for road freight transport



Activity: most of the research in this field has been concerned with the movement of freight in trucks, or heavy goods vehicles (HGVs), with a gross weight in excess of 3.5 tonnes. National surveys of trucking operations, such as those conducted in the EU in accordance with Eurostat requirements, relate to this category of vehicles. Lighter vehicles are classed as vans and treated as a separate vehicle type, partly because they are used at least as much for carrying people and equipment as for moving freight. In the UK, for example, a similar proportion of company van-kms is run for commuting as for carrying freight or returning from a freight delivery (34%) (Department for Transport, 2004b). As vans perform a much broader range of activities and exhibit differing trends from HGVs, managing their CO_2 emissions requires a separate set of policy initiatives. This paper focuses on CO_2 emissions from the exhausts of HGVs. It also excludes emissions from the non-transport activities of companies operating trucks, such as warehousing, goods handling and office work.

Industry sector: trucking is undertaken both by companies whose main activity is road freight transport (known variously as 'hire-and-reward' or 'for–hire' carriers or road hauliers) and companies in a range of other sectors for whom transport is a non-core activity and which run vehicles mainly, or exclusively, to carry their own products (known as 'own-account' or 'in-house' operators). In the UK national Environmental Accounts 'road transport of freight' (EA code 67) refers solely to hire-and-reward operations. The UK government has advised 'data users' to be '*aware that the road freight industry comprises solely the specialist road haulage companies and not all road freight activities*' (Department for Transport, 2004a).

The division of road freight movement (measured in tonne-kms) between these two types of operator varies widely between countries. If national emissions estimates for trucking relate solely to the hire-and-reward sector they will partly reflect the extent to which a country outsources its road freight transport. The analysis of emissions trends will also be distorted by changes in the degree of outsourcing through time. For example, between 1991 and 2001, the % of road tonne-kms moved by hire-and-reward carriers in the UK increased from 69% to 77% before falling back to 72% in 2006 (Department for Transport, 2007). The switch from own-account to hire-and-reward operations during the 1990s caused a transfer of demand for fuel between different road freight sectors rather than a net increase in the total demand for fuel and in CO_2 emissions. It was subsequently recognised by the UK government that there had been '*a misallocation between industry groups*' and the estimated CO_2 growth rate, which was mentioned at the start of this paper, was revised downward (Department for Transport, 2004).

Industry-specific estimates of emissions from road freight transport compiled for national environmental accounting purposes differ from other estimates in another important respect. They quantify total emissions from companies whose dominant activity is road haulage and not simply those emitted by HGVs. Included in the calculation are emissions from other categories of vehicle operated by the company, including vans and cars, and from buildings. It has been estimated in the UK that these non-HGV emissions account for roughly 3% of GHG emissions from road haulage businesses (Department for Transport, 2004a). This percentage partly depends on the nature of the logistics market. Over the past thirty years in developed countries, such as the US, UK and France, many carriers which originally provided a basic transport service have diversified their range of services into warehousing, goods handling and order processing. While their dominant activity has remained road transport, the proportion of CO_2 emissions from this source will have declined. One large logistics service provider, for example, has estimated that around 7% of CO_2 emissions from logistics operations in Europe emanate from warehousing. As the nature of the logistics market varies between countries and changes through time, the inclusion of non-HGV emissions limits the extent to which industry-based estimates of CO_2 can be used for international comparisons and time-series analyses.

Geography: The geographical boundary around a nation's road freight-related CO_2 emissions can be defined with respect to its territory, the country in which freight operators are registered and / or the places where HGV fuel is purchased. If one adopts the territorial definition, as we do in this paper, then CO_2 emissions from all road freight movements made by domestic- and foreign-registered trucks within the country must be included. This comprises internal journeys, with origins and destinations within the country, the domestic legs of international trips and international traffic transiting the country. In contrast, national environmental accounts restrict their measurement of CO_2 emissions to the operations of domestically-registered operators whose dominant activity is road transport. They exclude emissions both of foreign carriers operating in the country and domestic own-account operators. On the other hand, they do include emissions from the vehicles of domestically-registered hauliers while operating outside the country. This is done by estimating the total amount of fuel purchased by these hauliers, some of which will be consumed on foreign journeys. Fuel purchases made within the home country are directly recorded by customs / tax authorities, though, as discussed later, can be difficult to allocate between different categories of vehicle. The estimation of fuel purchases made outside the country by domestically-registered hauliers can be more difficult. This presents a particular challenge in the case of the UK because the large differential in fuel prices between the UK and neighbouring countries, gives British hauliers a strong incentive to fill their tanks in these countries (McKinnon, 2007a). It was estimated that in 2002 approximately 7% of the fuel used by British road haulage companies on domestic and international operations was purchased outside the country. Government statisticians calculated this figure by making a '*cross-border adjustment*' for externally-purchased fuel '*using information on average journey length, vehicle, type, fuel consumption rates and fuel tank capacities*' (Department for Transport, 2004). It is generally assumed that virtually all the fuel consumed by foreign-registered trucks in the UK is purchased abroad (Freight Transport Association, 2006).

An additional complication in the UK is the geographical distinction between Great Britain, which comprises the main land mass of England, Scotland and Wales, and the United Kingdom which also includes Northern Ireland. The main government survey of road freight transport, the Continuing Survey of Road Goods Transport (CSRGT), is confined Great Britain, while CO_2 statistical returns to the United Nations[1] must relate to the United Kingdom as a whole and include Northern Ireland. Separate estimates must therefore be made of CO_2 emissions from trucks operating in Northern Ireland.

The national road haulage industries of EU countries vary widely in the proportion of international work they undertake. There are also wide variations in the level of cross-border fuel purchasing (or 'tank tourism') by hauliers registered in different EU countries, reflecting differences in fuel prices across the continent. These international variations, combined with the differences in the hire-and-reward / own-account split and in the nature of the logistics market mentioned earlier, cause industry-based environmental accounting estimates of CO_2 emissions from road freight to deviate from the territorial estimates based on all HGV-activity undertaken by domestic- and foreign-registered carriers within national boundaries. A later section will measure the extent of this deviation in the case of the UK. Before then, however, we shall examine discrepancies in the estimation of road freight emissions using the 'territorial' approach. The next section reviews the main sources of data used in the derivation of these estimates.

[1] In accordance with the United Nations Framework Convention on Climate Change (UNFCCC)

3. Data sources

The data used to calculate and compare CO_2 emissions from trucking operations within the UK has come mainly from five sources:

1. Vehicle emission testing: this involves measuring emissions from a representative sample of trucks run '*under controlled laboratory conditions on a dynamometer (rolling road*)' (King et al, 2006). These trucks vary in their tare (i.e. empty) weights, dimensions, loading and Euro-emission standard and are run at varying speeds to simulate different drive cycles. Fuel consumption is monitored over these drive cycles and converted into carbon emissions using standard ratios. In the UK, this emission test-cycle data for HGVs has been compiled by TRL Ltd for the Department for Transport.

2. Survey of road freight operators: The annual government survey of road freight operators in the UK, the CSRGT, covers around 16,000 vehicles with a gross weight of 3.5 tonnes or more operated by British-registered hauliers (Department for Transport, 2008a). Sample vehicles have their activities monitored over a period of one week. Since 1989 the CSRGT has included a question about fuel consumption. Respondents are asked, '*How many litres of fuel were purchased or taken from your own supplies for this vehicle during the survey week.*' Data is also collected on the distance travelled by the sample vehicles over the week of the survey and annually. By relating this amount of fuel to the distance the vehicle travels over the survey week, it is possible to calculate the average fuel efficiency. Grossing up this data for the UK truck fleet as a whole and applying standard fuel-CO_2 conversion factors yields CO_2 estimates for the activities of British-registered truck operators in Great Britain (i.e. excluding Northern Ireland).

3. National Road Traffic Survey (NRTS): Manual and automated measurements of traffic flow are taken at regular intervals at numerous locations across the UK road network to measure the level of traffic flow, disaggregated by vehicle type (Department for Transport, 2008b). This provides an alternative measure of the distance travelled by trucks. As the sample of trucks monitored includes both UK- and foreign-registered vehicles, it provides a more comprehensive measure of truck-kms travelled.

4. *Records of diesel fuel purchases:* In compiling its energy statistics, the UK government measures the supply of diesel fuel for road vehicles (DERV). It does not,

however, differentiate vehicle type at point of purchase. The division of diesel fuel between different forms of transport or other uses must be undertaken retrospectively. Estimates are made of the levels of activity in those sectors consuming diesel fuel and their average energy-intensity. In the case of road freight operations, a combination of company survey (CSRGT), road traffic survey (NRTS) and test-cycle data is used to estimate annual fuel consumption. This allocation process and hence the macro-level estimate of fuel consumption by HGVs relies on similar data sources to the bottom-up estimates of CO_2 emissions described in later sectors. If this macro-level estimate were derived separately using records of fuel purchases made specifically for running HGVs, it could provide an independent check on the bottom-up estimates of fuel consumption and CO_2. Unfortunately, this is not the case.

The government estimates that HGVs' share of DERV consumption in the UK declined from 77% in 1986 to 41% in 2006, while the proportions consumed by cars / taxis and light goods vehicles (i.e. vans) increased, respectively, from 3% to 23% and 7% to 29% (Department for Business Enterprise and Regulatory Reform, 2008a).

5. *National Atmospheric Emissions Inventory (NAEI):* this is the main repository of UK data on all types of atmospheric emission from all sources. It is compiled by AEA Technology and can be accessed online (at www.naei.org.uk). Its measurement of CO_2 emissions from HGVs traditionally relied mainly on data sources 1 and 3, though in recent years has made much greater use of survey data on fuel efficiency from the CSRGT. This latter data is used to compile aggregate estimates of CO_2 emissions from HGV activity in the UK. There is also a requirement, however, to disaggregate these estimates by road class and vehicle type. As the CSRGT does not differentiate truck-kms or fuel efficiency by road class, it cannot be used for this purpose. A combination of vehicle test and traffic flow data (i.e. from sources 1. and 3.) must be used instead.

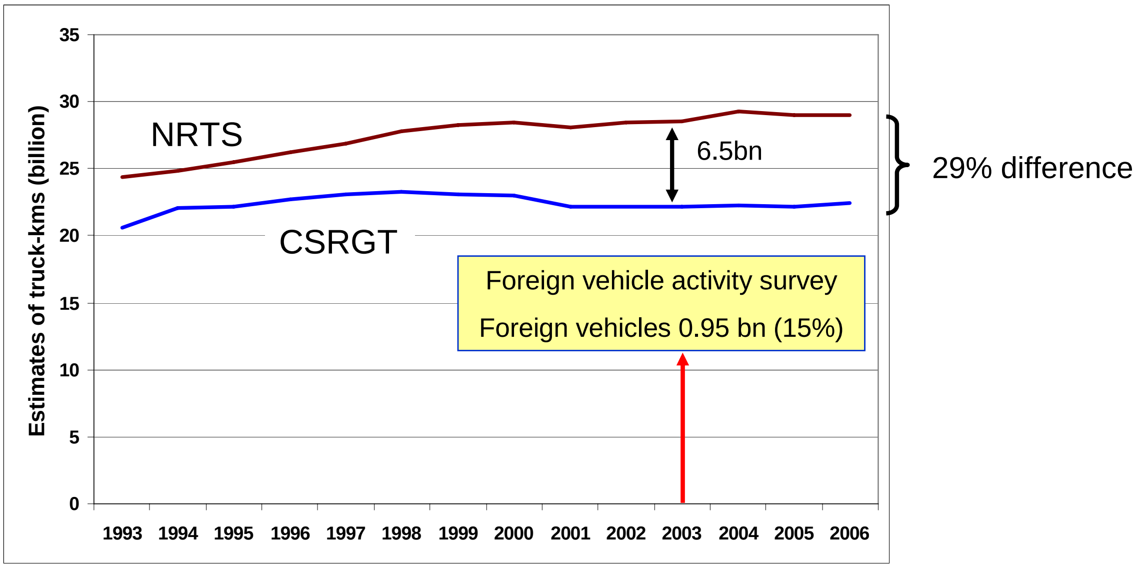
4. Estimation of Key Variables

Data from the first three sources have been used to derive values for two key variables: distance travelled by HGVs and their average fuel efficiency:

4.1 Distance travelled:

In the UK, as in other countries, truck-kms are estimated in two ways: by a postal questionnaire survey of truck operators (CSRGT in the UK) and by road-side traffic counts (NRTS in the UK).

Figure 2:
Comparison of total truck-km estimates for Great Britain: 1993-2006



Source: Department for Transport (2007 and 2008a)

In 2006, the NRTS yielded an estimate of truck-kms which was 29% higher than that derived from the CSRGT. This difference has significantly widened since the mid-1990s (Figure 2). It can be attributed chiefly to three factors:

1. *Exclusion of foreign-registered lorries from the CSRGT*: This survey is confined to UK-registered operators and takes no account of the activities of foreign hauliers operating in the UK. The movement of foreign trucks is, however, monitored by the NRTS. The Foreign Vehicle Survey of 2003 provided a separate estimate of the distance run by foreign lorries on UK roads (Department for Transport, 2003). In 2003, foreign lorry-kms accounted for only 15% of the

discrepancy between the CSRGT and NRTS distance estimates. This figure for foreign lorry-kms run on UK roads may be an under-estimate, however. The Eurostat estimate of road cabotage (i.e. domestic haulage undertaken by foreign-registered carriers) in the UK in 2003 (Pasi, 2008) was 2.6 times higher than the Department for Transport figure, suggesting that the exclusion of foreign trucks from the CSRGT might be responsible for 40% of the discrepancy. It seems likely that much of the divergence of the CSRGT and NRTS estimates of truck-kms since the late 1990s is associated with the sharp increase in foreign penetration of the UK road haulage market since the liberalisation of cabotage in 1998. It is important to emphasise, however, that much of the difference in truck-km estimates must be due to factors other than the inclusion / exclusion of the activities of foreign-registered hauliers in the UK.

2. *Under-reporting of the distance travelled by CSRGT respondents*: in completing the CSRGT questionnaire, operators could omit trips or under-estimate their mileage. In processing the CSRGT data, government statisticians use a vehicle routing software package to validate the quoted distances between the declared start and end points for trips. As this indicates quite a high degree of accuracy in the measurement of trip distances, the under-reporting appears to relate more to the number of trips. An analysis of the tachograph records of a sample of operators during a quinquennial review of the CSRGT did reveal significant under-estimation of total distance travelled. As under-reporting of haulage activity may be inherent to this type of survey, the credibility of vehicle-km estimates from this source is in doubt.

3. *Misclassification of lorries*: staff making manual traffic counts can confuse lorries and vans around the 3.5 gross weight threshold. The fact that the traffic count estimates of truck-kms are substantially higher suggests that this misclassification is systematically biased towards trucks.

Factors 1 and 2 cause substantial under-estimation of truck-kms in the CSRGT while factor 3 is likely to inflate the NRTS estimate. Overall, it is generally acknowledged that the traffic flow data from the NRTS provides a much more comprehensive estimate of the distance travelled annually by HGVs on UK roads.

4.2 Fuel efficiency:

Estimates of the fuel efficiency of different sizes and weights of trucks in the UK have been derived from surveys of actual road freight operations and artificial test-cycle experiments. Both have potential shortcomings:

1. Survey-based estimates: the largest survey of fuel consumption by British-registered road hauliers is the CSRGT. The estimation of fuel efficiency using data from this source may be affected by the acknowledged under-reporting of vehicle-kms discussed in the previous section. If the recording of fuel purchased by this survey is accurate, while vehicle-km figures are under-stated, the fuel efficiency of trucking operations would be systematically under-estimated.

Table 1:
Comparison of fuel efficiency estimates for HGVs from various sources (miles per gallon).

	Rigid						Articulated				
	3.5 t	7.5 t	12-14 t		17-18 t	24-26 t	32 t	33 t	38 t	40 t	44 t
FTA (2007)	25.0	15.5	12.0		13.0	10.0	8.0	9.0	7.8	7.6	7.3
RHA (2007)	27.0	18.0	14.0		12.0	9.5	8.0	9.0	8.0	7.8	7.2

	Rigid					Articulated	
	3.5-7.5 t	7.5-14 t	14-17 t	17-25 t	> 25 t	3.5-33 t	>33 t
CSRGT (2007)	13.7	11.4	9.1	9.5	6.7	8.9	7.9

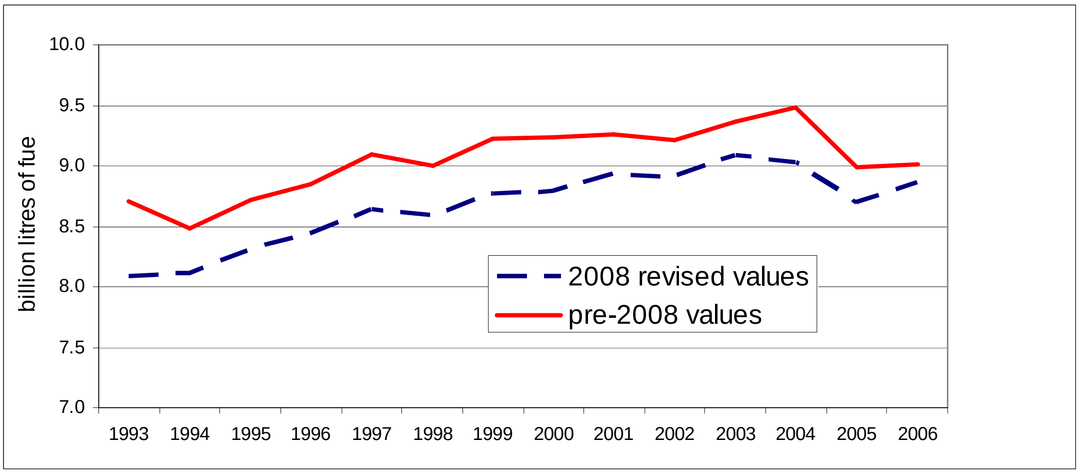
Sources : Freight Transport Association, 2007 ; DFF International, 2007 ; Department for Transport, 2008a.

It is possible to cross-reference these CSRGT-derived fuel efficiency values against fuel efficiency estimates obtained from other smaller surveys of trucking operations in the UK. Since 1997, a series of ‘Transport KPI’ benchmarking surveys have been commissioned by the government which measure the efficiency of truck fleets in particular sectors against a standard set of key performance indicators (KPIs), one of which is fuel efficiency (McKinnon, 2007b). The mean fuel efficiency values recorded in the 2002 KPI survey of road transport operations in the food supply chain were broadly in line with those derived from the CSRGT for different truck weight classes (McKinnon and Ge, 2005). Annual surveys by the Freight Transport Association (2007) and DFF International (2007) provide estimates of average fuel efficiency for different categories of HGV. Differences in the vehicle classifications used make it difficult to compare these estimates with those of the CSRGT (Table 1). There is, nevertheless, some correspondence of vehicle classes at the lower and upper ends of the vehicle weight range. At the lower end (rigids with gross weights below 7.5 tonnes) the CSRGT fuel efficiency figures are much lower, while at the upper end (articulated trucks with gross weights in excess of 38 tonnes) the CSRGT figure is broadly in line with mean value for the FTA and DFF International surveys. There is, therefore, some independent corroboration of the CSRGT fuel efficiency figures, suggesting that they do provide a credible basis for the calculation of CO_2 emissions for articulated vehicles, which account for 77% of total road freight movement by trucks in the UK, despite the apparent under-reporting of vehicle-kms.

In a recent publication, the Department of Transport (2008) has significantly revised its earlier estimates of HGV fuel consumption based on the CSRGT. The new figures show that between 1993 and 2006 the average fuel efficiency of UK road freight operations was around 4.5% higher than previously thought, though the average annual rate of improvement in fuel efficiency was slightly slower (Figure 3). The Department for Transport claims that the figures are more accurate as a result of changes to the methodology and improved data cleansing[2].

Figure 3:

Trend in fuel consumption by UK-registered HGVs before and after the 2008 revision of fuel efficiency estimates from the CSRGT.



Source: Department for Transport (2007 and 2008a)

[2] These changes included omission of Northern Ireland data, separately grossing up fuel purchase and distance travelled data and excluding fuel consumption estimates which were clearly outside realistic ranges.

2. Vehicle test-cycle estimates: test-cycle conditions cannot exactly replicate on-the-road HGV operations for several reasons:

a) a limited sample of vehicles are tested and extrapolation used to estimate values for other types, weights and vintages of vehicles. This inevitably involves significant approximation.

b) although emission levels are monitored at different speeds, the variability of speeds across the range of traffic conditions experienced on a typical journey cannot be accurately simulated. The effects of regular stopping and starting on fuel consumption are difficult to model in a realistic way. Stop-start driving can, nevertheless, have a dramatic effect on fuel efficiency. It has been estimated that a 40 tonne truck achieving an average speed of 50 km / hour would consume, respectively, 28 litres, 52 litres and 84 litres of fuel per 100 km if it stopped zero, one and two times per km (VDA quoted by Larsson, 2007).

c) simplifying assumptions have to be made about the average loading of trucks in test-cycle exercises. Across all truck classes included in the UK test-cycles, an average load factor of 50% is assumed. As shown in Table 2, however, according to the CSRGT, the actual lading factors[3], levels of empty running and overall load factors for the various classes of HGV vary significantly. For all vehicle classes, the assumed 50% load factor over-estimates the actual level of vehicle utilisation. Also, by assuming a constant average load factor, the test-cycle analysis makes no attempt to model the relationship between vehicle loading and fuel efficiency.

[3] The lading factor is defined as 'The ratio of the actual goods moved to the maximum tonne-kms achievable if the vehicles, whenever loaded, were loaded to their maximum carrying capacity' (Department for Transport, 2006, p. 44).

Table 2:
Loading of HGVs by vehicle type and weight (2006)

Rigid vehicles	***% of kms run empty***	***lading factor***	***overall load factor***
3.5-7.5 tonnes	25.4	0.42	31%
7.5-17 tonnes	24.8	0.38	29%
17-25 tonnes	23.9	0.45	34%
> 25 tonnes	34.5	0.64	42%
all rigid vehicles	27.5	0.53	38%
Articulated vehicles			
3.5-33 tonnes	22.9	0.45	35%
>33 tonnes	26.5	0.59	43%
all articulated vehicles	26.1	0.58	43%
All HGVs	26.8	0.56	41%

Source: Department for Transport, 2008a

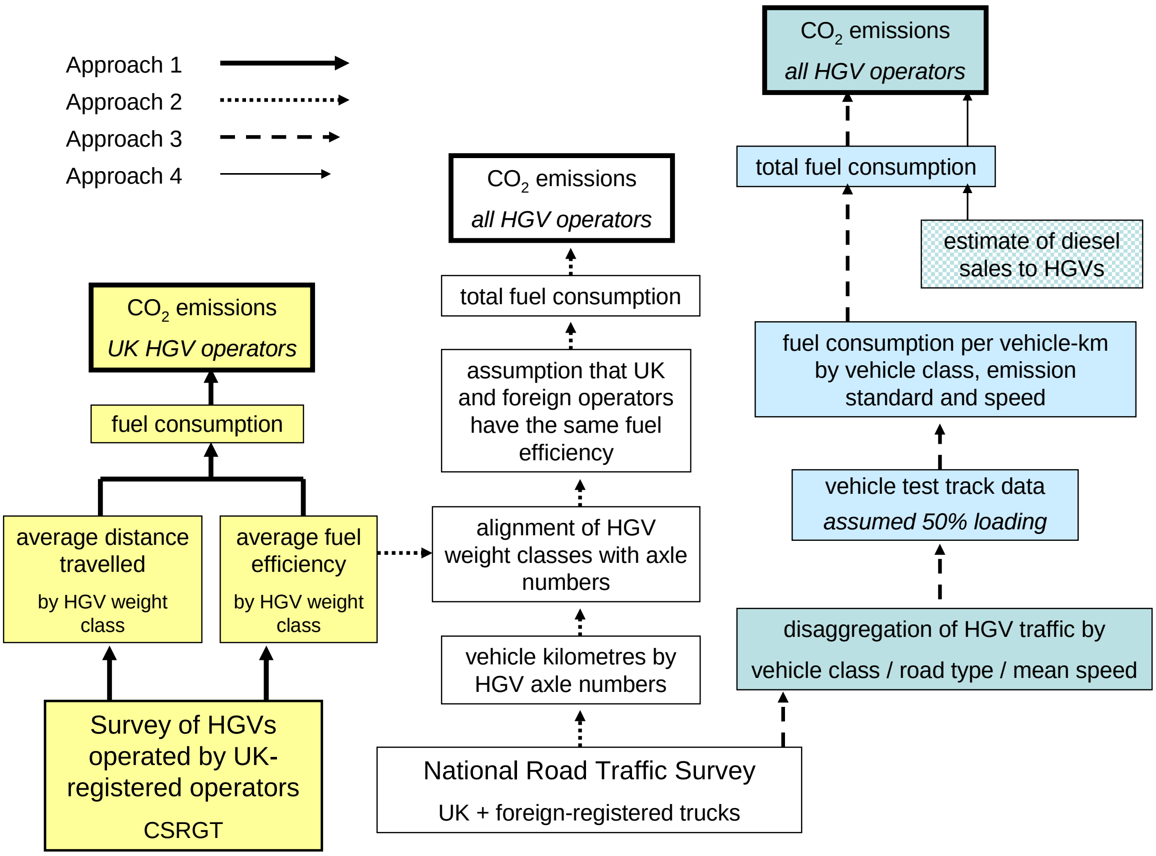
d) unlike published data from the CSRGT, the test-cycle analyses differentiate vehicles in terms of their Euro emission standards. Subsequent weighting of the HGV fleet by age, as a surrogate for Euro emission class, permits the averaging of fuel efficiency, though not in terms of the actual distances travelled by vehicles achieving the different emission standards.

Given the fundamental differences between these methods of measuring truck fuel efficiency, it is very unlikely that they would yield identical estimates. In the next two sections, we examine the way in which these estimates are incorporated into CO_2 calculations and assess the extent to which resulting fuel consumption and CO_2 totals diverge.

5. Methods of Calculation

Figure 4 outlines the four approaches that have been adopted in the UK to estimate CO_2 emissions from road freight transport on <u>a territorial basis</u>. For each approach a different type of arrow has been used to track the various stages in the calculation.

Figure 4:
Differing approaches to the calculation of territorial estimates of CO_2 emissions from HGVs



Approach 1: CSRGT-based estimation of CO_2 emissions from British-registered operators

This approach employs only survey data from the CSRGT. For the different classes of HGV, the average fuel efficiency and average annual distance travelled are multiplied to obtain a measure of total fuel consumption. Summing these measures yields an overall figure for fuel consumption by trucks being run on UK roads by British-registered operators. This is converted to CO_2 using the standard conversion ratio for diesel fuel

(2.63 kg per litre of diesel fuel) (Department of the Environment, Food and Rural Affairs, 2007).

By excluding foreign operators this approach gives only a partial view of emissions from road freight transport in the UK. The under-reporting of trip numbers / distance travelled in the CSRGT further undermines the validity of this approach.

Approach 2: combination of traffic flow estimates of truck-kms with survey- based fuel efficiency estimates[4].

As noted earlier, road traffic counts constitute a more comprehensive and accurate source of vehicle-km data for HGVs. This approach integrates this count-based truck-km data with survey-based fuel efficiency estimates derived from the CSRGT. This integration, however, is complicated by differences in the truck classification schemes used by the CSRGT and NRTS. The CSRGT categorises trucks by their gross weights, whereas the NRTS differentiates them by number of axles. It is necessary, therefore, to align gross weight classes with axle numbers for rigid and articulated HGVs. This has been done in Table 3. This alignment introduces a significant degree of approximation into the calculation.

Table 3:
Alignment of HGV classifications

Rigid HGVs

test-cycle	***NRTS***	***CSRGT***
tonnes	*axles*	*tonnes*
3.5-7.5	2	3.5-7.5
7.5-12	2	7.5-14
12-14	2	14-20
14-20	3	20-26
20-26	3	26-28
26-28	4	28-32
28-32	4	>32
>32	4	>32

Articulated HGVs

test-cycle	***NRTS***	***CSRGT***
tonnes	*axles*	*tonnes*
14-20	4	3-33
20-28	4	>33
28-34	4	>33
34-40	5	>33
40-50	6	>33

NRTS: National Road Traffic Survey
CSRGT: Continuing Survey of Road Goods Transport

[4] In a study for the UK Commission for Integrated Transport, McKinnon (2007c) adopted a simplified version of this approach using aggregate measures of vehicle-kms and average fuel efficiency. The method described here disaggregates these measures by HGV class.

Another source of approximation is the assumption that foreign operators achieve a similar level of fuel efficiency to domestic operators when running their trucks on UK roads. No data are available on the average fuel efficiency of foreign-registered trucks operating in the UK. These vehicles are exposed to the same traffic conditions as their British-registered counterparts, though they may have a different age profile, driving standards may vary and the fact that they run on cheaper fuel bought outside the UK may ease the financial pressure to adopt fuel economy measures. In the absence of empirical evidence of these various effects, the assumption of uniform average fuel efficiency is considered acceptable.

This is the approach now adopted to derive CO_2 emission estimates for HGVs in the NAEI. Until 2007, NAEI estimates of CO_2 emissions from trucks were largely based on vehicle test-cycle data. As discussed earlier, this data is still used for the disaggregation of road freight emissions by road and vehicle type, but the CSRGT is now considered a more accurate source of fuel consumption data for HGVs. As NAEI values relate to the United Kingdom they include an estimate of emissions from trucks operating in Northern Ireland, which are excluded from the CSRGT. Our calculations using this approach, exclude Northern Ireland.

Approach 3: combination of traffic flow estimates of truck-kms with fuel efficiency estimates based on vehicle test-cycles.

This approach again makes use of data from the NRTS, but in a much more disaggregated form, taking account of the classes of road on which HGVs travel and the average speeds attained on these roads. These average speeds can then be associated with the speed : fuel-efficiency ratios derived from the test-cycle analyses to obtain fuel consumption estimates that are sensitive to the pattern of HGV movement and the nature of the road infrastructure. Account can also be taken of the segmentation of the national truck fleet by Euro emission standard and the related fuel efficiency achieved at different speeds.

Approach 4: estimate of total fuel sales to HGVs multiplied by the CO_2 conversion ratio.

As explained earlier, macro-level data on the supply of diesel fuel to the UK market does not distinguish between different types of vehicle. After allowance has been made for off-road uses of diesel, DERV sales have to be apportioned retrospectively among vehicle types. This is done using a bottom-up analysis similar to Approach 3. The final estimate of fuel consumption by HGVs is published in the Digest of UK Energy Statistics (DUKES) (Department for Business Enterprise and Regulatory Reform, 2008b). To keep this estimate consistent with the fuel consumption figure used to derive a CO_2 estimate for HGVs in the NAEI, a 'normalisation' process is used[5] (Choudrie, S.L. et al, 2008). CO_2 estimates for HGVs based on the fuel consumption statistics in DUKES are therefore identical to those quoted in the NAEI. They do not therefore provide independent validation of CO_2 estimates based on Approaches 1 and 2.

[5] The fuel consumption estimates for HGVs derived from the CSRGT are taken as given as they are deemed to be the most accurate, while those for other types of vehicle are subject to the 'normalisation' process. This scales the energy consumption values for the other vehicle types relative to the HGV figure while keeping the total in line the macro-level measure of the amount of DERV supplied to the UK market.

6. Comparison of CO_2 Estimates for 2006

Figure 5 compares five estimates of CO_2 emissions from UK road freight transport in 2006. Two are taken directly from official government sources[6] (a, c(i) and c(ii)), while the other estimates were calculated by the authors using data obtained from various government sources.

a) National Environmental Accounts estimate for the 'road transport of freight' (EA code 67) i.e. UK hire-and-reward sector's activities in the UK and abroad.

b) HGV-activity of British-registered hauliers on UK roads using survey-based fuel efficiency estimates (Approach 1).

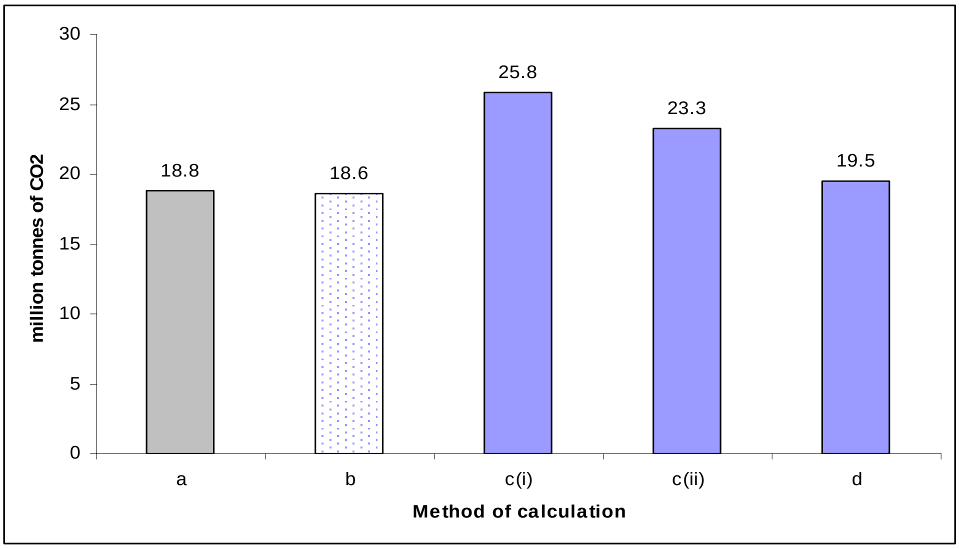
c) All HGV-activity using survey-based fuel efficiency estimates (Approach 2) for:

   (i) the United Kingdom (including Northern Ireland) – NAEI estimate

   (ii) Great Britain (excluding Northern Ireland).

d) All HGV-activity in Great Britain using test-cycle fuel efficiency estimates (Approach 3).

Figure 5 :
Estimates of total CO_2 emissions from UK road freight transport, 2006.



The variations in CO_2 estimates shown in Figure 5 are due mainly to differences in the scope of the calculation, methodology and alignment of vehicle classifications. The two lowest estimates (a and b) relate solely to British-registered operators and therefore

[6] No reference is made in this section to CO_2 estimates for HGVs based on DUKES figures for diesel fuel consumption as these are artificially aligned with the NAEI values using a normalisation process.

provide only a partial view of road freight activity in the UK. The other three estimates aim to provide a comprehensive measure of CO_2 emissions for road freight operations within Great Britain / United Kingdom. The 9.7% difference between estimates c(i) and c(ii) is almost entirely due to their differing geographical coverage. The inclusion of road freight operations in Northern Ireland increases the truck-km figure for Great Britain by roughly 8%. Our estimate of truck CO_2 emissions is therefore closely consistent with the NAEI value.

When set against estimates c(i) and c(ii) based on survey data for fuel efficiency, the figure derived from vehicle test-cycle results appears to under-estimate CO_2 emissions by a substantial margin (around 20% lower). It is surprising that this estimate is so low as the vehicle tests actually over-estimate vehicle loading. As discussed earlier, the 50% loading (by weight) in these tests exceeds the average vehicle utilisation recorded in the CSRGT. Combining CSRGT lading factor and empty running statistics yields an average load factor of 41% for HGVs. The heavier average loading used in the vehicle tests would be expected to result in higher rather than lower fuel consumption and CO_2 estimates. This upward bias appears to be more than offset by under-estimation of the effects of real-world traffic conditions on fuel efficiency, particularly on congested roads in urban areas. Support for this hypothesis comes from a comparison of the mean fuel efficiency values derived from the CSRGT and test-cycle analyses for different classes of HGV (Table 4). This shows that, in percentage terms, the gap between test-cycle and survey-based fuel efficiency estimates is substantially wider for lighter rigid vehicles than for the heavier articulated ones. The former vehicles are engaged mainly in local distribution in and around urban areas, often on multiple delivery and collection rounds. The heavier articulated trucks, on the other hand, are predominantly used for long distance trunking on motorways where they can achieve more steady running at fuel efficient speeds. The drive cycle tests can more accurately replicate this type of road haulage operation.

Table 4:
Comparison of test-cycle and CSRGT estimates of HGV fuel efficiency
(miles per gallon)

	Rigid HGVs			**Articulated HGVs**		
axle numbers	2	3	4+	3 - 4	5	6+
CSRGT	11.4	10.0	6.7	9.0	8.0	8.0
Test-cycle	16.3	11.7	9.3	11.3	9.0	8.2
Difference	4.9	1.7	2.6	2.3	1.0	0.2
%	30%	14%	28%	21%	11%	3%

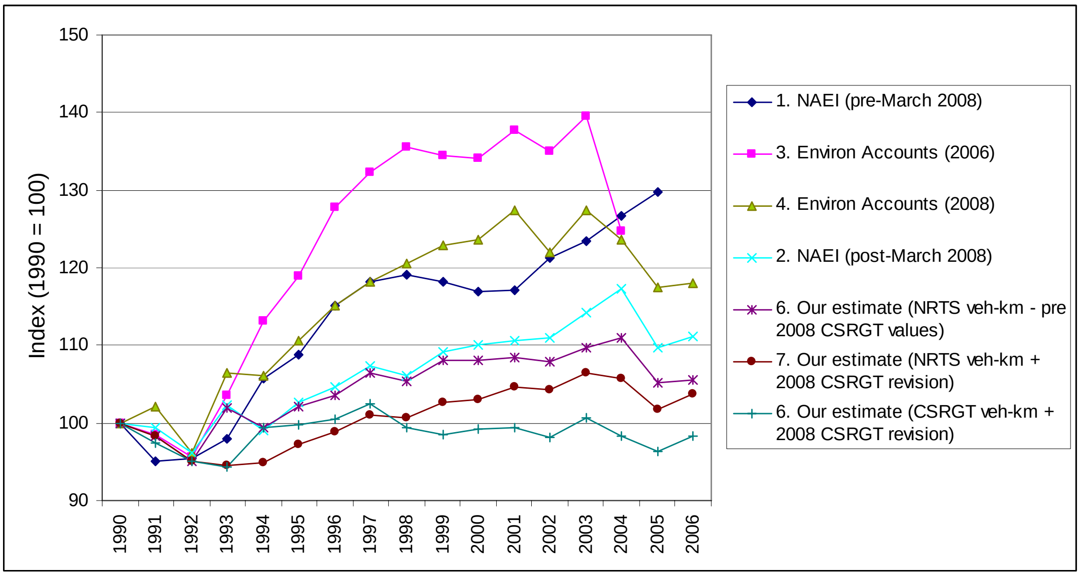
Some of the difference in CO_2 values between estimation methods c(i) and c(ii) and d) can also be attributed to the small sample of vehicles used in the test-cycle analyses and resulting need for extrapolation.

7. Comparison of CO_2 Trends for 1990-2006

Figure 6 plots seven trends for CO_2 emissions for UK road freight over the period 1990 to 2005/2006[7]:

1. NAEI (pre-March 2008)
2. NAEI (post-March 2008)
3. Environmental Accounts (2006)
4. Environmental Accounts (2008)
5. Our estimate (CSRGT HGV-km estimate + 2008 CSRGT revision)
6. Our estimate (NRTS HGV-km estimate – pre-2008 CSRGT values)
7. Our estimate (NRTS HGV-km + 2008 CSRGT revision)

Figure 6 :
Trends in CO_2 emissions from HGVs in Great Britain / United Kingdom



It shows the widely divergent paths followed by indices calculated in different ways. The divergence was at its greatest in 2003-4. Referring to CO_2 estimates for this period, the Commission for Integrated Transport (2007) noted that '*trend emission figures for lorries and vans can vary by a factor of 3*'. The trends had begun to converge by 2006, as the Environmental Accounts and NAEI estimates were revised downwards. Although the various trends have been consolidated in Figure 6, they are not directly comparable. Only the four 'territorial' estimates, two based on NAEI (pre-and post-March 2008) and two

[7] It was not possible to conduct a time-series analysis of estimates based on vehicle test data as only one set of data was available.

calculated by the authors on the basis of NRTS HGV-km data and CSRGT fuel efficiency data (before and after the 2008 CSRGT revision), are strictly comparable (i.e. trends 1, 2 and 6 and 7). It can be seen how the March 2008 revision of the CO_2-trend for HGVs in the NAEI, reflecting mainly the switch from test-cycle to survey data, has dramatically reduced the rate of growth since 1990. These estimates are based on the pre-2008 fuel efficiency estimates from CSRGT. Once the revised CSRGT fuel efficiency estimates are factored into the NAEI in future years, the rate of growth in CO_2 will be further reduced.

A government pocket book on '*Sustainable Development Indicators*' in 2006, drawing upon the NAEI, claimed that CO_2 emissions from HGVs rose by 29% between 1990 and 2004 (Department of the Environment, Food and Rural Affairs, 2006). In a Parliamentary Answer given in January 2008, the government indicated that between 1990 and 2004 CO_2 emissions from HGVs had risen by 30% (House of Commons, 2008). With the recent revision of the NAEI database, the overall increase between 1990 and 2005 has been reduced to 10%. This has largely closed the *'factor of 3'* gap observed by the Commission for Integrated Transport (2007). The high estimates of the growth in CO_2 emissions from HGVs released in government publications between 2004 and 2006 received coverage in the national press. In sharp contrast, the release of official data in 2008, suggesting that the CO_2 growth has been much more modest, has gone virtually unnoticed.

8. Lessons from the UK Experience

The UK government compiles a broader range of freight and energy statistics than many other countries. Elsewhere the methodological options for calculating CO_2 emissions from road freight transport, and hence the opportunities for discrepancies to arise between the resulting estimates, are much more limited. There are, nevertheless, wider lessons that can be learned from recent attempts in the UK to measure CO_2 emissions from HGVs. The first two lessons are essentially presentational; the remainder relate to the collection and analysis of emissions data:

1. Need to clarify the differing scope of CO_2 measurements: CO_2 emissions for road freight transport are measured in different ways for different purposes. The supply of emissions data to international agencies, such as the UN under its Framework Convention on Climate Change (UNFCCC) and the International Energy Agency, must conform to particular statistical requirements. National governments have discretion over the compilation of other statistics. Numerous emission statistics originating from government sources can therefore enter the public domain, often without supporting information about their scope and derivation. The emergence of conflicting values confuses the public, industry and politicians and undermines their confidence in the statistical reporting of carbon emissions from this sector.

2. Need to publicise revisions to statistical series: As the carbon auditing of freight operations is a relatively new science, methods of data collection and manipulation are still evolving. The application of new procedures may make it necessary, therefore, to revise historic data on emissions. There is a natural tendency to keep such revisions 'quiet' as they give the impression that errors have been made in the past. The discrepancies revealed in this paper have not been the result of past miscalculations, but rather differences in the scope of the calculation and nature of the input data. When methodological changes are made and the estimates revised, it is important that they are widely publicised because otherwise key opinion formers in the press, politics, academe and pressure groups will continue to quote previous statistics which may give a misleading view of major trends. The substantial revisions of CO_2 estimates for HGVs in the UK in early 2008, for example, have so far gone largely unreported. It must be acknowledged, however, that organisations compiling national inventories of emissions data face a formidable challenge in alerting stakeholders to revisions because they must derive estimates for a multitude of sectors and sub-sectors, using differing techniques and complying with different reporting conventions.

3. Need to reconcile differences in truck-km estimates based on operator surveys and roadside traffic counts: Total annual truck-kms is the main index of road freight activity used in the auditing of energy use and carbon emissions. It is imperative that it is measured accurately. Observed discrepancies in the UK of over 25% between survey and traffic flow estimates of truck-kms have therefore been a serious cause for concern. The UK Department for Transport has recently been reviewing this issue.

4. Benefit of differentiating vehicle type at point of fuel purchase: If a means could be found of differentiating vehicle types in the recording of fuel purchases by the transport sector, this fuel supply data could be used to provide an independent check on bottom-up CO_2 estimates for road freight operations.

5. Recognition of significant differences in emissions estimates based on survey and vehicle-test data: The measurement of fuel consumption and exhaust emissions from HGVs under laboratory conditions yields significantly lower values for lighter rigid vehicles than corresponding survey-based estimates. This is likely to be the result of a failure to allow for the fuel penalties associated with urban traffic conditions and stop-start running on multiple drop/collection rounds.

6. *Implications for the estimation of CO_2 emissions from other categories of traffic:* Given the method of CO_2 estimation used for road transport in the UK, altering the CO_2 figure for one category of traffic can affect that of other categories. As noted at the end of section 5, 'figures calculated for each vehicle type from a bottom-up approach, combining fuel consumption factors with traffic data, are normalised to force the total petrol and diesel consumption to equal the figures reported in DUKES (corrected for off-road consumption)' (Choudrie et al, 2008, p.310). The reduction in the estimated consumption of diesel fuel by HGVs may therefore have increased the corresponding estimate for cars, vans and buses. This reallocation of fuel consumption and CO_2 emissions between vehicle classes, and its impact on the analysis of their carbon intensity trends, requires further investigation. It also raises questions about the consistency of CO_2 statistics derived for the various types of road traffic, as different estimation methods

are used for HGVs, cars, vans and buses. It would clearly be preferable to employ a standard method of calculation, though this is currently prevented by differences in the nature and quantity of data available for each vehicle type.

7. Misrepresentation of national trends in international reports: This paper has illustrated the range of CO_2 values calculated for road freight operations in a single country. In collating national CO_2 figures for international comparison and aggregation, statisticians and researchers must ensure that they have been compiled on a similar basis. Inter-governmental organisations aim to achieve this by imposing strict rules on data conformity; other research agencies and individual scholars can find it difficult to ensure such consistency. Furthermore, the lead-times for collating and publishing multi-country energy and CO_2 statistics are generally much longer than for the compilation of national data sets. Revisions to these national statistics can take several years to be reflected in international reports. For example, two recent international comparative studies (Kamakate and Schipper, 2008; International Energy Agency, 2008) have indicated that the energy-intensity of UK trucking rose significantly between 1990 and, respectively, 2003 and 2005. This is broadly consistent with the trend based on macro-level DUKES data for HGVs up to 2006. The recent revision of this historic data, however, produces a markedly different trend which shows energy-intensity dropping by 6% between 1990 and 2005 rather than rising by 11% as the earlier DUKES data suggested (Department for Business Enterprise and Regulatory Reform, 2008).

8. Opportunity for using telematics data to model the relationships between road type, traffic conditions and CO_2 emissions: The application of new telematics systems permits the real-time monitoring of an HGV's location, speed and fuel consumption while travelling on the road. This permits the differentiation of road types and operating environments. Data from this source can provide more realistic modelling of on-the-road CO_2 emission profiles for trucks and may ultimately render lab-based test-cycle analysis obsolete.

9. Conclusions

This paper examines the difficulties encountered in trying to compile a definitive national set of CO_2 emission values for road freight transport. Based on the UK experience, it demonstrates the need for transparency in the initial calculation and any subsequent revision of CO_2 values. Depending on the scope of the analysis, the nature of the calculation and the assumptions made, one can produce widely varying estimates of CO_2 emissions from trucking. In the UK, different government departments and agencies released different CO_2 values casting doubt on the credibility of the values and making it difficult to establish a consensus both about the current level of freight-related emissions and historic trends. An understanding of these past trends is critical to the development of a sustainable distribution strategy which commands the support of business and other stakeholder groups.

Estimates of the growth of CO_2 emissions from HGVs in the UK between 1990 and 2005 have recently between revised downwards by a factor of three, mainly as a result of a switch from the use of vehicle test-cycle data generated under laboratory conditions to survey data on fuel efficiency collected from large samples of road freight operators. When related to the quantities of freight moved by HGVs (expressed in tonne-kms), the carbon intensity of road freight transport in the UK now appears to have fallen by 6% over this period rather than risen by 11% as suggested by the previous set of official statistics. It is clearly difficult for policy-makers to develop decarbonisation strategies for freight transport when key carbon indicators undergo such radical revision.

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