Measuring and Managing CO_2 Emissions

of European Chemical Transport

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Report prepared for cefic

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Foreword

Climate change is one of the biggest challenges facing industries, governments and society.

Policy makers and industry sectors across the world are working to understand their own role and required actions. Individual chemical companies are already doing a lot of work in the area of energy efficiency and innovation, recognising environmental performance – alongside health, safety and security – as essential for business success.

The chemical industry is uniquely placed to enable energy savings and reduce greenhouse gas emissions through the application of our products, for example building insulation and low-temperature detergents. The European chemical industry has an excellent track record over many decades of improving energy efficiency at its manufacturing sites.

To identify how we can improve the performance of the logistics operations of the chemical industry, we must first understand its current carbon footprint. By developing a common understanding of how to calculate this, along with related issues and challenges, individual companies will be able to assess themselves in a way that is comparable across the industry.

In this Report, Professor Alan McKinnon and Dr Maja Piecyk assess a range of existing tools and theories on carbon footprinting. Their review of available literature illustrates the numerous approaches and assumptions in this area. McKinnon and Piecyk also look at the lessons that can be learnt from what other industries are doing.

Although there is no definitive methodology on calculating carbon emissions at present, the report provides clear guidance in key areas.

By taking a closer look at the operations of some of the larger chemical companies, McKinnon and Piecyk are able to start to build a picture of current CO_2 emissions of the various transport modes. Finally, they consider some of the potential decarbonisation measures available to the chemical industry and the possible challenges that need to be overcome to achieve these.

This Report represents the first step to understanding how we can assess and improve our operations. In commissioning this work, the chemical industry is taking a proactive role in improving the measurement and management of transport-related carbon emissions as part of its continuing commitment to safe, efficient and sustainable logistics.

Jack Eggels
Chairman

Cefic Strategy Implementation Group Logistics

Cefic - European Chemical Industry Council

Executive Summary

This report examines the options for measuring and reducing carbon dioxide (CO_2) emissions from transporting chemicals produced in Europe. It is based on a review of literature, the results of a preliminary survey of large chemical companies undertaken by Cefic, interviews with senior logistics managers in the chemical industry and a high-level workshop on the subject convened by Cefic. The study also investigated the measurement of carbon emissions from transport in other industrial sectors to see what lessons, if any, can be learned by chemical companies.

The report begins by considering the reasons why companies need to carbon footprint their transport operations. It then discusses a series of key issues that must be resolved when designing a carbon measurement system for freight transport. These include the choice of approach (either energy-based or activity-based), the definition of corporate, functional, system and geographical boundaries around the logistics system to be audited, the types of greenhouse gas (GHG) and transport modes to be included in the calculation, the degree of analytical disaggregation and assumptions to made about the allocation of emissions from the empty repositioning of vehicles and containers.

We then review the published data, at both European and national levels, on carbon emission factors for the various transport modes used by chemical companies. A range of values exist for each mode reflecting differences in primary data sources and assumptions about vehicle load factors, fuel efficiency and type of energy (for electrified railfreight services). Tables have been compiled to show the range of values reported in published reports and data-sets. A series of average emission factors are then recommended for the movement of chemicals by each of the transport modes, taking account of the particular characteristics of chemical logistics. In the case of trucking, the dominant mode of chemical transport, matrices are presented to show how the average emission factors vary with the weight-based loading factor and percentage of empty running. Given the diversity of waterborne freight services, separate average emission factors are provided for different types of short-sea and deep-sea operations. Mode-specific emission factors have been combined to derive composite emission factors for inter-modal freight services.

As the European chemical industry is not alone in trying to carbon footprint its transport operations, a comparison has been made of similar initiatives in nine other sectors: cement, fertiliser, steel, metal cans, bitumen, wine and spirits, food, paper and board/packaging and postal services. Several of these sectors, such as fertiliser, packaging and wines and spirits, have gone through a similar process to the European chemical industry in adopting an activity-based approach to the carbon footprinting of transport.

Overall, however, the chemical industry appears to be one of the most progressive sectors in its measurement of transport-related emissions.

Having measured these emissions, the next stage is for companies to develop strategies for reducing them. The remainder of the report examines a range of decarbonisation measures for chemical transport operations within a 'green logistics' framework. This framework focuses attention on five key parameters: freight modal split, supply chain structure (i.e. number and length of links in the supply chain), vehicle utilisation, energy efficiency and the carbon intensity of the energy source. Opportunities for altering each of these parameters is assessed. Consideration is also given to the general cost-effectiveness of these decarbonisation measures. Available data suggests that most of the measures which cut carbon emissions also reduce costs and prove self-financing in the short to medium term.

The concluding section shows how, as the availability of data on energy use, load factors and consignment routing increases, the measurement of carbon emissions from chemical transport can evolve from the current activity-based approach to a more accurate and flexible energy-based approach.

1. Introduction

To meet the ambitious carbon reduction targets that governments are now setting for 2020 and beyond, individual companies and industry sectors will have to implement decarbonisation strategies over the next few years. The longer that it takes them to get onto an appropriate carbon reduction trajectory, the harder it will be to reach the targets. Many industry sectors and companies are still at an early stage in this process, analysing their greenhouse gas (GHG) emissions and exploring options for reducing them. As the old business mantra states, 'if you can't measure it you can't manage it' and so the logical place to start is with detailed measurement of GHG emissions.

Efforts have been made internationally to standardise the measurement and reporting of these emissions in order to ensure comparability. At present there is no single agreed standard, though the two main standards developed by the World Business Council on Sustainable Development/World Resources Institute (2004) (the Greenhouse Gas Protocol) and International Standards Organisation (ISO 14064) are broadly similar. Both set out guidelines for the carbon auditing of individual businesses and provide advice on the scoping of the calculation, data collection methods and the allocation of emissions. Neither, however, provide detailed guidance on how carbon emissions from specific activities, such as transport, should be measured. A separate initiative by CEN, the European standards organisation, is currently developing and agreeing standards for the measurement of GHG emissions from transport, but this process is unlikely to be completed until the middle of 2012.

In the meantime, companies and industry bodies can obtain advice on the carbon auditing of transport operations from government departments/agencies, such as DEFRA in the UK and ADEME in France, and national standards bodies, such as the British Standards Institution and the French AFNOR. In the absence of agreed measurement standards, however, there is a danger that individual sectors will adopt standards and procedures that produce inconsistent results. One purpose of this report is to examine the ways in which carbon emissions from freight transport are being measured in Europe and, on that basis, recommend a carbon footprinting procedure for chemical transport operations.

Cefic has recently conducted a survey which collected data on tonnages and distances moved by different transport modes and permitted the calculation of aggregate figures for CO_2 emissions.This initial exercise has highlighted the problems of choosing suitable emission factors for the various transport modes. The present study aims to achieve three major objectives:

- Provide advice on measuring the carbon footprint of European chemical transport, in particular on the choice of appropriate average carbon emission factors for the different modes of transport
- Review similar initiatives in other industrial sectors to see if there are lessons to learned
- Identify major opportunities for reducing the carbon footprint of European chemical transport operations

In undertaking this study we have reviewed relevant published literature, data sets and websites. All the main estimates of carbon emission factors for European freight transport have been compared. In some cases hypothetical values have been inserted into online carbon calculators, simulating freight movements that would be typical of the chemical industry. To gain a deeper insight into chemical transport operations and the practical problems of collecting emissions-related data and opportunities for decarbonisation, we have conducted telephone interviews with senior logistics managers in large chemical companies.
A workshop was also held at Cefic's offices in Brussels to discuss an earlier draft of this report, which was attended by logistics managers from chemical companies. In this report primary data collected from the interviews and this workshop has been integrated with secondary, published data obtained from other sources.

In assessing the range of measures that can be applied to cut CO_2 emissions from chemical transport, we have adopted an analytical framework developed in the course of a UK university research project called Green Logistics[1].

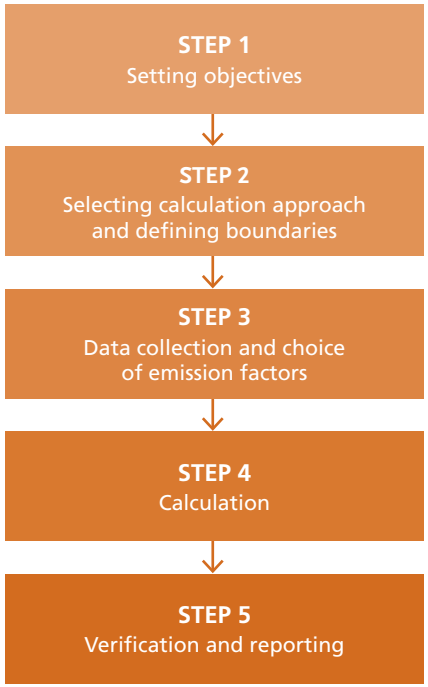
Sections 2 and 3 of the report deal with carbon measurement issues, while section 4 concentrates on possible carbon reduction options for European chemical transport.

1 More details of this research project can be found at www.greenlogistics.org.

2. Measurement of CO_2 Emissions

The UK Carbon Trust[2] has recommended a five step procedure for the measurement and reporting of carbon emissions from businesses *(Figure 1)*. In this section we will discuss each of these steps as they relate to chemical transport operations.

FIGURE 1
Carbon Measurement Process (adapted from the Carbon Trust, 2007)



2.1 Setting objectives for carbon measurement

It is important for a company or industry to establish at the outset why they are measuring carbon emissions because the answer to this question largely determines the required degrees of coverage, accuracy and disaggregation. There are several possible reasons, some external to the business and others yielding internal benefits:

External factors

1. Legal obligation: in sectors covered by the European Emissions Trading Scheme (ETS) or national carbon taxation/levy schemes, carbon measurement is compulsory. While the production activities of chemical companies are currently covered by these schemes, transport and logistics operations are still excluded. (Air transport will be included in the ETS in 2012, though chemical companies send only a tiny proportion of their freight by this mode.)

2. Customer request: industrial customers can ask for estimates of the amount of carbon 'embedded' in the products they buy. This is beginning to happen in the retail grocery sector, though is still uncommon in the chemical industry.

3. Corporate social responsibility: carbon auditing and reporting is becoming a key aspect of CSR.

4. Participation in industry-wide surveys and benchmarking exercises: industry sectors are keen to demonstrate and improve their 'carbon credentials'.

Internal motives

5. Identifying opportunities for cutting carbon and improving efficiency

6. Assessing the carbon impact of logistics decisions and investments

7. Measuring changes in carbon emissions through time

2.2 Selecting methods of calculation

There are basically two approaches to the estimation of CO_2 emissions from freight transport operations: one based on energy consumption and the other on the level of transport activity[3].

Energy-based approach: since almost all CO_2 emissions from freight transport are energy-related, the simplest and most accurate way of calculating these emissions is to record energy use and employ standard emission factors to convert energy values into CO_2. The unit of energy will typically be litres of fuel for trucks, diesel-hauled trains, barges and ships, and kilowatt hours for electrified rail and pipeline.
For carriers and companies with inhouse transport

2 Carbon Trust (2007) 'Carbon Footprints in the Supply Chain: the Next Steps for Business' London.

3 Piecyk, M. 'Carbon Auditing of Companies, Supply Chains and Products' in McKinnon, A.C. et al (eds) (2010) 'Green Logistics', Kogan Page, London.

operations, which have direct access to the energy data, the energy-based approach is clearly preferable. As most transport operations in the European chemical industry are outsourced, however, shippers lack direct access to this energy data. Some chemical companies have asked for this data and received estimates of average fuel efficiency from their carriers. No evidence has been found of carriers providing fuel consumption data on a journey-by-journey basis for chemical flows. The issue of obtaining fuel data from carriers is more fully discussed in a section 4.4.

Activity-based approach: In the absence of energy data, it is possible to make a rough estimate of the carbon footprint of a transport operation by applying a simple formula:

CO_2 = tonnes transported x average distance travelled x CO_2 emissions factor per tonne-km

Company records, ERP systems and delivery manifests can provide the necessary data on tonnages moved. For road movements, estimates of average length of haul can also be based on data from these sources. If necessary, software packages such as MapPoint and Autoroute can be applied to lists of customer locations to estimate road distances. Obtaining distance data for rail and water-borne transport can be more problematic, though the EcoTransit online environmental assessment tool can be used for this purpose. In the case of intermodal transport, shippers often do not know the route followed or the distance split between different transport modes. They usually rely on carriers to provide this information, though the EcoTransit tool[4] provides approximate routing and distance data for intermodal flows specified by the user.

One of the most difficult issues to resolve in applying the activity-based approach is the choice of carbon emission factors for each mode. These are generally expressed as grammes of CO_2 per tonne-km. This weight-based measurement of emission factors is well suited to the chemical industry as its products have a relatively high density and cause vehicles to 'weigh out' before they 'cube out'. As a consequence, vehicle load factors in the chemical industry are generally measured in weight terms.

One of the chemical companies consulted had obtained fuel consumption data from some of its carriers and managed to derive its own set of emission factors. No general emission factors, however, have so far been calculated for chemical transport as a whole. It is necessary to rely, therefore, on the numerous studies that have been undertaken in Europe over the past decade to estimate emission factors for the general movement of freight by different modes. They are reviewed in section 2.5.

2.3 Defining boundaries

Four types of boundary must be drawn around the transport system to delimit the extent of the calculation: corporate, functional, system and geographical boundaries.

2.3.1 Corporate boundary

This determines the division of responsibility for carbon emissions between the company and its suppliers, customers and carriers. The line should be drawn in a way that minimises double-counting and allocates responsibility to the entity that has the greatest control over the emissions. This usually reflects the allocation of financial responsibility. Whoever pays for the activity should be assigned the related CO_2 emissions. For companies taking ownership of the goods, the delivery terms provide a solid commercial and legal basis for allocating the transport emissions. Where the finished product is sold on a delivered price basis, the shipper will be responsible for these emissions as far as the customer's premises. If, on the other hand, as happens with around 20-30% of chemical sales, the customer arranges collection from the plant, he must assume responsibility for the transport CO_2.

The situation with carriers is more complicated and requires judgement and negotiation. Where transport is outsourced, the emissions fall into what the Greenhouse Gas Protocol calls Scope 3, i.e. emissions from activities performed by other companies on your behalf. It is now considered good practice for businesses to count these Scope 3 emissions as part

4 This tool can be found at the www.greencargo.com website.

of their carbon footprint. There remains some debate, however, over the allocation of a carrier's emissions between its clients. Where a chemical company despatches a full load of product, it would be allocated all the emissions from this outbound journey leg. As a large proportion of outbound deliveries in the chemical industry fall into this category, this makes the allocation relatively straightforward. More contentious is the repositioning of empty vehicles to collect consignments of chemicals. Broadly speaking one can take two views on this issue:

1. It is the responsibility of the carrier to find return loads for its vehicles. This gives it a commercial incentive to find a backload. Many carriers are reluctant to divulge information about empty running and return loading, on the grounds that this would weaken their commercial position in negotiations. If it is assumed that it is the carrier's job to maximise backloading and that he will not disclose the level of empty running, it seems logical that he should take responsibility for related emissions. The carrier, after all, has much more control over the use of backhaul capacity than the shipper.

2. The repositioning of empty vehicles is an integral part of the transport service provided by a carrier. The shipper indirectly pays for the empty legs as part of the rate the carrier charges and, hence, it should accept at least some of the responsibility for the related carbon emissions. Most of the published emission factors for road freight also make an allowance for empty running.

Discussions with logistics managers in the chemical and other industries indicate that the first proposition commands a good deal of support. However, as a significant amount of empty running is inevitable and attributable to the outbound delivery of chemicals, it seems reasonable that chemical companies should assume some responsibility for carbon emissions from empty journey legs. In the estimation of emission factors for road transport in Section 2.4, therefore, the effects of differing levels of empty running on road emission factors were modelled.

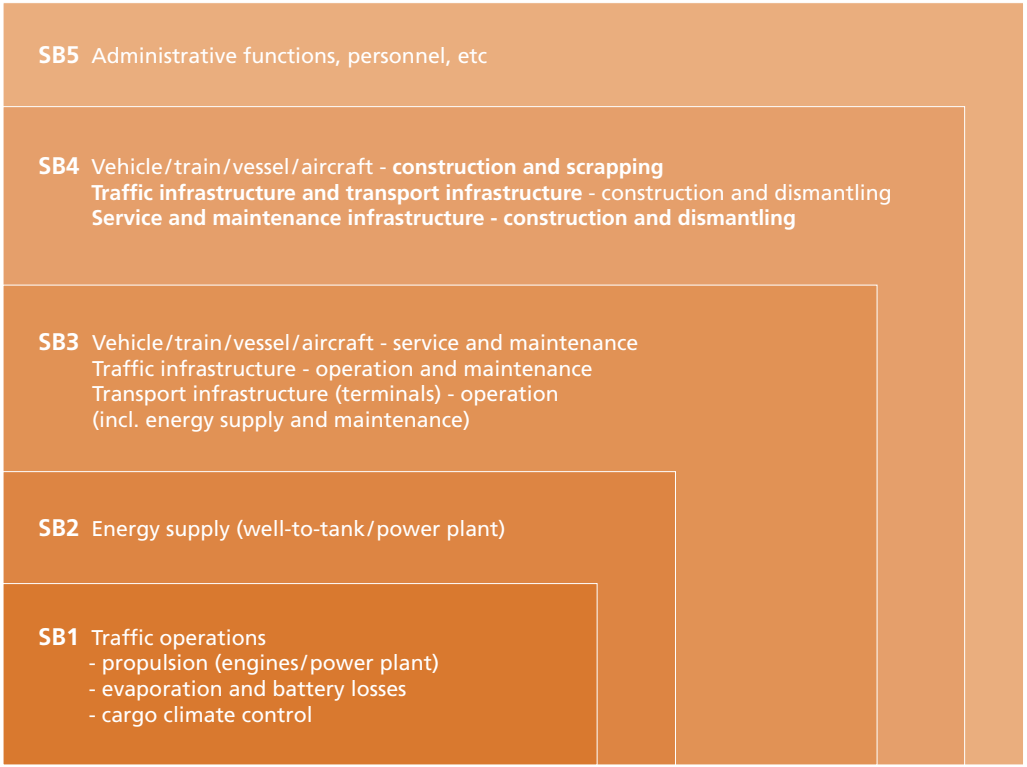
2.3.2 Functional boundary

Boundaries must also be drawn internally to define the scope of the transport calculation. In the case of chemical logistics there are two areas where this is particularly significant:

Internal supply chain: there is unanimous agreement that outbound delivery to customers and inter-plant transfers should be included in the calculation and that the movement of materials on the production site be excluded. On-site transport is considered part of the production process. Opinions differ on whether inbound flows of materials should lie within the scope of the calculation. The easiest way of dealing with this issue is to apply the rule discussed above under the corporate boundary heading (section 2.3.1) i.e. if the company takes responsibility for collecting inbound supplies (i.e. buys them on an ex works basis and pays for the transport) then they should also assume responsibility for the related carbon emissions.

Related logistics activities: should the calculation include emissions from warehousing, materials handling operations, tank cleaning etc to permit more comprehensive carbon footprinting of logistics as a whole? For example, using data provided by a major tank cleaning company, we estimate that the CO_2 emissions associated with this process represent around 5-7% of the average CO_2 emissions from a road shipment of chemicals. One major benefit of adopting a broader approach is that it exposes carbon trade-offs in the management of these inter-related logistical activities. Decarbonisation efforts could then be more effectively co-ordinated across the entire logistics function. While this would be a worthwhile goal in the medium term, the priority at present lies in refining carbon measurement of the transport function.

FIGURE 2
System Boundaries around Transport Operations for Carbon Measurement (source: NTM)



2.3.3 System boundary

The Swedish environmental organisation, NTM, has differentiated five levels of system boundary that can be drawn around a transport operation and labelled them SB1-SB5 *(Figure 2)*. These levels are cumulative:

SB1: confines the calculation to emissions from the actual transport operation, most of which emanate from the vehicle exhaust, though in the case of electrified railfreight operations include emissions from the electrical power source.

SB2: also takes account of the extraction, production, refining, generation and distribution of energy, taking a so-called 'well-to-tank' perspective.

SB3: also includes the servicing and maintenance of vehicles and transport infrastructure

SB4: broadens the scope even further to include emissions from the manufacture of the vehicles, construction of transport infrastructure and their subsequent scrappage and dismantling.

SB5: also includes emissions associated with the management of transport operations, essentially office functions and the activities of staff.

It may be a long term aspiration to adopt the SB5 level of auditing, but at present most measurement of carbon emissions from freight transport is conducted at the SB1 level. Some organisations have compiled emission factors that embrace levels

SB2 and SB3 for some transport modes. It might be possible, therefore, to make rough estimates of the carbon footprint of chemical transport at levels SB1, SB2 and SB3, though the focus of this report will be on emissions within SB1.

It is important to apply the system boundary level consistently across transport modes. For example, it is essential to include emissions from the generation of electricity for electrified rail freight operations. At the SB1 level, only direct emissions from the electrical generating plant are included and can be compared with fuel burned by non-electric vehicles.

2.3.4 Geographical boundary

The European chemical industry serves a global market and much of its export volume is sold on a delivered price or 'cost insurance freight' (cif) basis, making the companies responsible for transport at least as far as the foreign port of entry. While the main focus of the carbon measurement exercise is on transport operations within Europe, allowance is also made for emissions from the export of chemicals by deep-sea vessels and, to a much lesser extent, air freight.

2.4 Factors affecting the choice of emission factors

Several issues have to be resolved in choosing appropriate emission factors for chemical transport operations:

a) Greenhouse gases to be included
b) Transport modes to be covered
c) Degree of disaggregation by type of vehicle and power source
d) Energy supply chain
e) Assumptions about vehicle load factors and empty running
f) Nature of the product
g) Logistical operations at differing levels in the chemical supply chain
h) Geographical variability

2.4.1 Greenhouse gases

CO_2 is estimated to account for around 93-95% of total GHG potential of emissions from freight transport. Nitrous oxide and refrigerant gases make up most of the remainder. As few if any chemical consignments require temperature-control, the CO_2 share of total GHG emission from chemical transport is likely to be even closer to 100%. Furthermore, most of the published emission factors for freight are expressed solely in terms of CO_2[5]. It is recommended therefore that the carbon footprinting of chemical transport also be confined to CO_2.

2.4.2 Transport modes

Emission factors will be required for the main modes of freight transport used to move chemicals in Europe:

- Road
- Rail
- Inland waterway/barge
- Short-sea shipping: bulk, tanker, ro-ro ferry, container
- Deep-sea shipping
- Pipeline
- Air

Although only a tiny proportion of chemical consignments move by air, they travel long distances by this mode and airfreight services have a carbon intensity around ten times that of road haulage.

It is possible to calculate composite emission factors for intermodal transport by weighting mode-specific factors with estimates of the distances travelled by each mode. While this can be done for individual flows on particular routes using online tools (such as EcoTransit), no published data are available on the distance split between modes that would be required to calculate average emission factors for different intermodal combinations at a European level. Average values for this distance split have had to be estimated.

5 ADEME quote their emission factors in gCO_2 equivalent.

2.4.3 Degree of disaggregation by vehicle type and power source

One can either use average values for each of the main modes or disaggregate them by vehicle type and power source. The available datasets vary in the extent to which they disaggregate emission factors and in the classifications they use. The mode offering the greatest degree of disaggregation by vehicle type is road. This is fortunate as chemicals are predominantly moved by road. It is possible to differentiate the carbon intensity of heavy articulated trucks, which account for a large proportion of the total movement of chemicals in Europe.

Much less disaggregation is possible for railfreight operations. The main distinction is between electrified and diesel-hauled freight trains, with the former further sub-divided to take account of wide differences in the carbon intensity of the various forms of electricity generation. While it is possible to obtain a range of emission factors for these different railfreight energy categories, it is very difficult to apply them in practice as rail companies and intermodal operators do not provide shippers with a breakdown of the distance travelled or tonne-kms moved using different power sources. Until this information is routinely provided, chemical companies have little choice but to use emission factors for railfreight that reflect the average diesel/electric traction split for freight trains and average mix of electrical power sources.

There is also limited differentiation of vessels moving freight on the inland waterway network or by sea. In the case of maritime operations, the gross weight of the vessel is a key determinant of the emission factor. Some data bases contain indicative emission factors for vessels of differing gross weights.

2.4.4 Energy supply chain

As discussed above, one of the main decisions that must be made in any carbon measuring exercise is whether or not to include emissions from the extraction, production and distribution of energy, in other words whether the calculations should be done on a 'well-to-wheel' basis or only take account of emissions at the point of energy consumption on the vehicle ('tank-to-wheel'). The emission factors quoted in this report relate solely to fuel consumption onboard the vehicle, except in the case of electrified rail freight operations where emissions from the generation of electricity in power plants is included.

2.4.5 Assumptions about vehicle loading and empty running

Average carbon emission factors are very sensitive to these assumptions. This is illustrated by *Figure 3* which shows how the emission factors for the movement of freight in a 44 tonne truck (with a 380 brake horse power tractor unit) have a negative exponential relationship with payload weight. The calculation is based on data collected by Coyle[6] in vehicle trials for the UK government to monitor the effects of payload on the fuel efficiency of trucks. Over the payload range 1-10 tonnes there is a dramatic reduction in the carbon emission factor. Thereafter the rate of reduction is relatively gentle as the curve becomes asymptotic to the X-axis. *Figure 4* magnifies the lower section of the curve and shows how, even across this flatter section, modest changes in payload can have a significant impact on the emission factor. Increasing the load from 20 to 26 tonne, for example, reduces the gCO_2 per tonne-km from 48 to 41.5. No allowance is made in this calculation for the empty running of the truck. *Table 1* adds an extra dimension to the calculation and shows how varying levels of empty running affect the emission factor. For a given payload on the laden section of the journey, the level of empty running can have a marked effect on the emission factor. For example, for an average payload of 26 tonnes on the laden section, the emission factor can vary from 41.5 gCO_2 per tonne-km with no empty running to 68.6 gCO_2 per tonne-km when 40% of the kilometres are run empty.

It is much easier to assess the effects of vehicle loading on emission factors in the road freight sector than it is for other transport modes. This is partly because much less research has been done on the relationship between loading, energy use and emissions in the case of these modes, but also because shippers often have little knowledge of the utilisation of freight trains, barges and ships. It is possible for them to monitor the loading of trucks as well as dedicated trains and barges leaving their sites. Where chemical companies' consignments are grouped with those of

6 M.Coyle (2007) 'Effects of Payload on the Fuel Consumption of Trucks' Department for Transport, London.

FIGURE 3

Relationship between Carbon Emission Factor and Truck Load in tonnes (full range)

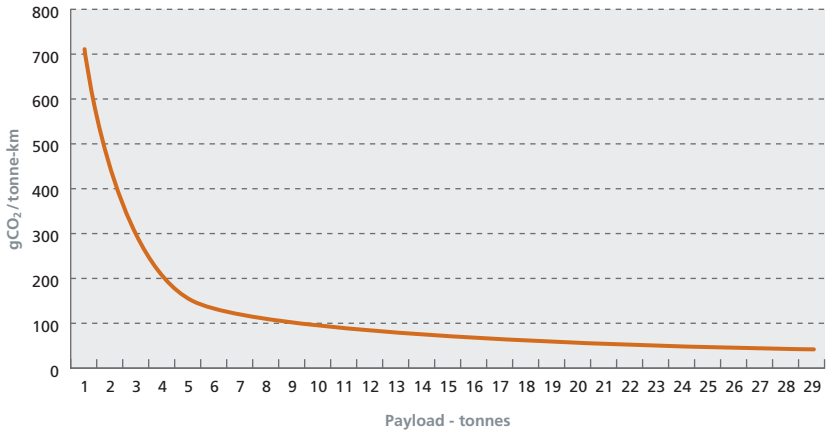


FIGURE 4

Relationship between Carbon Emission Factor and Truck Load (10-29 tonnes) (based on data from Coyle 2007)

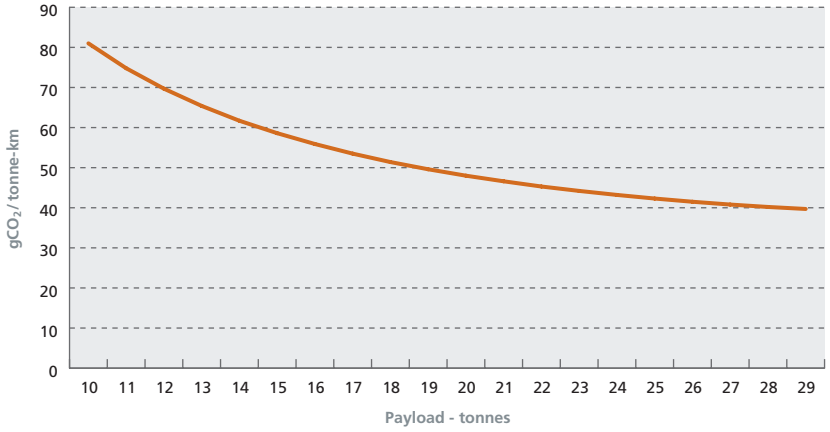


TABLE 1

Carbon Emission Factors (gCO_2/tonne-km) for 40-44 tonne Truck with Varying Payloads and Levels of Empty Running

load tonnes	% of truck-kms run empty								
	0%	5%	10%	15%	20%	25%	30%	35%	40%
10	81.0	85.2	89.9	95.1	101.0	107.6	115.2	124.0	134.2
11	74.8	78.7	83.0	87.8	93.2	99.4	106.4	114.5	123.9
12	69.7	73.3	77.3	81.8	86.8	92.6	99.1	106.6	115.4
13	65.4	68.8	72.5	76.7	81.5	86.8	93.0	100.0	108.3
14	61.7	64.9	68.5	72.4	76.9	82.0	87.7	94.4	102.2
15	58.6	61.6	65.0	68.7	73.0	77.8	83.3	89.6	97.0
16	55.9	58.8	62.0	65.6	69.6	74.2	79.4	85.4	92.5
17	53.5	56.3	59.3	62.8	66.6	71.0	76.0	81.8	88.6
18	51.4	54.1	57.0	60.3	64.1	68.3	73.1	78.6	85.1
19	49.6	52.2	55.0	58.2	61.8	65.8	70.5	75.8	82.1
20	48.0	50.5	53.2	56.3	59.8	63.7	68.2	73.4	79.4
21	46.6	49.0	51.6	54.6	58.0	61.8	66.2	71.2	77.0
22	45.3	47.6	50.2	53.2	56.4	60.1	64.4	69.2	74.9
23	44.2	46.5	49.0	51.8	55.0	58.6	62.8	67.5	73.1
24	43.2	45.4	47.9	50.7	53.8	57.3	61.3	66.0	71.4
25	42.3	44.5	46.9	49.6	52.7	56.1	60.1	64.6	69.9
26	41.5	43.7	46.0	48.7	51.7	55.1	59.0	63.4	68.6
27	40.8	42.9	45.3	47.9	50.8	54.2	58.0	62.4	67.5
28	40.2	42.3	44.6	47.2	50.1	53.4	57.1	61.4	66.5
29	39.7	41.7	44.0	46.6	49.4	52.6	56.3	60.6	65.6

other companies in trains and vessels, however, the overall degree of loading is not known. One must then rely on estimates based on average loading of these modes. There has been evidence in the past of modal biases in the assumptions made about vehicle loading, with emission factors for some modes based on full loading and for others only on average load factors. It is important that the organisations compiling emission factor datasets make assumptions about vehicle utilisation explicit. Where they are not declared, caution must be exercised in using the quoted emission factors.

A further complication exists in the case of ro-ro ferries and container vessels. Estimating a carbon emission factor for the movement of chemicals by these modes requires a two-tier assessment of loading. The first is the loading factor of the vehicle or container and the second the loading of the available space onboard the vessel. The average emission values currently available for ro-ro ferries neither make this distinction nor declare the assumptions on loading.

2.4.6 Nature of the product

The Cefic survey of chemical transport operations asked companies to distinguish bulk from packaged product. The nature of the product and its packaging will influence its density and hence the weight-based load and emission factors. It is our understanding, however, that in the chemical industry most packaged product is also dense and results in a high proportion of loads reaching the maximum vehicle weight limit. There may, therefore, be little need to apply different emission factors for bulk and packaged product. If it were necessary to do this, new empirical research would be required as none of the published sets of emission factors currently differentiate freight by physical characteristics, other than weight.

2.4.7 Logistical operations at different levels of the chemical supply chain

The nature of the freight transport operation varies across the chemical supply chain. At the upper end of the chain, primary producers of base chemicals distribute their products mainly in bulk in volumes that can fill road vehicles, barges, ships, wagons and even whole trains. They also make relatively heavy use of the lower carbon transport modes (rail, water-borne services and pipeline). The average carbon intensity of these operations will, therefore, be significantly lower than those of more specialist producers further down the chain whose output is despatched in smaller orders to a more diverse mix of customers, sometimes on road-based multiple-drop delivery rounds. Ideally, separate emission factors should be applied to companies at different levels of the chain to reflect these differences in carbon intensity. Simply extrapolating the carbon footprint of transport operations at the primary end of the chain to the industry as a whole, in proportion to tonnages or sales, is likely to under-estimate total carbon emissions from European chemical transport.

2.4.8 Geographical variability

The average emission factors for particular modes vary from country to country in Europe as a result of several factors:

Road: nature of the road infrastructure, level of traffic congestion, maximum vehicle weight, level of fuel taxes, climate, topography, driving styles etc.

Rail: % of railfreight services electrified, % of railfreight electricity from low carbon sources, railway loading gauge, density of access points on the network etc.

Inland waterways: maximum draught, size, weight and age of vessels, density of access points on the network etc.

Some databases (e.g. Tremove, INFRAS and IFEU) contain separate average emission factors for different countries. Some countries also maintain national emission inventories, based on country-specific emission factors. The range of carbon emission factors currently available at country level for the various transport modes is too limited to conduct the analysis an a country basis. This would also require the chemical companies to provide a breakdown by country of the quantities of freight moved and average distance travelled. It may eventually be possible to obtain all the necessary country data for a 'bottom up' analysis of European chemical transport emissions. For the foreseeable future, however, it will be necessary to rely on average modal emissions factors for Europe

as a whole and hope that these faithfully reflect the national pattern of transport emissions across the continent.

2.5 Review of European data sources on freight emission factors

Numerous studies have been undertaken over the past 20 years within Europe to develop emission factors for different forms of transport. Much of this work has been sponsored by the European Commission and national governments. These studies can be divided into two general categories; those which have compiled primary data from laboratory experiments, running vehicles under artificial conditions on roller beds and those based on the collection of fuel consumption data from vehicles in the course of normal, real-world operation. Recent research in the UK[7] has suggested that, where the objective is to measure carbon emissions from trucks at a national level, the latter method yields more accurate and realistic results. Under controlled conditions in laboratories, however, it is possible to model relationships between vehicle speed, loading, energy consumption and emissions in much greater detail. While this is required for environmental modelling of traffic flows by public agencies, it goes well beyond the needs of the current Cefic initiative to carbon footprint chemical transport operations. Some of this primary data on vehicle emissions, from major projects such as MEET, PHEM, ARTEMIS and COPERT, has nevertheless been used to calibrate more generalised emission factor data sets, such as Tremove. It is the more generalised data sets, derived either from laboratory test-bed analysis or industry surveys, which are most relevant to the present study. Some of these data sets relate to transport at a European level, others to national transport systems.

2.5.1 EU-wide studies

INFRAS / IWW / IFEU: These organisations developed emission factors for a range of freight and passenger transport modes in the course of a project funded by CER, the main organisation of European Railways, to calculate the 'external costs' of transport. Emission factors are provided for Europe as a whole and for individual European countries. The last set of figures was published in 2004[8].

IFEU: On a separate contract from European railway companies, this organisation has developed the EcoTransit tool which allows users to compare the environmental impact of moving goods by different transport modes on specific, user-defined routes across Europe. In a separate manual, IFEU outlines the methodology and choice of emission factors[9]. Unfortunately, in this manual, the emission factors for the various transport modes are expressed using different metrics (e.g. gCO_2 per tonne-km, gCO_2 per kg of fuel), making it difficult to compare them on a consistent basis. By applying the tool to a sample of freight movements, however, it is possible to determine the underlying emission factors using the standard gCO_2 per tonne-km ratio.

TREMOVE: This dataset is compiled by Transport Mobility Leuven (TML) on contract to the European Commission. The Tremove 2.7b spreadsheet (February 2009) provides past, present and future estimates of total tonne-kms, energy consumption and emissions for trucks, vans, railfreight services and 'inland ship' for seventeen EU countries. Many of the emission factors have been derived from COPERT and other earlier studies. By dividing estimates of CO_2 emissions for the various modes by the corresponding tonne-kms, it is possible to calculate the average emission factors.

TREND: This is another EU-funded project which has reviewed past trends in emissions by all transport modes and projected their future course. Again, by analysing the relevant spreadsheets it is possible to establish the embedded emission factors for the major freight modes.

2.5.2 National studies

Sweden

The Swedish transport and environment organisation NTM has gained a reputation as an authoritative source of transport emission values. Its online NTM Calc tool employs a series of emission factors for freight movements by road, rail, inland waterway, sea and air, in each case split by vehicle type and, where appropriate, power source. In most cases these values have been obtained from transport operators. The NTM calculator also gives users the option of measuring emissions on a well-to-tank basis (SB2) and with infrastructure-related CO_2 emissions included (SB3).

7 McKinnon, A. and Piecyk, M. (2009) 'Measurement of CO_2 Emissions from Road Freight Transport : A Review of UK Experience.' Energy Policy, Vol. 37, no.10.

8 INFRAS/IWW/IFEA (2004) 'External Costs of Transport: Update Study' Zurich/Karlsruhe.

9 Knorr, W. and Reuter, C. (2005) 'EcoTransIT: Ecological Transport Information Tool - Environmental Methodology and Data' IFEU, Hiedelberg.

NTM will be releasing an updated and more refined version of their calculator (NTM CALC 3.0) in 2010. Much more data has been obtained from operators to permit greater differentiation by vehicle type and power source.

UK

The Department of the Environment, Food and Rural Affairs (DEFRA) publishes guidelines[10] for companies on the reporting of CO_2 emissions which contain indicative emission factor values for several freight transport modes. In the case of road freight movements, different load factors are specified, though the updated version of this guidance in 2007 actually reduced the four levels of loading (empty, 25%, 50%, 75% and 100% full by weight) to only three (empty, 50% and 100% full).

The National Atmospheric Emissions Inventory also contains emission factors for heavy goods vehicles and rail freight operations, though in the latter case only a single average is quoted. The road freight emission factors for different classes of truck were originally based solely on laboratory test bed studies, though now make greater use of surveys of road freight operators.

France

The main freight emission factors used in France were compiled by the state environmental agency ADEME. It publishes an Emissions Factor Manual, which is now in its fifth version[11]. This only contains emission factors for road and rail freight operations. The published emission factors for road are based on average levels of vehicle loading and empty running in France and so may not be transferable to other countries.

None of these datasets on their own provide a comprehensive set of emission factors for use by the chemical industry. They vary in their coverage of freight transport modes, the extent to which they differentiate by vehicle type and power source and in the assumptions they make about vehicle loading (where this is made explicit). It is necessary therefore to 'cherry-pick' in compiling an appropriate set of emission factors for chemical transport operations. Other sectors, such as the Wine and Spirit Trade Association, and companies, such as J.F. Hillebrand the world's largest distributor of wines and spirits, have adopted a similar approach.

2.6 Characteristics of chemical transport operations

In developing a system of carbon footprinting for chemical transport operations, it is important to recognise that these operations have several distinguishing features:

1. Almost all chemical transport, with the exception of movements by pipeline, is outsourced. As chemical companies do not control the transport, they cannot collect energy and emissions data directly and must rely on their carriers to provide the necessary information.
2. Chemical companies employ the full range of freight transport modes. Unlike in some other sectors, in which all but a small proportion of freight moves by a single mode, a broad range of modal emission factors are required for the carbon footprinting exercise. The chemical industry is also one of the few to make extensive use of pipelines as a transport mode.
3. The chemical industry generates a high proportion of full loads, particularly at the upper end of the supply chain where large volumes are produced and distributed. This reduces the need to allocate CO_2 emissions between different types of freight traffic sharing the same vehicle.
4. As transport costs represent a relatively high proportion of product selling price, chemical companies are under strong pressure to maximise load size and weight and thus maximise their use of transport capacity. It can be assumed, therefore, that vehicles carrying chemicals achieve high load factors.
5. The relatively high density of chemical products, particularly at the upper end of the supply chain, results in road vehicles reaching their maximum weight limit before their volume limit. This heavy weight-based loading of vehicles is well aligned with weight-based emission factors now widely used for freight transport (gCO_2/tonne-km).

10 DEFRA (2009) 'Guidance on how to measure and report your greenhouse gas emissions' London.

11 ADEME (2007) 'Emission Factors Guide: Emission Factors Calculation and Bibliographical Sources Used' Version 5.0.

6. The nature of the transport operation changes as products move down the chemical supply chain: the proportion of packaged goods increases, average order size declines, the average number of drops per delivery and relative use of non-road modes decreases. As these changes affect the carbon intensity of the transport operation per tonne-km, it is important that any carbon measurement system adequately represents the different tiers in the supply chain.

7. While the majority of chemical sales in Europe are made on a delivered-price basis, a substantial minority (estimated to be around 20-30%) involve the customer collecting the product. This has implications for the division of transport-related CO_2 emissions within the chemical supply chain.

8. No other industry interfaces with so many sectors as the chemical industry, as chemicals are incorporated into a broad array of products. At the specialist end of the chemical industry these interfaces can blur, making it difficult, in terms of product classification, to determine where the outer perimeter of the chemical industry should be drawn.

2.7 Average emission factors for the movement of chemicals by the different transport modes

This section discusses the choice of average emission factors for the range of modes used to transport chemicals. They can be used to estimate the total carbon footprint of chemical transport operations or by individual companies as default values. It is clearly preferable, if possible, for companies to derive emission factors for their specific transport operations, reflecting the characteristics of their supply chains, products and customer base.

2.7.1 Road

It is assumed that the standard vehicle used for chemical deliveries is a 40 tonne articulated truck carrying a maximum payload of 26 tonnes[12]. *Table 2* shows the published emission factors for such a vehicle and indicates the assumptions made about vehicle loading, where these are disclosed. These emission factors vary widely from 59 to 109 gCO_2/tonne-km. Some, but not all, of this variation can be explained by differences in the definition of the vehicle weight class and assumptions about average vehicle load factors on laden trips and the level of empty running.

12 Estimates of the emission factors for the 44 tonne trucks permitted in the UK and Ireland are shown on Figure 4 and Table 1. These vehicles can carry a maximum load of around 29 tonnes.

TABLE 2
Published Emission Factors for Heavy Articulated Truck

organisation	gCO_2/tonne-km	assumptions about vehicle loading
NTM	59	60% utilisation
IFEU	66	average
Tremove	77.2	
DEFRA	82	> 32t GVW/27% empty running/59% load factor
INFRAS	91	
ADEME	109	max load 25t/21% empty running/57% load factor

TABLE 3
Published Emission Factors for Rail Freight Movement (gCO_2/tonne-km)

organisation	all rail freight	diesel-hauled	electric-hauled
ADEME	7.3	55	1.8
NTM	15	21	14
AEA Technology	20		
DEFRA	21		
INFRAS	22.7	38	19
TRENDS	23		
Tremove	26.3		
IFEU		35	18
McKinnon/EWS		18.8	

An independent analysis, referred to in Section 2.4.5 above, was carried out for this study using UK data collected in on-the-road trials of maximum weight articulated vehicles running with varying payloads. The values in the bottom half of *Table 1* tend to confirm emission factors at the lower range of values shown in *Table 2*. If, for example, weight based load factors across the chemical supply chain averaged 77% and the level of empty running around 20%, an average emission factor of 59.8 gCO_2/tonne-km would apply, similar to the NTM value. A 77% load factor would be substantially higher than the average for maximum weight articulated vehicles, though in other sectors a higher proportion of loads 'cube out' before they 'weigh out'. On the other hand, the need to clean tanks and containers prior to backloading may result in the average level of backloading in the chemical industry being lower than the average for heavy trucks. If one were to combine an average load factor of 80% with a 25% empty running figure, the result would be an average industry emission factor of roughly 62 gCO_2/tonne-km, slightly above the NTM figure, but well below the average figures for road haulage as a whole adopted by Tremove, INFRAS and the British and French governments. Individual companies may however use different emission factors that better reflect the particular circumstances of their transport operations *(see Table 1)*. An average emission factor of **62 gCO_2/tonne-km** is recommended for road transport.

2.7.2 Railfreight

Average emission factors for railfreight range from 7.3 to 23 gCO_2/tonne-km, though most estimates lie within the range 15-23 *(Table 3)*. As explained earlier, these averages are influenced mainly by four factors: the split between diesel and electric haulage, the carbon intensity of the electrical power source, the energy efficiency of the locomotive and assumptions about train load factors. All four can vary widely between countries, making it difficult to establish a representative emission figure for the whole of Europe. It is worth noting the wide variations in the carbon intensity of different types of electrified railfreight service from 0.003 gCO_2/tonne-km for electricity generated by renewables (NTM) to 1.8 for predominantly nuclear powered services in France to 19 for the electrical energy mix across the EU, comprising 55% fossil fuel, 30% nuclear and 15% renewables. The figure of 7.3 recommended by ADEME for France is clearly an outlier, reflecting the high proportion of electrified railfreight services and heavy dependence on nuclear power. A study undertaken by McKinnon (2007)[13] in the UK found that the country's electrical energy mix resulted in electrified railfreight services having a very similar carbon intensity to diesel-hauled services. For the purpose of this study an average industry emission factor of **22 gCO_2/tonne-km** is recommended.

TABLE 4
Published Emission Factors for Inland Waterway / Barge Movements

organisation	gCO_2/tonne-km
INFRAS	31
TRENDS	31
Tremove	32.5
IFEU	28-35

2.7.3 Inland waterway

There are fewer published estimates of average emission factors for barge movements on inland waterways and a much narrower range of values *(Table 4)*. Indeed the close similarity between some of these values suggest that the figures may have been derived from the same source. Reflecting the apparent consensus between the studies on the carbon intensity of this mode, it is recommended that a value of **31 gCO_2/tonne-km** be used.

13 McKinnon, A.C. (2007) 'CO_2 Emissions from Freight Transport in the UK' Commission for Integrated Transport, London.

2.7.4 Shipping

Short sea shipping operations can be divided into three types: ro-ro ferry operations (carrying trucks and/or railwagons), bulk ships and container vessels. For each of these maritime modes two sets of published emission factor values were found, though they are not directly comparable given differing assumptions made about the vessel weight class *(Table 5)*. There is therefore little choice in the selection of emission values for shipping. An overall emission factor for short-sea shipping of **16 gCO_2/tonne-km** is proposed.

Across a sample of nine **deep-sea** container shipping lines, Clean Cargo/BSR found the weighted average emissions of CO_2 per TEU-km to be around 93g. Assuming that the average TEU carries a load of 11 tonnes, this yields a carbon intensity value for deep-sea container shipping of **8.4 gCO_2/tonne-km**. (This emission factor makes no allowance for the repositioning of empty containers.) An estimate of the carbon intensity of deep-sea tanker operations has been obtained from NTM, **5 gCO_2/tonne-km**.

TABLE 5
Published Emission Factors for Maritime Transport

	gCO_2/tonne-km	Source
Bulk ship		
Small tanker (844 tonnes)	20	DEFRA
Large tanker (18371 tonnes)	5	DEFRA
Small (solid) bulk vessel (1720 tonnes)	11	DEFRA
Large (solid) bulk vessel (14201 tonnes)	7	DEFRA
Container vessels		
Small container vessel (2500 tonnes)	13.5	DEFRA
Larger container vessel (20000 tonnes)	11.5	DEFRA
Average deep-sea container vessel	8.4	BSR/Clean Cargo
(assuming mean 11 tonne load per TEU)		
Deep-sea tanker (120,000 tonnes)	5	NTM
All Maritime	**14**	**TRENDS**

2.7.5 Intermodal transport

Once a set of emission factors has been agreed for individual transport modes, these values can be used to derive composite emission factors for intermodal operations. These composite values need to be weighted by the relative distances travelled on each of the modes in the course of the intermodal journey. Chemical companies often do not know the routeing of intermodal consignments and hence the distance split between the modes. One company contributing to the Cefic survey, assumed that the average road-rail intermodal haul was 1000 km long and that road feeder movements at both ends of the rail line-haul would be around 100 kms long. It is not known if these figures would be representative of the European chemical industry as a whole and of other intermodal combinations. One way of obtaining a representative value would be to survey large intermodal operators specialising in the movement of chemicals and ask them to provide average values of the distance splits for different intermodal combinations. In the meantime, we have constructed a table showing a range of emission factors for different types of intermodal service with the road share of the total distance travelled varying from 5% to 20% *(Table 6)*. Until more data is provided by intermodal operators, we propose that a 10% road feeder distance be adopted and that emission factors in the second column of Table 6 be used for intermodal services (bolded).

2.7.6 Airfreight

Relatively small amounts of chemicals move by air. The Cefic survey indicated that only 0.01% of tonnes and 0.07% of tonne-kms move by air. These are mainly specialist polymers, samples and emergency consignments. Published carbon emission factors for airfreight vary widely, reflecting differences in the length of haul and nature of the operation *(Table 7)*. Two sources, WRI/World Business Council for Sustainable Distribution and NTM, have provided different emission factors for each distance range. As the mean length of haul for airfreight movements in the Cefic survey was 7000 kms, an average of the two long haul emission factors is proposed i.e. **602 gCO_2/tonne-km.**

2.7.7 Pipeline

The only published figure that we have been able to find for pipeline appeared in a report published by the UK Royal Commission on Environmental Pollution in 1994[14]. This study assigned a value of 10 gCO_2/tonne-km to pipelines. Since then the carbon content of electricity has reduced as a result of the switch to gas-fired stations and renewables. It is also likely that the energy efficiency of pipeline pumping equipment will have improved. It has been decided therefore to use a lower value of **5 gCO_2/tonne-km** at present, pending further enquiries.

TABLE 6
Composite Emission Factors for Intermodal Combinations

intermodal combination		Road distance as % of total			
		5%	10%	15%	20%
road-rail	average railfreight	24.0	**26.0**	28.0	30.0
	electrified rail (EU average)	21.2	**23.3**	25.5	27.6
	electrified rail (France)	10.0	**12.8**	15.5	18.2
	diesel rail	25.9	**27.8**	29.7	31.6
road-inland waterway		32.6	**34.1**	35.7	37.2
road short-sea	ro-ro ferry - truck	49.7	**50.3**	51.0	51.6
	ro-ro ferry - rail	38.3	**39.5**	40.8	42.0
	small tanker (844 tonnes)	22.1	**24.2**	26.3	28.4
	large tanker (18371 tonnes)	7.9	**10.7**	13.6	16.4
	small bulk vessel (1720 tonnes)	13.6	**16.1**	18.7	21.2
	large bulk vessel (14201 tonnes	9.8	**12.5**	15.3	18.0
	small container vessel (2500 tonnes)	15.9	**18.4**	20.8	23.2
	larger container vessel (20000 tonnes)	14.0	**16.6**	19.1	21.6
	all short sea	18.3	**20.6**	22.9	25.2

TABLE 7
Emission Factors for Air Freight Transport

short haul	medium haul	long haul	source
1580	800	570	WRI/WBCSD (2003)
1925	867	633	NTM (2005)
	673		INFRAS/TRENDS (2004)

14 Royal Commission on Environmental Pollution (1994) 'Transport and the Environment' HMSO, London.

2.8 Recommended average emission factors for chemical transport operations

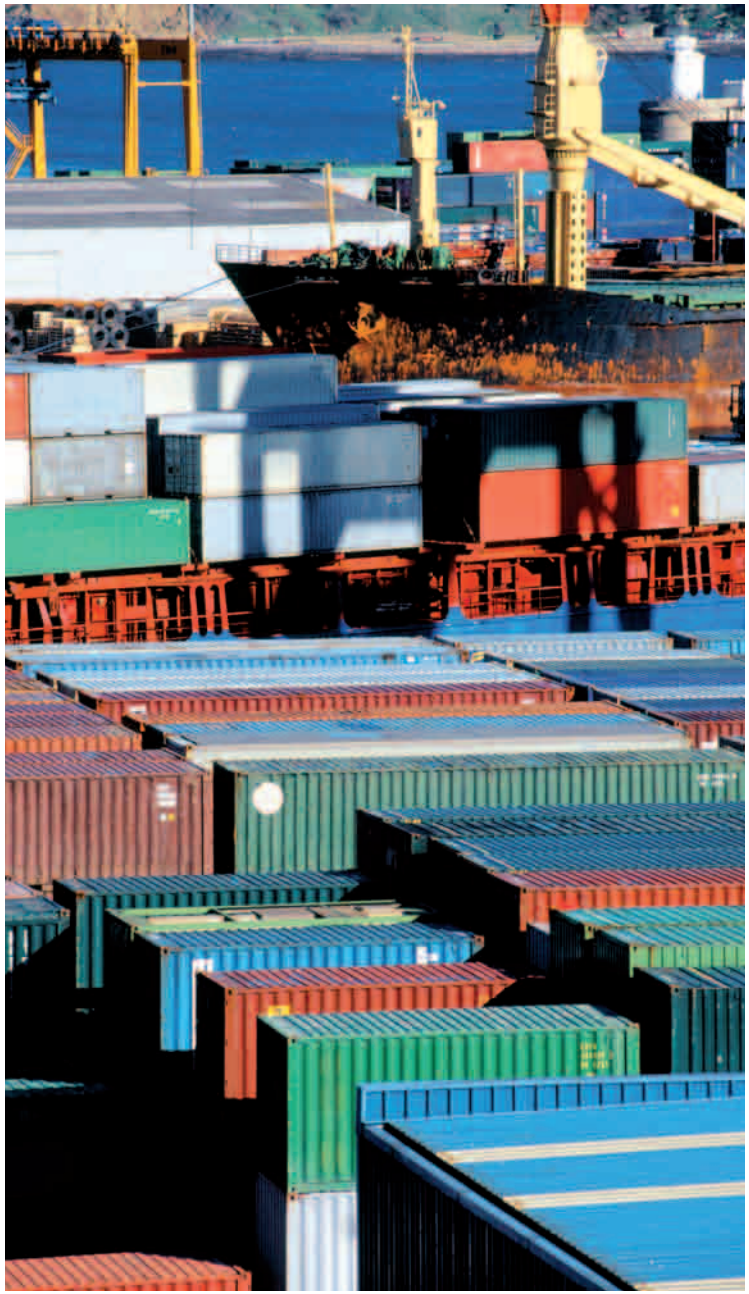
The proposed set of carbon emission factors are summarized in *Table 8*.

These recommended emission factors are average values for the wide range of transport activities of the chemical industry. They can be used to estimate the total carbon footprint of chemical transport operations or by individual companies as default values.

It is clearly preferable, if possible, for companies to derive emission factors for their specific transport operations, reflecting the characteristics of their supply chains, products and customer base.

TABLE 8
Recommended Average Emission Factors

Transport mode	gCO_2 / tonne-km
Road transport	62
Rail transport	22
Barge transport	31
Short sea	16
Intermodal road/rail	26
Intermodal road/barge	34
Intermodal road/short sea	21
Pipelines	5
Deep-sea container	8
Deep-sea tanker	5
Airfreight	602



3. Measurement of Transport-related Emissions in other Sectors

The European chemical industry is not alone in trying to carbon footprint its transport operations. Other sectors have launched similar initiatives. It is possible that the chemical industry may be able to learn from the experience in these other sectors. As part of this study, therefore, a review was conducted of other industrial and commercial sectors to examine their efforts to measure CO_2 emissions from their transport operations. This mainly involved an online search of the websites of industry trade bodies and companies, combined with key word searches for reports, papers and presentations. Informal discussions were also held with logistics specialists in several industries who have contributed to our previous research projects.

This review has revealed that in most sectors carbon measurement is at a fairly early stage and relates principally, and in some cases solely, to emissions from the core activity, such as primary processing, manufacturing or packaging. Little reference is made to the carbon footprint of transport operations, particularly in those sectors, such as cement, with a highly carbon-intensive production process. Where industry associations or companies have published data on transport-related emissions, they seldom disclose the methods used to derive these statistics, the underlying assumptions and their choice of emission factors.

It is possible to detect an evolutionary path in the development of carbon measurement capability at an industry level. Initially macro-level, top-down estimates of aggregate emissions are compiled with little or no differentiation by activity. These are typically based on simple relationships between, on the one hand, total output, sales and energy consumption and, on the other hand, carbon emissions. At a later stage, surveys of key companies in the industry permit more accurate 'bottom-up' estimation of CO_2 emissions and some differentiation of emissions by activity, including transport. At first, the carbon auditing of transport relies on general, cross-industry average emission factors, but can subsequently be refined with the development of sector-specific emission factors. Further evolution sees the disaggregation of transport-related carbon measurement by industry sub-sector and can lead to inter-company benchmarking of carbon intensity. Most of the sectors reviewed are currently in the early stages of this evolutionary path. The chemical industry appears to be one of the more progressive in its efforts to quantify carbon emissions from its transport operation and develop carbon reduction strategies for transport. It may, nevertheless, benefit from adopting some of the ideas and practices of other sectors. The current situation in these other sectors can be summarised as follows:

Cement

The 'Cement Sustainability Initiative', led by the World Business Council for Sustainable Development, has published a report[15] on 'getting the numbers right' in measuring 'energy and CO_2 performance'. None of the numbers in this report relate to transport, however. Carbon measurement is confined to the production operation, with only a brief reference to the transport of inbound clinker being minimal as cement plants are generally located beside quarries. The Cement Industry GHG Protocol currently excludes 'off-site' transport because 'these emissions are small compared to emissions from the kiln and difficult to quantify in a consistent manner'. If companies choose to include transport-related emissions they are encouraged to use the WRI/WBCSD 'Mobile Combustion Tool' for this purpose. LaFarge, one of the largest European cement producers, estimates that its outbound distribution by road represents 5% of its 'manufacturing emissions', though gives no indication of the method of calculation.

Fertiliser

The International Fertiliser Industry Association[16] has included transport and logistics in its analysis of GHG emissions. It concedes, nevertheless, that this 'is difficult because of continuously shifting trade and transport patterns and because trade accounts for only a minority of fertiliser movements'. It estimates that distribution represents 'about 3% of total emissions associated with the fertiliser life cycle' (this excludes the upstream transport of raw materials). The method adopted by the IFIA is very similar to that of Cefic: 'multiplying the number of tonnes by the number of kilometres and the coefficient for the appropriate form of transport'. It encourages companies to obtain 'locally adjusted coefficients', in recognition of the fact that 'there seems to be some regional variation with regard to whether transport by rail and inland

15 WBCSD (2009) 'Cement Industy Energy and CO_2 Performance: Getting the Numbers Right' Geneva.

16 International Fertiliser Industry Assoc (2009) 'Fertilisers, Climate Change and Enhancing Agricultural Productivity Sustainably' Paris.

waterway has the least environmental impact'. The modal emission factors quoted in the IFIA report are obtained from McKinnon (2007)[17] and NTM.

Steel

The World Steel Association[18] provides advice to member companies on the calculation of CO_2 emissions and has calculated the industry's total carbon footprint (1.7 tonnes of CO_2 emitted per tonne of steel produced). Transport of raw materials upstream of the plant are 'excluded from the system boundary'. Presumably downstream distribution of finished products is included, though the WSA's 'CO_2 Emissions Data Collection' report offers no guidance on how the related carbon emissions should be measured. All the published emission factors apply to production operations.

Metal cans

Can Makers, the trade body representing manufacturers for metal cans, commissioned consultants to construct a carbon calculator for their supply chain operations. This tool can be calibrated with company-specific emission factors or standard default values derived mainly from DEFRA.

Bitumen

Nynas, one of the main producers of bitumen, has carbon footprinted the production operation and upstream supply chain for this product. This includes the inbound movement of oil to their European production facilities, but excludes distribution of the finished product. No details are given of the method of calculation, though DEFRA appears to be the main source of emission factor values.

Wine and spirits

The Wine and Spirits Trade Association[19], jointly with J.F. Hillebrand, have developed a carbon calculator for measuring carbon emissions from transport in this sector. This 'represents an objective, reasonable and conservative assessment of emissions from one of the most complex elements of the beverage supply chain'. The calculator allows users to estimate, on a lane by lane basis, CO_2 emissions per litre of wine transported by different transport modes, for bulk and packaged product and for full-loads and groupage. The WSTA and Hillebrand indicate the sources of all the modal emission factors built into their calculator. These include DEFRA, McKinnon, the UK National Atmospheric Emissions Inventory for road; Tremove, NTM and INFRAS for rail and NTM, McKinnon and Maersk for shipping. Typical payloads are also provided for wines/spirits moved by road trailer or container in different countries. In a separate initiative, the Scotch Whisky Association, has analysed (with the assistance of the Scotch Whisky Research Institute), on a life cycle basis, total CO_2 emissions from the production and world-wide distribution of whisky. This has established that outbound distribution of the finished product constitutes around 11% of the total. The macro-level footprint was calculated by multiplying outbound tonnages by carbon emission factors for the different transport modes used, assuming high level modal split estimates. An emission factor of 85 gCO_2/tonne-km is used for road movements, obtained from the UK Low Carbon Vehicle Partnership. In the second phase of this project, the main whisky producers are providing much more detailed figures on the quantities of Scotch moved on different lanes by different modes. Carriers have also been asked to provide fuel consumption and emissions data to help to refine the calculation and reduce reliance on standardised, cross-industry emission factors.

Food

Numerous studies have carbon footprinted the supply chains of food products on a life cycle basis. Many have been motivated by concern about the 'food miles' issue i.e. the trend to source food products from more distant locations. This has focused attention on emissions from the transport operation. Given the public/government interest in this topic, much of this work has been publicly-funded rather than commissioned by trade associations or companies. Studies, such as Smith et al (2005)[20], for example, have produced macro-level estimates of transport-

17 McKinnon (2007) op.cit.

18 World Steel Association (2008) 'CO_2 Emissions Data Collection: User Guide version 6' Belgium.

19 WSTA Logistics Group 'Transport Emissions Carbon Calculator' London.

20 Smith, A. et al (2005) 'Validity of Food Miles as an Indicator of Sustainable Development' DEFRA, London.

related CO_2 emissions for different classes of food by multiplying tonnage, distance and modal emission factor values. Over the past three years, however, much more progress has been made at the micro-level, measuring carbon emissions from the supply chains of specific products to permit carbon labelling.

Numerous studies have been conducted on product carbon footprinting in the UK, France, Germany, Korea and Japan. In an effort to standardise this process, the British Standards Institute (BSI) published guidelines on the carbon footprinting of consumer products (PAS 2050)[21] which includes a section on transport operations. It provides advice, for example, on the allocation of CO_2 emissions between consignments sharing the same vehicle.

In the case of loads limited by mass (i.e. weight), the allocation is by mass; where the load is volume-constrained, CO_2 is to be divided by volume. This recommendation is crude, however, and offers little guidance on how to deal with many commonly-encountered transport situations such as: where the load is neither mass- nor volume-constrained, where a load comprises a mixture of high and low density consignments or where goods are delivered/collected on multiple-stop rounds.

As it is unlikely, for the foreseeable future, that chemical companies will be required to disaggregate transport CO_2 estimates by product or consignment, this recent development of carbon auditing in the food sector is likely to be of limited interest in the short to medium term.

21 British Standards Institute (2008) 'PAS 2050: Specification for the measurement of embodied greenhouse gas emissions in products and services' London.

Paper and board / Packaging

The 'framework for the carbon footprinting of paper and board products' was completed in 2007 and approved by the Confederation of European Paper Industries (CEPI)[22] later that year. It defined 'transport-related greenhouse gas emissions' as one of the 'ten toes' of the industry's carbon footprint. This includes 'transporting raw materials, products and wastes along the value chain'. The GHG calculation procedure is as follows, with data coming from 'companies providing transport services, company transport experts and life-cycle databases':

Calculation steps:

1. Use system boundaries, cut-off criteria and knowledge from other studies to decide which type of transport to include in the analysis
2. Estimate emissions associated with the selected aspects of transport
3. If transport is used for multiple products, use appropriate allocation methods to identify the emissions associated with the product of interest
4. If needed to satisfy the objectives of the footprint, divide the emissions into categories reflecting control
5. Record the greenhouse gas emissions attributable to the functional unit of the product being studied in the appropriate reporting form

For paper products an Environmental Paper Assessment Tool (EPAT) has been developed in North America which includes a calculation of 'transport emissions associated with carrying product from the mills to a distribution point or converter'. This 'provides buyers and sellers of paper products with a consistent language and framework to evaluate and select environmentally preferable paper'. The Federation of European Corrugated Board manufacturers (FEFCO) which is affiliated to CEPI, has published a more technical manual on the carbon footprinting of this class of products. This makes no explicit reference to transport, though indicates that the British PAS 2050 methodology has been employed in its GHG calculations.

Concern about the environmental impact of the growth of packaging and, in some countries the proposed introduction of taxes on packaging, has stimulated research on the environmental auditing of the packaging supply chain. A study by CE Delft[23] has estimated the transport-related CO_2 emissions from the supply chains of a range of packaging products. This has used a series of CO_2-intensity values for different transport modes (78 g/tonne-km for road and 34g/tonne-km for rail and inland waterway). It has also estimated the average length of each link in the packaging supply chain within the Netherlands and quantities of product moving on each of these links.

Postal services

Although the movement of mail presents very different transport challenges to the distribution of chemicals, a recent initiative by the International Post Corporation[24] (IPC), whose members handle 80% of global mail volume, merits attention. It has established an Environmental Measurement and Monitoring System (EMMS) that member organisations and their customers can use to carbon footprint their mail operations, which are essentially logistical. EMMS was developed to 'implement a common carbon measurement and reporting framework in line with customer requirements and stakeholder expectations'. It scores companies' 'carbon management proficiency' on a consistent basis using the 'plan-do-check-act' approach advocated by the International Standards Organisation. The IPC has set its members a target of reducing their total CO_2 emissions by 20% by 2020.

Summary

There is no industry or sector which can currently be regarded as best practice in terms of transport-related carbon auditing. Some, such as fertiliser, packaging and wines & spirits, have gone through a similar process to Cefic in adopting an activity-based approach to carbon measurement and surveying large member companies to compile the necessary base data for macro-level estimation of CO_2 emissions.

Several of the sectoral initiatives outlined above, most notably those relating to fertiliser, food and paper & board, go beyond carbon measurement and provide advice to companies on methods of decarbonising their transport operations.

22 CEPI (2009) 'Frameworks for the Development of Carbon Footprints for Paper and Board Products' Brussels.

23 CE Delft (2007) 'Environmental Indices for the Dutch Packaging Tax' Delft.

24 International Post Corporation (2009) 'Postal Sector Sustainability Report 2009' Brussels.

4. Opportunities for Decarbonising Chemical Transport Operations

These opportunities will be examined within a framework developed for the Green Logistics research project in the UK *(Figure 5)*. This framework maps the complex relationship between the weight of goods produced in an economy or industrial sector and the CO_2 emissions from its freight transport operations. This relationship pivots on a set of seven key parameters:

Modal split indicates the proportion of freight carried by different transport modes. Following this split, subsequent parameters need to be calibrated for particular modes. The rest of *Figure 5* has been defined with respect to road transport.

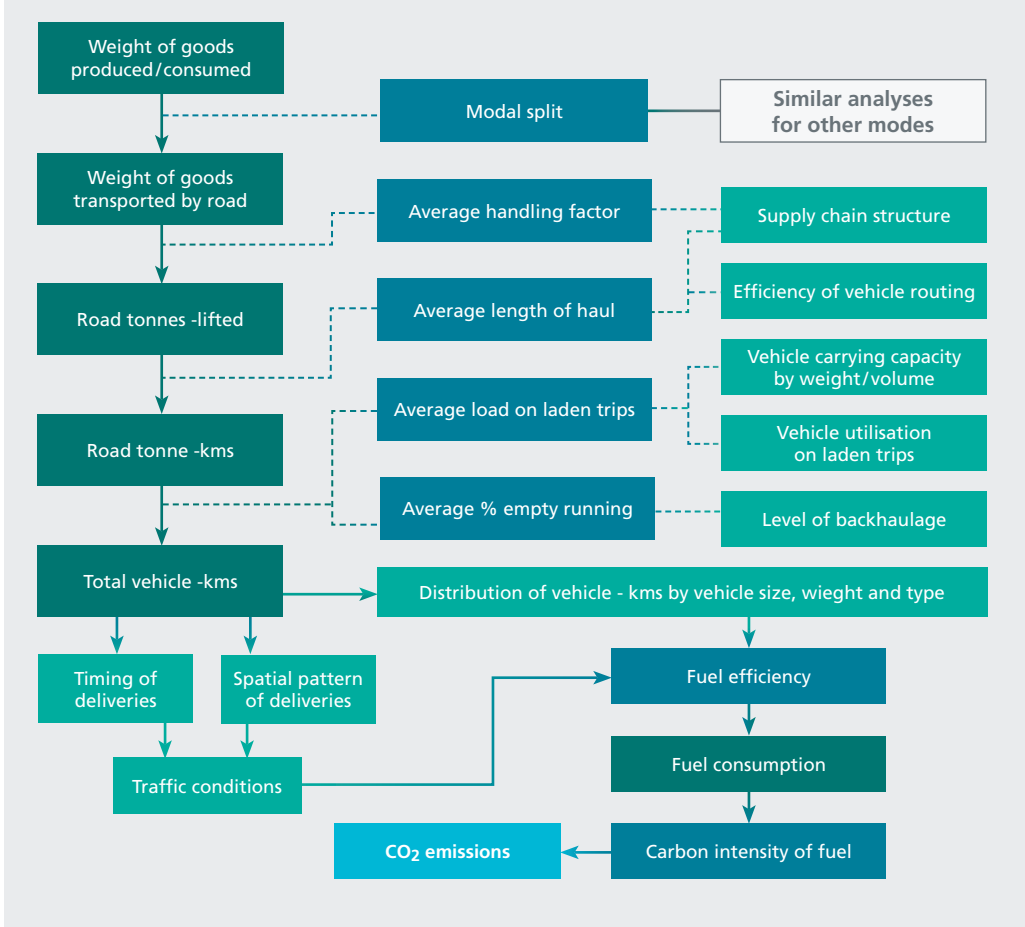
Average handling factor: this is the ratio of the weight of goods produced by an industrial sector to freight tonnages loaded onto vehicles at the start of a journey, allowing for the fact that, as they pass through the supply chain, products are loaded onto vehicles several times. The handling factor serves as a crude measure of the average number of links in a supply chain.

Average length of haul: this is the mean length of each link in the supply chain and essentially converts the tonnes-lifted statistic into tonne-kms.

Average handling factor and length of haul reflect that overall supply chain structure.

Average payload on laden trips and **the proportion of kms run empty** are the two key vehicle utilization parameters. Average payload is normally measured solely in terms of weight. This is very ap-

FIGURE 5
Decarbonisation Framework for Freight Transport



propriate in the chemical industry as a large proportion of loads are weight constrained.

Energy efficiency: defined as the ratio of distance travelled to energy consumed. It is a function mainly of vehicle characteristics, driving behaviour and traffic conditions.

Carbon intensity of the energy source: i.e. the amount of CO_2 emitted per unit of energy consumed either directly by the vehicle or indirectly at the primary energy source for electrically-powered freight operations.

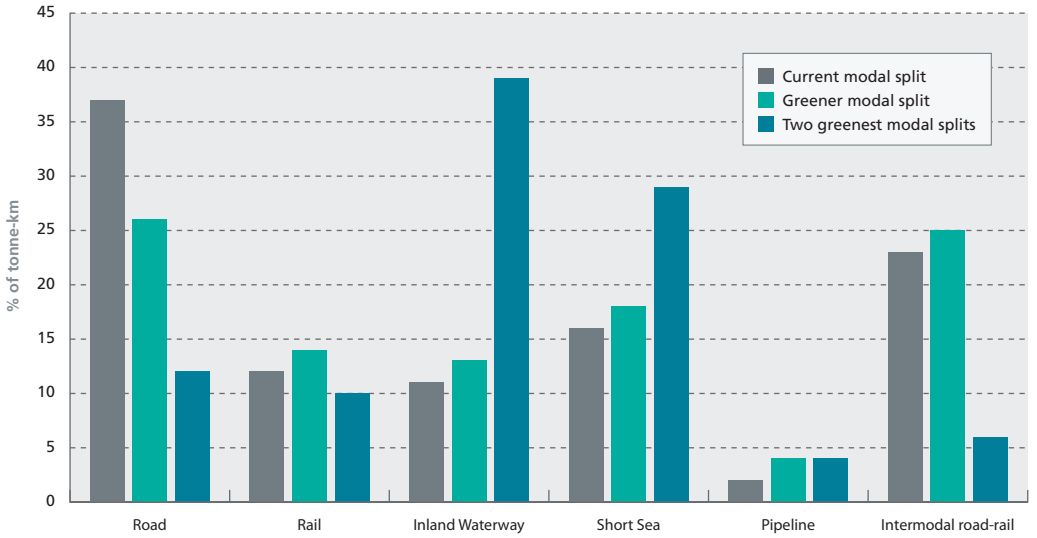
4.1 Modal split

It has been seen how carbon intensity (expressed as gramme of CO_2 per tonne-km) varies widely between transport modes. Shifting from modes with relatively high carbon intensities to those with much lower carbon emissions can help to decarbonise freight transport. To illustrate the potential savings in CO_2 from freight modal shift within the chemical supply chain two hypothetical scenarios have been constructed on the basis of the data collected in the Cefic survey *(Figure 6)*. The first reduces road's share of chemical tonne-kms from 37% to 27% and spreads the displaced traffic evenly around the other lower carbon modes. The second applies the average modal split of the two companies in the Cefic survey which send the lowest proportions of their freight tonnage by road. In the first scenario, a net CO_2 saving of 15% would be achieved, while in the second it would be almost 27%.

All the companies consulted indicated that there was a potential to shift more freight to rail and water-borne services, though some companies have already increased their relative use of lower carbon modes over the past decade. Modal shift was being constrained by several factors:

1. **Short lengths of haul:** it was argued that, in chemical distribution, rail tends only to become competitive where the length of haul is greater than 400-500 kms. The threshold distance partly depends on whether the origin and/or destination are rail-connected and, if not, the extent to which flows have to deviate from the direct road route to pass through intermodal terminals. Many European chemical plants lack a rail connection.

FIGURE 6
Impact of 2 Modal Shift Scenarios on CO_2 Emissions from Chemical Transport



Greener modal split: Marginal reallocation of road freight to lower carbon modes: 15% less CO_2
Two greenest modal splits: Applying the two "greenest" modal splits in Cefic sample: 27% less CO_2

2. **Length of the transit time:** water-borne services, in particular, are often too slow to meet customer order lead time requirements.

3. **Inadequate reliability:** while full trainload deliveries tend to be quite reliable, there can be quite wide variations in the transit times for wagon load traffic on the European rail network.

4. **Lack of cost advantage:** modal switch to rail or water still cannot be justified purely on environmental/decarbonisation grounds. There must also be a commercial case for it and this is often lacking.

5. **Capacity limits:** the rail and, to a lesser extent, waterway networks can lack sufficient capacity on key links at busy times to accommodate a substantial mode shift from road.

4.2 Supply chain structure

For some chemical companies the average length of haul is currently increasing as their market areas expand. The gradual centralisation of production and inventory in the chemical industry is also increasing its freight transport intensity. There is little prospect in the foreseeable future for these well-established geographical trends being reversed. There are, nevertheless, other measures that companies can take to offset these trends and possibly reduce the industry's transport-related carbon footprint.

Expanding swap arrangements[25]: by essentially reducing the demand for transport and eliminating tonne-kms, swapping is an ideal decarbonisation measure. It is already widely applied in the chemical industry for commodity products such as ethylene, propylene and benzene, though, in the opinion of several of the managers consulted, it could be expanded. No general data is available on the current level of swaps or the resulting saving in transport and CO_2 emissions. It is not possible, therefore, to model the potential savings from a further increase in swaps. To achieve a significant increase in the level of swapping, it would probably be necessary to treat as standard commodities some products that are currently branded and differentiated for marketing purposes.

Disintermediation: in other words, allowing larger consignments to bypass distributors and external warehouses and travel directly from plant to customers. This eliminates a link in the supply chain, reducing the 'handling factor' and cutting total tonne-kms. This already happens, even where the sale is still handled by the chemical distributor, but is relatively uncommon. Companies would have to ensure that this did not contravene EU competition rules and that high vehicle load factors were maintained on these direct deliveries.

Improved routing: the circuitous routing of products, both at a supply chain level via intermodal terminals, warehouses and tank cleaning stations, and on the road and rail networks can generate unnecessary tonne-kms. There is probably scope for optimising chemical transport operations at both these levels, using more advanced logistics planning and vehicle routing tools. In the case of hazardous chemicals, more careful routing of the products also reduces the risk of accidents and thus yields safety benefits.

4.3 Vehicle utilisation

The loading of road and rail vehicles, tanks and containers in the chemical industry is already high, particularly at the upper levels of the supply chain. As transport costs represent a relatively large proportion of product value, companies are under intense pressure to maximise vehicle utilisation. Pricing structures also give customers a strong incentive to take full truck, tank and container loads. Further down the supply chain, however, a combination of just-in-time pressures and product diversification is making it difficult for chemical companies to maintain load factors, let alone increase them. *Figure 7* (page 28) lists the range of factors that typically constrain vehicle loading and groups them into five categories. All of these factors impinge on chemical transport operations. There are, nevertheless, some measures that would permit a significant increase in vehicle fill. Several of them are discussed in the EPCA/Cefic reports published in 2003 and 2004 on supply chain excellence in the European chemical industry[26]. They all have the merit of saving money as well as cutting carbon:

Increase in the maximum vehicle weight: many trucks carrying chemical products reach their maximum legal weight before all the available deck/cubic

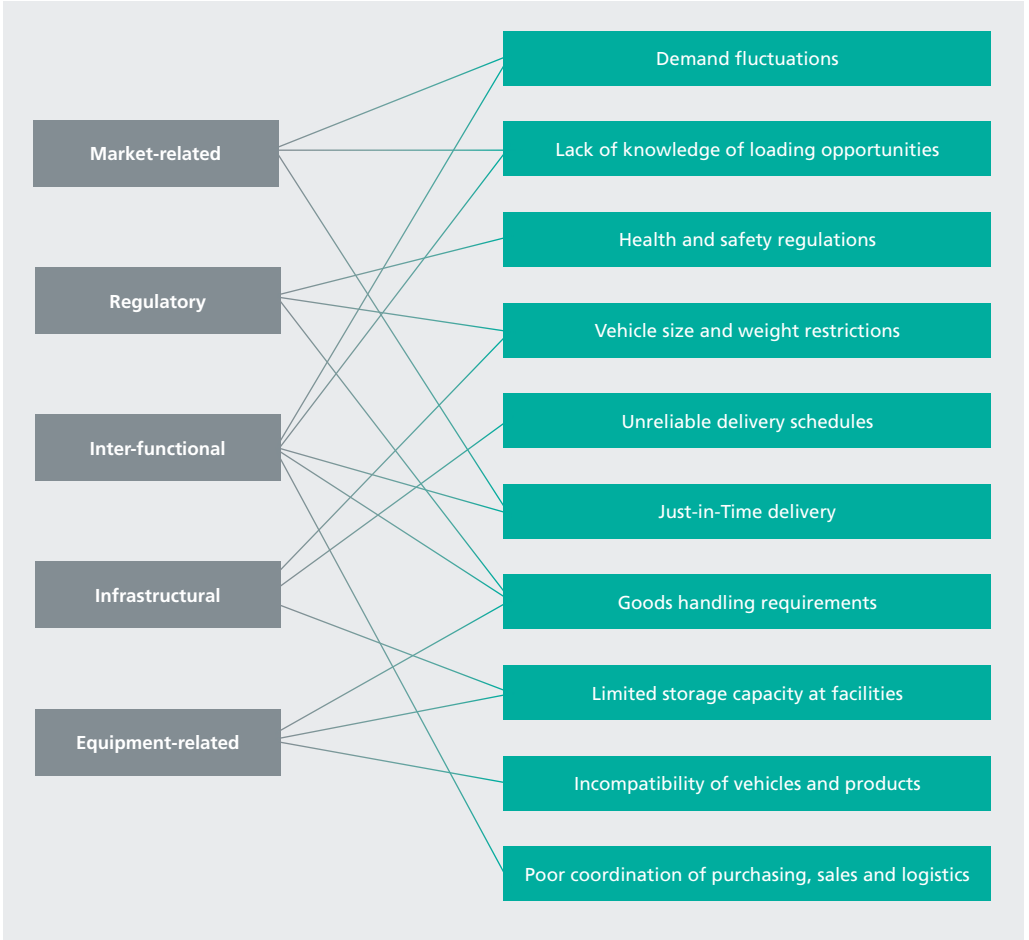
25 Chemical companies in 'swap arrangements' supply customers with standard products, often branded by a particular company, from the nearest production plant. Company A may therefore supply Company B's customer if its plant is closer and vice versa. This minimises the average distance over which products are distributed.

26 McKinnon, A. (2004) 'Supply Chain Excellence in the European Chemical Industry' EPCA/Cefic, Brussels. Braithwaite, A. (2005) 'Maximising Performance: The Power of Supply Chain Collaboration' EPCA/Cefic, Brussels.

capacity is occupied. A relaxation of government weight restrictions from 40 to 44 tonnes across Europe would therefore permit greater load consolidation. Within three years of the UK government increasing the maximum weight limit to 44 tonnes, 61% of tonne-kms in the petrol and petroleum products commodity class were being moved in trucks registered at this higher weight limit[27]. In estimating the net carbon savings from greater load consolidation in 44 tonne trucks, allowance would have to be made for any erosion of chemical traffic from rail and water-borne modes. If, however, the increase in maximum truck weight were accompanied by an even greater increase in the weight limit for intermodal units to 50 tonnes, as currently proposed by Cefic, any negative impact on rail could be neutralised.

Relax monthly order-invoice cycles: This was identified in the EPCA/Cefic supply chain excellence initiative as an important efficiency improvement measure. It would help to reduce the artificial peaking of freight flows at the start of the month. The interviewees in the present study, however, differed in their assessment of its potential benefit in both cost and carbon terms. One company had moved to a system of rolling credit mainly to reduce peaking and relieve pressure on loading bays. This is also likely to have cut carbon emissions, though these savings had not been quantified.

FIGURE 7
Factors constraining vehicle utilisation



27 McKinnon, A.C. (2005) 'The Economic and Environmental Benefits of Increasing Maximum Truck Weight: the British Experience' Transportation Research part D, vol. 10, pp.77-95.

Improve loading practices: more careful loading of consignments, for example putting more stackable products lower in the vehicle, can improve vehicle fill. This often requires better staff training and supervision.

Expanding storage capacity at delivery points: vehicle loading is partly constrained by the storage capacity of silos and tanks at the customer's premises. Investment in additional storage capacity could increase the proportion of full load deliveries, particularly when linked with vendor management of the customer's inventory.

Vendor managed inventory: the EPCA/Cefic supply chain excellence studies highlighted the potential economic and environmental benefits of VMI in the chemical industry. Five years on, an even stronger case can now be made, in terms of decarbonisation, for the wider adoption of VMI in this sector.

Logistical collaboration: in other industies, most notably the fast moving consumer goods sector, logistical collaboration initiatives are gathering momentum and achieving significant reductions in vehicle-kms, transport energy use and emissions, mainly by exploiting backloading opportunities. As revealed by the EPCA/Cefic study, large potential exists for transport collaboration in the European chemical industry.

More effective management of drivers' hours: drivers' hours restrictions limit the amount of product that can be delivered by a vehicle, particularly on multiple-drop rounds. Although it is unlikely that these legal restrictions are going be relaxed, it may be possible that improved routing and scheduling would allow companies and their carriers to improve average loading within existing constraints.

4.4 Fuel efficiency

As most chemical transport is outsourced, responsibility for maximising fuel efficiency rests with the carrier. 'Open-book' contracts with carriers give shippers visibility of fuel consumption, but tend only to apply to dedicated transport operations and appear to be comparatively rare in the chemical industry. Many carriers would be unwilling to divulge information about their fuel efficiency as this could influence commercial negotiations. At least two of the chemical companies consulted, however, had managed to obtain this information without too much difficulty from carriers. If this information were routinely provided, carriers could be benchmarked on their fuel performance, as has happened in the UK in the series of government-sponsored transport KPIs surveys. Most of the KPIs that chemical companies request from their transport providers relate to service quality rather than operational or energy efficiency. By taking a greater interest in the fuel efficiency standards and programmes of their carriers, chemical companies might be able to exert more pressure on them to cut fuel consumption. One can take the view, however, that carriers are already under strong cost pressure to minimise fuel consumption, as it accounts for 25-30% of total costs, and that the incremental effect of shippers 'taking greater interest' in the subject could be relatively small. Benchmarking surveys in the UK, Germany, Canada and other countries, however, reveal quite wide variations in the average fuel efficiency of road carriers, even those engaging in similar types of haulage work. It would probably be beneficial, therefore, in both carbon and financial terms, to work with the European Chemical Transport Association to establish and disseminate best practice in fuel management among the chemical industry's carrier community.

Best practice in fuel management involves applying a range of fuel economy measures[28]. These can be divided into three categories relating to the design, maintenance and operation of vehicles.

4.4.1 Vehicle design

Five vehicle attributes have a strong influence on fuel consumption:

- **Fuel efficiency of new trucks:** There are significant variations in the fuel efficiency of different makes and models of new truck on the market. Trade publications report variations of 5-10% in fuel consumption over a standard trial route for a particular class of vehicle.
- **Engine power-rating:** It is common for companies to purchase tractor units that are more powerful than they need to be for a particular type of distribution operation.

28 McKinnon, A.C. 'Increasing Fuel Efficiency in the Road Freight Sector' in McKinnon, A.C. et al (eds) (2010) 'Green Logistics', Kogan Page, London.

- **Vehicle tare (i.e. empty) weight:** Fuel efficiency can also be enhanced by reducing this tare weight. Use of lighter materials, such as aluminium or carbon fibre, and the removal of unnecessary fittings can significantly cut the tare weight.

- **Aerodynamic profiling:** A series of good practice guides and case studies (e.g. Dept for Transport, 2007)[29] have reported potential fuel savings in the range 6-20% for improved aerodynamic styling of trucks. In articulated vehicles, both tractor and trailer need to be streamlined either at the time of manufacture or by subsequently retrofitting with 'fairings'.

- **Installation of fuel economy devices:** These can include anti-idling controls, fuel metres and speed governors.

4.4.2 Vehicle maintenance

In under-maintained vehicles there are numerous technical defects which can prevent a lorry from operating at optimum fuel efficiency. They include fuel leaks, under-inflated tyres, mis-alignment of axles and poor engine tuning. More regular and thorough maintenance cuts fuel losses associated with these defects.

4.4.3 Vehicle operation

The key measures to be introduced under this heading are:

- **Improved driver training:** It is generally accepted that driving style is the single greatest influence on fuel efficiency. Driver training programmes have been shown to improve fuel efficiency by as much as 8-10%.

- **Driver incentive schemes:** To derive longer term benefit from driver training, companies have to give drivers an incentive to continue driving fuel-efficiently.

- **Reducing speed limits:** Imposing tighter limits on vehicle speeds has been shown to achieve significant fuel savings often with minimal increases in the order lead time.

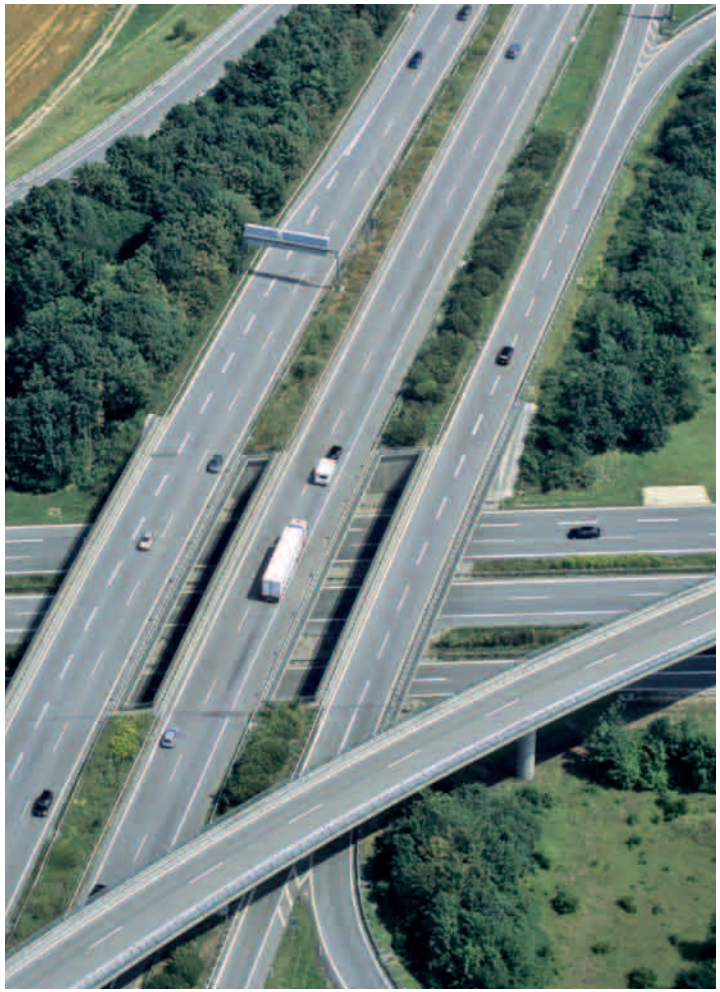
- **Fleet management:** This includes assigning the 'right vehicles to the right jobs'. Fleet management can also be reinforced by the appointment of a 'fuel champion' whose job it is to analyse the pattern of fuel consumption, promote fuel saving initiatives and generally instil a fuel-saving culture in the workforce.

4.5 Carbon intensity of fuel

Good fuel management also includes an assessment of the costs and benefits of using alternative fuels, some of which, on a life-cycle or well/field to wheel basis, can yield net reductions in carbon emissions. As with fuel economy measures, however, the main decision on whether to switch to biofuels or compressed natural gas will continue to rest with the carrier. Chemical companies could significantly cut the carbon footprints of their transport operations by prioritising the use of rail in those countries generating a large proportion of their electricity from nuclear and renewal sources, where the commercial conditions are favourable. It is likely, however, that they will gain only limited carbon benefit from the hybridisation and full electrification of trucks. It is operators of smaller rigid vehicles that will derive most of the benefit of hybrid and plug-in technology. The heavy articulated trucks, which are the 'work-horses' of the European chemical industry, are likely to continue running on conventional diesel fuel for the foreseeable future. Recent research for the Low Carbon Vehicle Partnership in the UK suggests that, in the medium term, powering heavy goods vehicles with biomethane will prove a much more cost-effective means of decarbonising long distance road haulage operations than the use of biodiesel blends.

29 Dept for Transport (2007) 'Aerodynamics for Efficient Road Freight Operations' Freight Best Practice Programme, London.

5. Cost Effectiveness of Decarbonisation Measures



The numerous decarbonisation measures outlined in the previous section vary in their relative cost effectiveness as illustrated, in a rather idealised fashion, in *Figure 8*. This figure shows a tentative ranking of some of the main measures in terms of the initial set-up and/or capital costs. Insufficient data is available at present to calibrate this graph. It should be noted that many of these measures would have a fairly short payback period and, on an ongoing basis, yield both cost and CO_2 savings.

A Invest in pipeline network
B Modal shift to rail / inland waterways
C Expand swap arrangements
D Use of alternative fuels
E More efficient vehicle routing
F Enhanced vehicle aerodynamics
G Improved vehicle utilisation
H Driver training in fuel efficient driving

FIGURE 8
Variations in the Relative Cost-effectiveness of Decarbonisation Measures

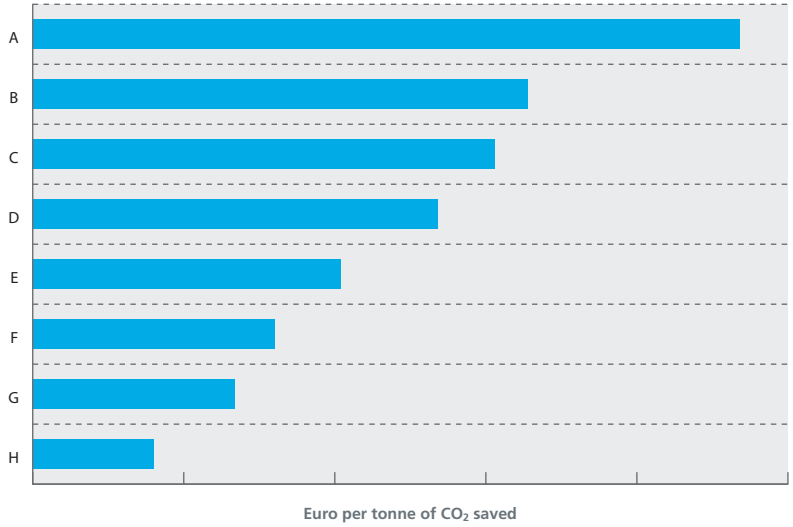


FIGURE 9
Cost and Carbon Savings Accruing from Improved Fuel Efficiency (fully laden 40t gross weight articulated vehicle)

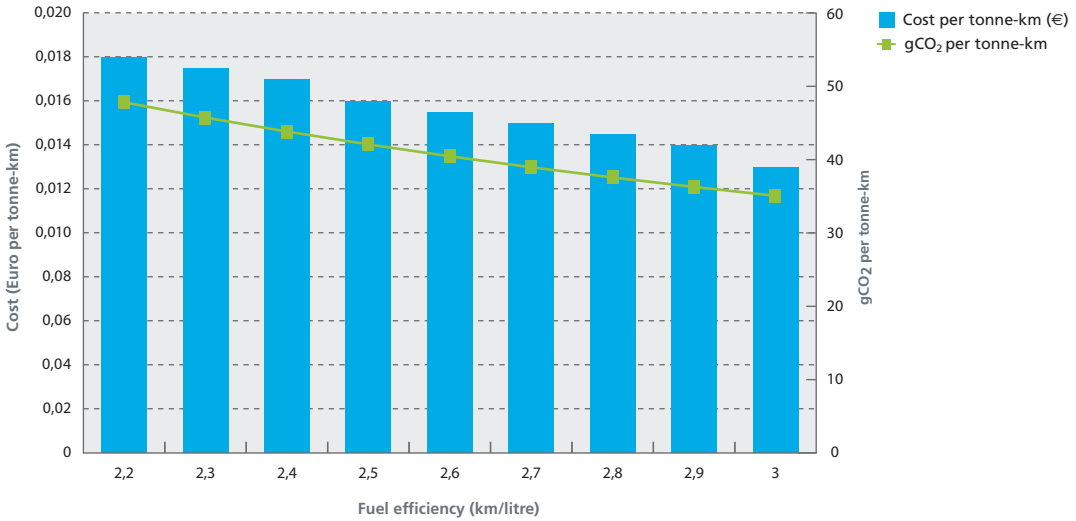


TABLE 9
Estimated Cost-effectiveness of Carbon Reduction Measures.

Measure	Appraisal period (years)	£/tonne of carbon saved
Driver training in fuel efficient driving (over 5 years)	5	65-75
Financial incentive for modal shift to rail (over 3 years)	3	90
Streamlining of HGVs (over 5 years)	5	130
Company advice on HGV fuel efficiency (over 5 years)	5	190
Company advice on vehicle routing and telematics	5	240

The direct linear relationship between cost and CO_2 reductions can be easily demonstrated in the case of measures which improve fuel efficiency *(Figure 9)*.

An attempt has been made in the UK to assess the cost-effectiveness, over a 3-5 year time frame, of a range of carbon reduction measures in the freight transport sector *(Table 9)*.

Researchers at the Eindhoven University of Technology[30] have also modelled the relative cost and carbon impacts of logistical measures such as freight modal shift and improved backloading using data from case study companies. Their analysis suggests that, in the case of two companies, carbon emission reductions of up to 15% might be achieved at a net saving in transport costs *(Figure 10)*.

Efforts have also been made to assess the relative effects of a range of low carbon vehicle technologies and practices on costs and CO_2 emissions. An analysis of this type, undertaken for the UK government[31], assessed the relative degree of risk in the development and application of these measures *(Figure 11)*. It identified measures such as training in safe and fuel efficient driving (SAFED), low rolling resistance tyres and the retrofitting of aerodynamic devices ('aero fairings') to vehicles as offering large reductions in tail-pipe CO_2 emissions at relatively low cost.

30 Jan C. Fransoo, Tarkan Tan, A.G. (Ton) de Kok, and Henny P.G. van Ooijen (2010) 'Measuring and regulating carbon emissions in transportation', Working Paper, School of Industrial Engineering, Eindhoven University of Technology.

31 Ricardo (2009) 'Review of Low Carbon Technologies for Heavy Goods Vehicles' UK Dept for Transport, London.

FIGURE 10

Effects of Freight Modal Shift on Transport Costs and CO_2 Emissions

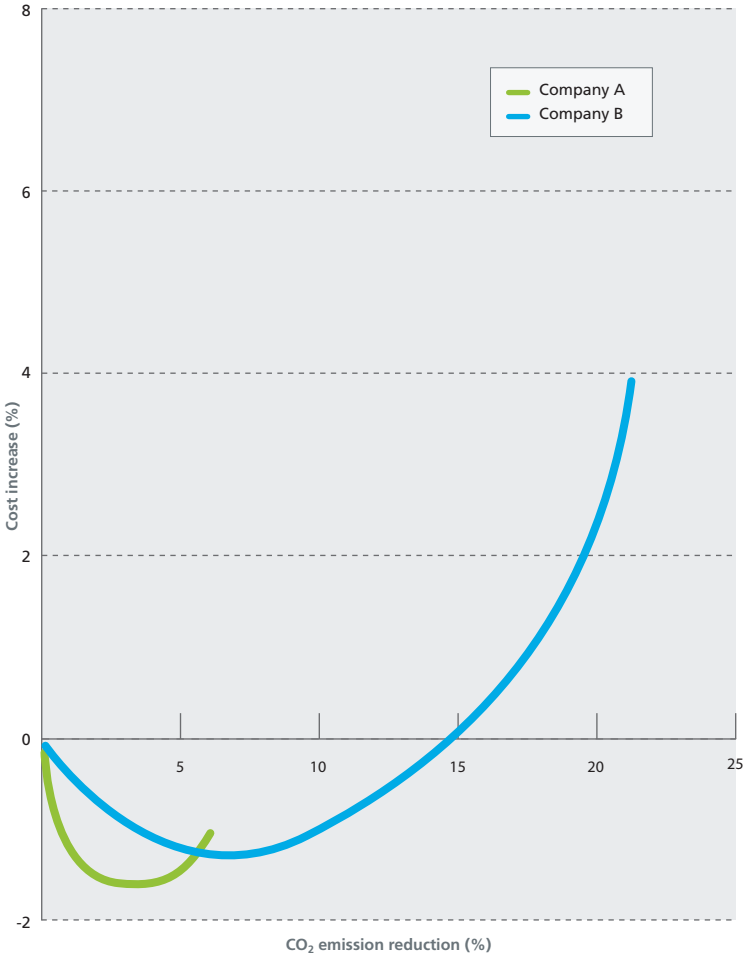


FIGURE 11

Relative Cost-effectiveness of Low Carbon Truck Technologies and Practices (Adapted from Ricardo / UK Department for Transport)[31]

6. Conclusion

The measurement of carbon emissions from freight transport operations is still at an early stage in most industrial sectors. The review of initiatives in other sectors suggests that the European chemical industry is relatively progressive in its efforts to carbon footprint its freight transport operations, despite that fact that they account for only a small proportion of total CO_2 emissions. At present, this industry, like others, has little choice but to adopt the 'activity-based' approach to measuring transport-related emissions, applying standardised carbon emission factors to estimates of tonne-kms moved by different modes.

It will be desirable, however, to migrate to an 'energy-based' method of calculation using fuel consumption data provided by carriers. This will permit much more accurate estimation of CO_2 emissions. As it may take several years to achieve this goal, it may be possible, as an interim measure, to develop a 'refined activity-based' approach involving closer collaboration between shippers and carriers. This would incorporate into the CO_2 calculation sample data on distances travelled, consignment routing, backloading and fuel efficiency provided by carriers to permit the calibration of emission factors specific to the chemical industry *(Figure 12)*. This could lead in the medium term to full operational, energy and carbon 'transparency' between shippers and carriers.

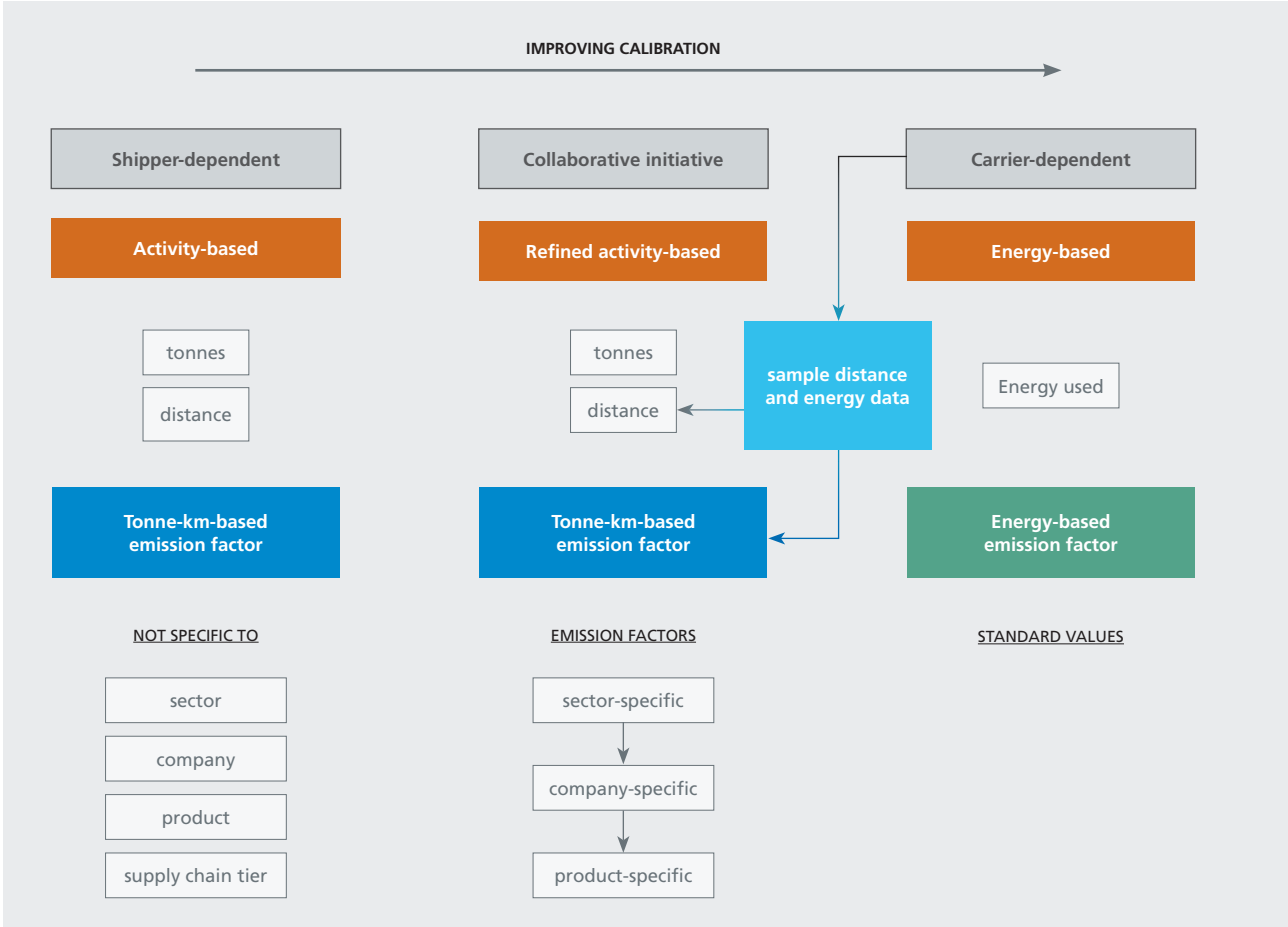
The refinement of the carbon measurement process will help the chemical industry to develop a transport decarbonisation strategy embracing the various measures outlined in this report. These measures can be targeted on five key freight transport parameters: modal split, supply chain structure, vehicle utilisation, energy efficiency and carbon intensity of the energy. The first two parameters are under direct control of chemical companies. Responsibility for vehicle utilisation is shared with carriers, while energy efficiency and the carbon content of fuel is much more strongly influenced by the logistics provider.

Measures that chemical companies, and their carriers, have introduced in recent years primarily to improve the economic efficiency of transport will also have cut carbon. More research is required, however, to assess the relative cost effectiveness of a broader range of decarbonisation measures.

From discussions with chemical logistics managers, it seems that there is still a reasonable amount of 'low hanging fruit' to be harvested, which will be self-financing in the short to medium term, though require some initial investment. Some of these self-financing, quick payback measures can be implemented by individual companies, while others will require inter-company collaboration as recommended in earlier reports on the European chemical supply chain[32].

32 McKinnon, (2004) op.cit.; Braithwaite (2005) op.cit.

FIGURE 12
Possible Evolution of Carbon Measurement Process



Biographies

Professor Alan McKinnon is director of the Logistics Research Centre at Heriot-Watt University, Edinburgh, UK. A graduate of the universities of Aberdeen, British Columbia and London, he has been researching and teaching in freight transport / logistics for thirty years and has published extensively in journals and books. Alan has conducted studies for numerous public and private sector organisations and been an adviser to several UK government departments and parliamentary committees and various international agencies, including the International Transport Forum and International Energy Agency. In 2003-4 he facilitated the 'Supply Chain Excellence' initiative of the European Petrochemical Association and Cefic. In recent years much of his research has focused on the decarbonisation of logistics. Alan is a member of World Economic Forum's Global Agenda Council on the Future of Transportation and recipient of the Sir Robert Lawrence Award, the highest distinction of the UK Chartered Institute of Logistics and Transport.

Dr Maja Piecyk is a Lecturer in the Logistics Research Centre, based at Heriot-Watt University, Edinburgh. Her research interests focus on the environmental performance of supply chains and sustainability of freight transport operations. Much of her current work centres on the CO_2 auditing of businesses and forecasting of long-term trends in energy demand and the environmental impacts of logistics.

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