# EU Transport GHG: Routes to 2050?

## Operational options for all modes (Paper 4)

18th December 2009


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# Executive Summary

This paper is one of five papers on GHG reduction options for transport drafted under the EU Transport GHG: Routes to 2050? Project. This paper reviews the operational, non-technical options that could contribute to reducing transport's GHG emissions, both up to 2020 and in the period from 2020 to 2050. It aims to provide a high-level summary of the evidence based on existing studies.

Various operational GHG mitigation options were identified for all transport modes. GHG reduction potential, cost and cost effectiveness was assessed for all options, as much as data availability allowed.

In **road transport**, the transport mode with the largest share in the greenhouse gas emissions of Europe's transport sector, operational measures that can be taken are fuel efficient driving, tyre pressure monitoring and vehicle downsizing[1]. Vehicle downsizing has high potential, as smaller engines and lighter vehicles directly reduce $CO_2$ emissions. The short term potential of the first two measures is significant (up to more than 10%), but they are expected to diminish over the coming decade as vehicle technology will automate these behavioural changes.

In **inland shipping**, the following operational measures were identified: Improved maintenance of ship hulls, propellers and engines, speed optimization and just in time routing. Each of these measures may typically reduce GHG emissions by 1-5%, although the potential of speed optimisation may be higher. However, there is very little evidence on the GHG reduction potential and cost of these measures..

Quite a large range of operational measure were found for **rail transport**, ranging from **r**unning shorter trains when extra capacity is not required and better recording of energy consumed, to control and command signalling. Running shorter trains, energy efficient driving, disconnecting electric trains from the grid and reducing idling of diesel engines seem to have the largest potential for $CO_2$ reduction, with reasonable cost/benefit ratios. However, data on potential and cost of these measures is limited, and may vary between countries and rail operators.

A number of operational measures were also identified for **aviation**: training of the crew, various measures in air traffic management and aircraft performance, and electricity at the gate. The potential of crew training has not been quantified, but measures in air traffic management could reduce $CO_2$ emissions by 6-12% in 2050. Many initiatives are already in place to implement these measures and harvest a large part of that potential. Operational measures to improve aircraft performance have much less reduction potential. The potential of electricity at the airport gate is expected to be relatively low, but cost effective.

There are quite a number of operational measures that may reduce emissions of **maritime shipping**, including voyage optimization, fleet management and speed reduction. Evidence on potential effects are quite limited, but we conclude that improvements in fleet management and special hull coatings have the highest potentials for reduction: fleet management between 5 and 50% (the high estimate if significant speed reductions can be achieved), coatings can achieve up tot 15% reduction. Speed reductions also have significant potential, of about 1-5%.

[1] Please note that modal shift and logistical optimization are part of Paper 5 of this series.

# 1 Introduction

## 1.1 Topic of this paper

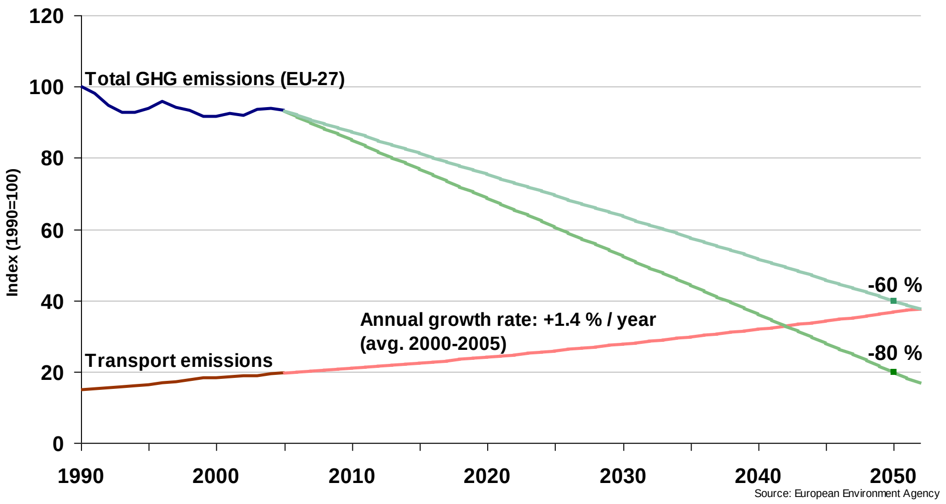
This paper is one of five papers on GHG reduction options for transport drafted under the *EU Transport GHG: Routes to 2050?* Project. These papers review the options – technical and non-technical – that could contribute to reducing transport's GHG emissions, both up to 2020 and in the period from 2020 to 2050. This paper focuses on operational options to reduce GHG emissions from transport. The papers aim to provide a high-level summary of the evidence based on existing studies.

This paper was presented in draft form to a Technical Focus Group meeting (at which stakeholders were present) in July 2009 after which it has been updated on the basis of the discussion at the meeting and the comments and further evidence that were received.

## 1.2 The contribution of transport to GHG emissions

The EU-27's greenhouse gas (GHG) emissions from transport have been increasing and are projected to continue to do so. The rate of growth of transport's GHG emissions has the potential to undermine the EU's efforts to meet potential, long-term GHG emission reduction targets if no action is taken to reduce these emissions. This is illustrated in Figure 1 (provided by the EEA), which shows the potential reductions that would be required by the EU if economy-wide emissions reductions targets for 2050 of either 60% or 80% (compared to 1990 levels) were agreed and if GHG emissions from transport continued to increase at their recent rate of growth. The figure is simplistic in that it assumes linear reductions and increases. However it shows that unless action is taken, by 2050 transport GHG emissions alone would exceed an 80% reduction target for all sectors or make up the vast majority of a 60% reduction target. This illustrates the scale of the challenge facing the transport sector given that it is unlikely that GHG emissions from other sectors will be eliminated entirely.

**Figure 1: EU overall emissions trajectories against transport emissions (indexed)[2]**

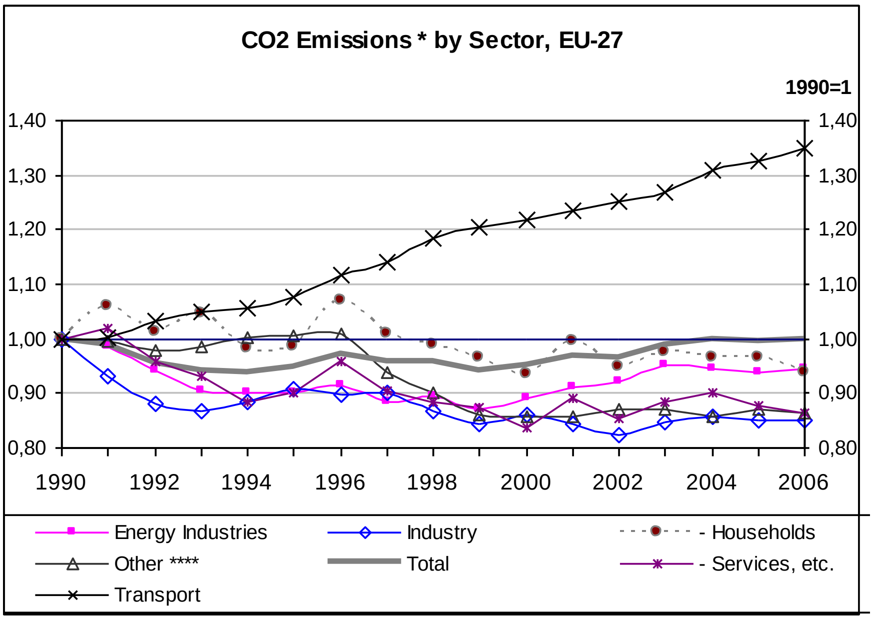



The extent of the recent growth in transport emissions is reinforced by Figure 2, which presents a sectoral split of trends in $CO_2$ emissions over recent years. Whilst the $CO_2$ emissions from other sectors have levelled out or have begun to decrease, transport's $CO_2$

[2] Graph supplied by Peder Jensen, EEA

emissions have risen steadily since 1990. It should be noted that whilst Figure 2 is presented in terms of $CO_2$ emissions, very similar trends are evident for GHG emissions (in terms of $CO_2$ equivalent) since $CO_2$ emissions represent 98% of transport's GHG emissions.

**Figure 2: Carbon dioxide emissions by sector EU-27 (indexed)[3]**

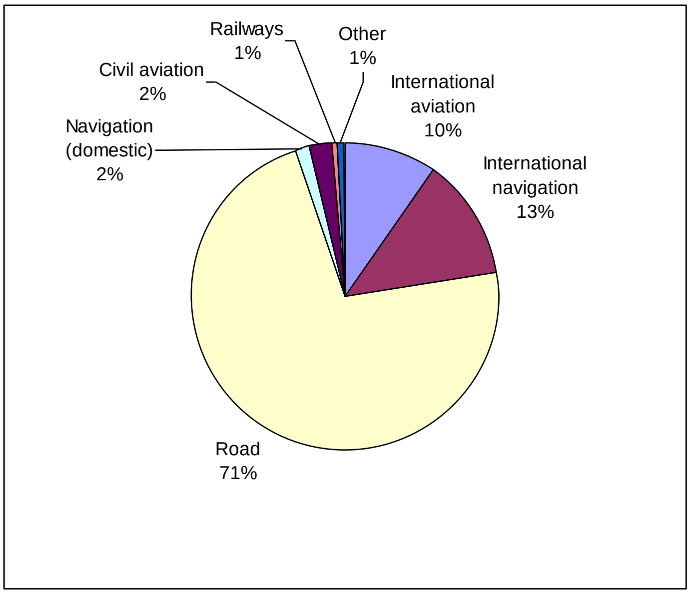



*Notes:*
*i) The figures include international bunker fuels (where relevant), but exclude land use, land use change and forestry*
*ii) The figures for transport include bunker fuels (international traffic departing from the EU), pipeline activities and ground activities in airports and ports*
*iii) "Other" emissions include solvent use, fugitive emissions, waste and agriculture*

The vast majority of European transport's GHG emissions are produced by road transport, as illustrated in Figure 3, while international shipping and international aviation are other significant contributors.

[3] Graph based on figures in DG TREN (2008) *EU energy and transport in figures 2007-2008: Statistical Pocketbook* Luxembourg, Office for Official Publications of the European Communities.

**Figure 3: Greenhouse gases emissions by transport mode (EU-27; 2005)[4]**




Note: The figures include international bunker fuels for aviation and navigation (domestic and international)

Recent trends in $CO_2$ emissions from transport are also expected to continue, as can be seen from Table 1 below. Between 2000 and 2050, the JRC (2008) estimates that GHG emissions from domestic transport in the EU-27 will increase by 24%, during which time emissions from road transport are projected to increase by 19% and those from domestic aviation by 45%. It is important to note that these projections do not include emissions from international aviation and maritime transport, which are also expected to increase due to the growth in world trade and tourism.

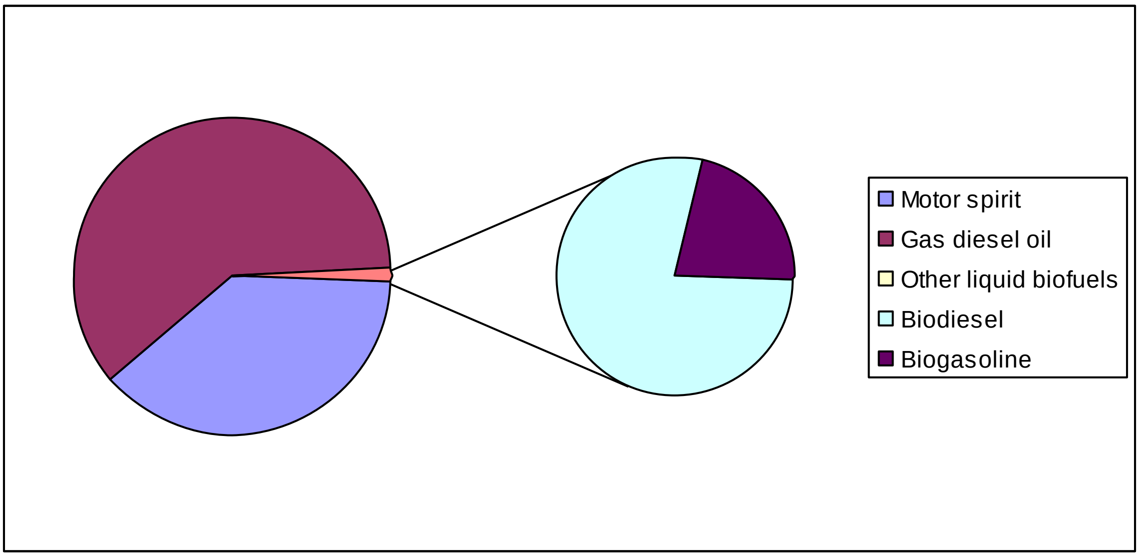
**Table 1: $CO_2$ emissions projection for 2050 by end-users in the EU-27, in Millions tonnes of Carbon[5]**

| End user Category | 1990 | 2000 | 2010 | 2020 | 2030 | 2050 |
|---|---|---|---|---|---|---|
| Road transport | 695 | 825 | 905 | 980 | 1002 | 1018 |
| Rail | 29 | 29 | 27 | 27 | 21 | 20 |
| Domestic Aviation | 86 | 134 | 179 | 206 | 237 | 244 |
| Inland navigation | 21 | 16 | 16 | 17 | 17 | 17 |
| **Total** | **810** | **988** | **1110** | **1213** | **1260** | **1299** |

Figures from the EEA (2008), illustrate the recent growth in GHG emissions from international aviation, as they estimate that these increased in the EU by 90% (60 Mt $CO_2$e) between 1990 and 2005; international aviation emissions will thus become an ever more significant contributor to transport's GHG emissions if current trends continue. Furthermore, the IPCC has estimated that the total impact of aviation on climate change is currently at least twice as high as that from $CO_2$ emissions alone, notably due to aircrafts' emissions of nitrogen oxides ($NO_x$) and water vapour in their condensation trails. However, it should be noted that there is significant scientific uncertainty with regard to these estimates, and research is ongoing in this area.

[4] Graph based on figures in EEA (2008) *Climate for a transport change – TERM 2007: Indicators tracking transport and environment in the European Union* EEA Report 1/2008, Luxembourg, Office for Official Publications of the European Communities.
[5] Taken from JRC (2008) *Backcasting approach for sustainable mobility* Luxembourg, EUR 23387/ISSN 1018-5593, Office for Official Publications of the European Communities.

**Figure 4: Final transport energy consumption by liquid fuels in EU-27 (2005), ktoe**[6]




The principal source of transport's GHG emissions is the combustion of fossil fuels. Currently, petrol (motor spirit), which is mainly used in road transport (e.g. in passenger cars and some light commercial vehicles in some countries), and diesel, which is used by other modes (e.g. heavy duty road vehicles, some railways, inland waterways and maritime vessels) in various forms, are the most common fuels in the transport sector (see Figure 4). Additionally, liquid petroleum gas (LPG) supplies around 2% of the fuels for the European passenger car fuel market (AEGPL, 2009[7]), while the main source of energy for railways in Europe is electricity, neither of which are included in Figure 4. While, alternative fuels are anticipated to play a larger role in providing the transport sector's energy in the future, currently they only contribute 1.1% of the sector's liquid fuel use.

## 1.3 Background to project and its objectives

The context of the *EU Transport GHG: Routes to 2050* is the Commission's long-term objective for tackling climate change, which entails limiting global warming to 2$^{o}$C and includes the definition of a strategic target for 2050. The Commission's President Barosso recently underlined the importance of the transport sector in this respect be noting that the next Commission "needs to maintain the momentum towards a low carbon economy, and in particular towards decarbonising our electricity supply and the transport sector"[8]. There are various recent policy measures that are aimed at controlling emissions from the transport sector, but these measures are not part of a broad strategy or overarching goal. Hence, the key objective of this project is to provide guidance and evidence on the broader policy framework for controlling GHG emissions from the transport sector. Hence, the project's objectives are defined as to:

- Begin to consider the long-term transport policy framework in context of need to reduce greenhouse gas (GHG) emissions economy-wide.
- Deal with medium- to longer-term (post 2020; to 2050), i.e. moving beyond recent focus on short-term policy measures.
- Identify what we know about reducing transport's GHG emissions; and what we do not.
- Identify by when we need to take action and what this action should be.

Given the timescales being considered, the project will take a qualitative and, where possible, a quantitative approach. The project has three Parts, as follows:

[6] Graph based on figures in DG TREN (2008), page 206
[7] European LPG Association (2009) *Autogas in Europe, The Sustainable Alternative: An LPG Industry Roadmap,* AEGPL, Brussels. See http://www.aegpl.eu/content/default.asp?PageID=78&DocID=994
[8] http://ec.europa.eu/commission_barroso/president/pdf/press_20090903_EN.pdf

- Part I ('Review of the available information') has collated the relevant evidence for options to reduce transport's GHG emissions, which was presented in a series of Papers (1 to 5), and is in the process of developing four policy papers (Papers 6 to 9) that outline the evidence for these instruments to stimulate the application and up take of the options.
- Part II ('In depth assessment and creation of framework for policy making') involves bringing the work of Part I together to develop a long-term policy framework for reducing transport's GHG emissions.
- Part III ('Ongoing tasks') covers the stakeholder engagement and the development of additional papers on subjects not covered elsewhere in the project.

As noted under Part III, stakeholder engagement is an important element of the project. The following meetings were held:

- A large stakeholder meeting was held in March 2009 at which the project was introduced to stakeholders.
- A series of stakeholder meetings (or Technical Focus Groups) on the technical and non-technical options for reducing transport's GHG emissions. These were held in July 2009.
- A series of Technical Focus Groups on the policy instruments that could be used to stimulate the application of the options for reducing transport's GHG emissions. These were held in September/October 2009.
- Two additional large stakeholder meetings at which the findings of the project were discussed.

As part of the project a number of papers have been produced, all of which can be found on the project's website, as can all of the presentations from the project's meetings.

## 1.4 Background and purpose of the paper

This paper is one of five "options" papers (Papers 1 to 5) that were developed under the *EU Transport GHG: Routes to 2050* project. The aim of these papers was to review the technical and non-technical options that could contribute to reducing transport's GHG emissions, both up to 2020 and in the period from 2020 to 2050. A series of papers (Papers 1 to 6) on "policy instruments" that could be used to stimulate the application and take up of these options was also developed. For the purpose of the project, we used the following definitions:

- **Options** deliver GHG emissions reductions in transport – these can be technical, operational or modal shift.
- **Policy instruments** may be implemented to promote the application of these options.

The options were reviewed in the following papers:

1. Technical options for fossil fuel based road transport.
2. Alternative energy carriers and powertrains.
3. Technical options for non-road transport modes.
4. Operational options for all modes.
5. Modal split and decoupling.

This paper is the fourth in this series of papers, all of which use evidence from existing studies to assess each of the options. It was presented in draft form to a Technical Focus Group meeting (at which stakeholders were present) in July 2009 after which it has been updated on the basis of the discussion at the meeting and any comments and further evidence received. This revised version of the paper can be found on to the project's website.

## 1.5 Structure of the paper

The paper is structured as follows.

The following chapters address operational measures for each transport mode: road transport is discussed in chapter 2, rail and inland shipping in chapter 3 and aviation and maritime shipping in chapter 4. Each chapter first outlines the operational measures which might be possible, and then provides an assessment of the effect of the measures.

Chapter 5 provides conclusions and issues for further research and discussion.

# 2 Operational options for road transport

## 2.1 Introduction

In road transport, a number of operational measures are available to reduce GHG emissions:

- fuel efficient driving (ecodriving),
- tyre pressure monitoring and
- vehicle downsizing.

These will first be introduced in the following section, a more detailed assessment of the expected short term and long term potential effects is given in section 2.3. Note that operational options related to logistics of road transport are discussed in paper 5.

## 2.2 Overview of measures

### 2.2.1 Fuel efficient driving of light-duty and heavy-duty vehicles

The fuel economy of a given vehicle depends on driving style of its occupant. A significant reduction in fuel (and thus $CO_2$ emission) can therefore be obtained by changing the behaviour of the driver.

Ecodriving includes a number of techniques:

- ensuring that the engine at its most efficient, for instance by early gear changes and fewer hard braking and accelerating,
- applying rules to minimise redundant energy use, ie., not using the air-conditioning if it is not needed, remove unused roof racks and weight and minimise idling
- maintaining the tyre pressure at the specified level.

These changes in behaviour can be influenced by for instance public awareness campaigns, voluntary Eco-driving courses or including fuel efficient driving in the training for the drivers licence. The effects of Eco-driving vary between individual drivers depending on how efficient the driving style was before fuel efficient driving was initiated. It could also, in theory, vary between member states reflecting different, cultural driving styles.

In the EU, the European ecodriving campaign was held between 2006 and 2008 (www.ecodrive.org), in order to increase public awareness. This campaign was supported by Intelligent Energy Europe, and 9 EU countries participated: Austria, Finland, Czech Republic, Belgium, Poland, France, Greece, the UK and Netherlands.

Another important factor is vehicle technology. The current generation of hybrids already automate some of the eco-driving techniques (gear changes, retrieval of brake energy and preventing unnecessary idling), making the rules less efficient. Tyre pressure monitoring (discussed further in the next section) will automatically warn drivers if tyres need to be inflated, or even inflate them automatically. It is also likely that different vehicle technologies (e.g., hybrid, electric, hydrogen) require different efficient driving rules.

### 2.2.2 Tyre pressure monitoring

Maintaining the tyre pressure at the specified level affects vehicle handling, safety, tyre wear and fuel economy. It is often considered to be part of the eco-driving techniques described above, but can also be treated as a separate measure to increase fuel efficiency. Surveys by tyre manufacturers and car owner associations show that a large share of passenger cars and heavy duty vehicles are being driven with underinflated tyres.

Tyre pressure monitoring systems (TPMS) can function as an early warning system and aid the driver or fleet manager in keeping the tyres at the specified pressure, thus saving fuel, reducing tyre wear and improving road safety. More advanced (and expensive) systems can even be set up to inflate the tyre when the pressure drops below a specified level thus eliminating the need for human intervention entirely.

In 2008, a regulation was proposed in the EU to oblige car manufacturers to include TPMS in new car types starting in 2012 (and for all types in 2014). In the US, tyre pressure monitoring is already compulsory in new cars. In addition, the European Commission has recently issued two regulations that are aimed at reducing the rolling resistance of tyres: regulation 661/200 defines maximum levels of the rolling resistance of motor vehicles in the type approval requirements, regulation 2008/348 (to be adopted in 2010) provides for energy efficiency labelling of tyres. that limits the maximum levels of rolling resistance,

### 2.2.3 Vehicle downsizing

The term vehicle downsizing is used here to indicate that consumers buy smaller cars or less powerful engines than they would otherwise do[9]. There are two main aspects of vehicle downsizing that have an impact on $CO_2$ emissions and fuel consumption. First of all, there is the technical aspect. Downsizing of the engine directly reduces the fuel economy. Downsizing of vehicles will typically reduce the weight of the car and possibly air resistance. This results in direct improvements of the fuel efficiency, as fuel consumption increases with vehicle weight and resistance. It also leads to further, indirect improvements of fuel efficiency, as the reduced weight allows the use of smaller engines (with less cylinder content) for the same driving performance, and possibly also smaller tyres. This will further improve fuel efficiency.

This technical downsizing overlaps to a certain extend with hybridisation. Hybrid cars can generally make do with a far smaller engine that non-hybrids of the same size while maintaining a comparable level of performance – due to the battery-electric power that is installed, not because of size of performance reductions.

The second aspect is to do with the cultural or societal change associated with downsizing. This includes changing consumer behaviour towards buying smaller, less luxurious cars or cars with less power and accessories. Here, significant change is required reflecting that he trend during the last 30 years has been in the other direction. Part of this weight increase, [Ricardo, 2007] estimates about 60% in the previous decade, has been due to vehicle safety improvements, in many cases because of more stringent safety standards set by the EU). However, the average car has also become a lot larger and heavier due to consumer preferences for larger and more luxurious cars, enabled by increasing GDP.

In can be expected that fuel efficiency gains achieved with vehicle downsizing can also have a positive effect on hybrid and electric cars, as smaller sized batteries will need to be used – a reduction in weight and thus fuel consumption.

## 2.3 Assessment of measures

### 2.3.1 Fuel efficient driving

The reduction in fuel consumption that can be achieved by following an eco-driving course, in the current vehicle fleet, ranges from 5 to 25 % directly after the course (TNO, 2006)(UKERC, 2009). The magnitude of the short term effect is strongly dependent on the original driving style of the driver - the more uneconomic the behaviour was to start with, the greater the effect. On average the impact is about 10 % (TNO 2006, ECOdriven 2008). The fuel savings typically outweigh the costs, making this a very cost effective measure.

For heavy duty vehicles the effects a year or more after the training are estimated at 5% (TNO 2006) to 7% (ECN 2007).

[9] Technical options to reduce the $CO_2$ emissions of cars without reducing their size or performance are discussed in paper 1.

The results, however, slowly diminish over time as the drivers revert to their original driving style. For passenger cars drivers, the effects a year or more after the training course are estimated to be in the range of 10% (UKERC, 2009)(ITF, 2008). However, there is a lack of ex-post evidence on the longevity of the effects of eco-driving programmes, as literature provides estimates ranging from 2 to 40 years. Main barriers to harvesting the full potential of this measures are securing driver participation, and ensuring that eco-driving habits are sustained over time (UKERC, 2009). The first barrier is partly tackled by the EU requirement that eco-driving is taught to novice drivers. In-car equipment such as gear shift indicators, cruise controls and on-board computers giving feedback on fuel consumption raise awareness, and help drivers to maintain a fuel efficient driving style (ITF, 2008).

About half of the effect of eco-driving is due to maintaining the correct tyre pressure – see the next paragraph. Using assisting technology (such as a gear change indicator) can add a further 1.5% to the effect.

Driver training is not expensive (in the order of €100 per training) but training driving instructors to teach new drivers fuel efficient behaviour is even more cost efficient. Driving instructors can be taught to teach eco-driving in a day (TNO 2006, ECOdriven 2008) and will then pass on their knowledge to thousands of new drivers.

Besides fuel consumption and CO2 emission benefits, empirical evidences also suggests that ecodriving can increase safety, significantly lowering accident rates (Ecodriven, 2008). The emphasis on a calmer driving style, with greater anticipation on the road ahead and the advice to avoid excessive speeds leads to a saver driving style. Financial savings due to reduced servicing, maintenance and repair costs that result from reduced wear and tear on components such as brakes, tyres and clutch are also expected (Ecodriven, 2008). Studies have shown that ecodriving does not generally increase journey times, as may be expected from a calmer driving style (Ecodriven, 2008)

Drivers of heavy duty vehicles are professionals and more stringent requirements on their competence are included in EU legislation. EU directive EU 2003/59 obliges Member States to incorporate driver training into their legislation. The driver training is to assure professional competence and is build up out of two parts. An initial driver training (in parallel with the drivers licence) and a compulsory periodic training course (every five years) both with emphasis on "road safety and rationalisation of fuel consumption". The legislation on the initial qualification (and periodic courses) is to be implemented on 10 September 2009 drivers of road freight vehicles, and on 10 September 2008 for drivers of vehicles for passenger transportation.

As vehicle technology progresses more and more aspects of fuel economic driving will be automated. Changes in technology will also require changes in eco-driving techniques, perhaps even different courses for different subtypes of vehicles. A number of the rules will apply regardless of technology (reducing weight by limiting unused luggage, improving aerodynamics by removing unused roof racks, not using the air-conditioning). Maintaining the correct tyre pressure is an important feature of eco-driving. With the oncoming introduction of tyre pressure monitoring systems (see the next paragraph) this will no longer be an issue. In any case, as the effect of training diminishes over time, regular (periodic) courses seem to be necessary to reach the full potential of fuel efficient driving techniques.

The overall long term reduction potential is hard to estimate especially because the distribution of technologies in the vehicle fleet by 2050 is unknown. Vehicle technology is expected to automate more and more of the eco-driving techniques, reducing the potential benefits of these operational measures. The current generation of hybrids already automate gear changes, retrieval of brake energy and preventing unnecessary idling, and tyre pressure monitoring that will automatically warn drivers if tyres need to be inflated (or inflate them automatically) will become compulsory in the future, as will be discussed in the next section. It is also likely that different vehicle technologies require different efficient driving rules. For instance, a hybrid drive might benefit from driving methods that are based on the optimal utilisation of the electric buffer, and electric cars might require other techniques than cars running on hydrogen-fuel cells or hybrids. Depending on the distribution of technologies in the fleet a single Eco-driving training might no longer have the desired effect.

### 2.3.2 Tyre pressure monitoring

The (air) pressure inside a tyre is one of the large variables determining the rolling resistance of the vehicle. If the pressure is 0.5 bar lower than specified for that type of tyre, in a passenger car the rolling resistance increases by about 10 % and fuel consumption increases with about 2.5% (TNO, 2006).

Installing a TPMS in a passenger car will make the driver aware of under inflation and together with the common availability of (free) pressurised air at petrol stations can bring about a significant reduction in the number of cars with under inflated tyres. On average maintaining the correct pressure is thought to be able to reduce fuel consumption and $CO_2$ emission by about 2.5 % (TNO, 2006). In addition, this measure has the potential to significantly reduce road accidents and reduce tyre wear and thus replacement cost (TNO, 2006).

The proposed EU regulation on TPMS will effectively bring about a high degree of penetration of TPMS by 2020. By 2050 all cars will have TPMS installed and under inflation will be rare. We thus assume that the GHG reduction potential of tyre pressure monitoring will be negligible by that time.

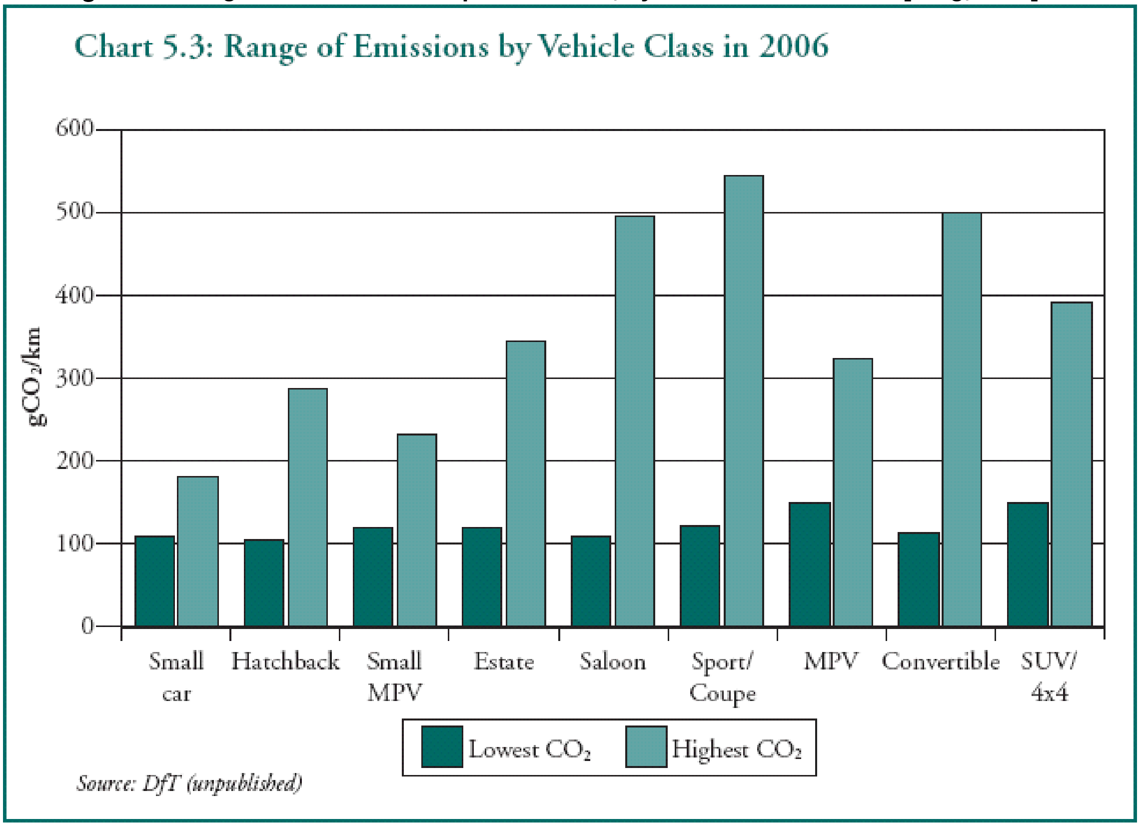
### 2.3.3 Vehicle downsizing

Vehicle downsizing is an option that will have most potential for passenger cars and some light commercial vehicles. Reducing the size of heavy duty vehicles (HDV) typically increases the fuel consumption per tonne kilometre, as larger vehicles can transport goods more efficiently than smaller vehicles (provided the load factor is high). The choice for a specific size of a truck is strongly related to the overall logistics, which is not discussed here but in paper 5.

A car's $CO_2$ emissions depend strongly on the type and size of vehicle driven. Currently, at the extremes, a powerful sports car or a Sports Utility Vehicle can emit 3 or 4 times as much $CO_2$ per kilometre travelled (and therefore costs 3 or 4 times as much in fuel) as an efficient small car [King, 2007]. Emissions vary according to vehicle class, but there can also be substantial variance between different vehicles within the same class.

This is illustrated in the next figure. Part of this range is due to technological differences (e.g., gasoline versus diesel engines, hybrid drives, engine technology, etc.), but another part is due to more 'soft' consumer choices as engine size, auxiliaries, vehicle size and weight. For example, moving down an engine size typically sees a reduction of around 5 % in fuel consumption and $CO_2$ emissions [King, 2007]. Note that in practice, the market share of the upper range $CO_2$ values in the segments shown here might be relatively small.

**Figure 5: Range of $CO_2$ emissions per kilometre, by vehicle class in 2006 [King, 2007]**




The analysis in [Ricardo, 2007] concludes that, for a typical Lower Medium segment vehicle, for every increase of 110 kg, there is a fuel consumption penalty of 4-5% for a conventional vehicle and 2-3% for a hybrid vehicle, over the NEDC (New European Drive Cycle). The impact on a hybrid vehicle is lower because the regenerative braking recovers some of the extra energy required. These results were found to be in line with that of other research reports.

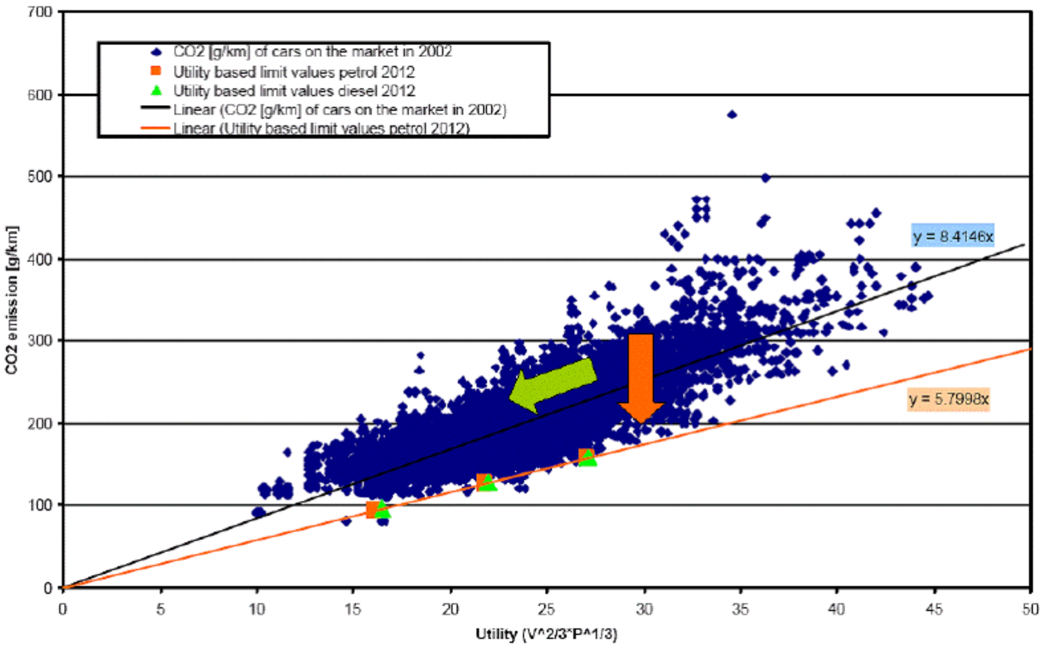
The total technical potential of downsizing is estimated in at about 5% by 2012 (TNO, 2006), since only a minor level of engine downsizing could be achieved in such a short time. Strong downsizing can have a more profound effect of 12% or 7% reduction for petrol and diesel vehicles respectively. This potential can be reached by 2050 but is also likely to be included in other options described elsewhere (see paper 1, where the technical options for $CO_2$ reduction are discussed). Large scale hybridisation also overlaps with this potential. Note that quite a number of current vehicle safety measures also contribute to vehicle weight, and that one may argue that downsizing might be detrimental to safety. (UKERC, 2009) concludes that the (scarce) literature on this suggests if a uniform downsizing across all vehicles took place, there would be a slight reduction in the total number of casualties in car accidents. However, if a non-uniform downsizing occurs, further research would be needed to assess the effect on accident casualties. Downsizing may also impact driving comfort, due to the smaller car size, reduced engine power etc.

Influencing consumers to buy more fuel efficient cars can be achieved in two ways. First, consumers can be encouraged to buy the most efficient car in a given class. This stimulates the sales of technologically downsized cars but also cars with other (technical) measures to reduce fuel consumption. There is a myriad of policy options to stimulate the sales of fuel economic cars (tax exemptions and differentiation, subsidies, energy labelling etc). The overall potential of buying the most efficient car within a class is estimated at 10-20% (CE, 2007).

Second, a much larger theoretical potential can be achieved by stimulating consumers to buy a smaller class of car. This is however much more difficult to effectuate. The vehicle choice is rarely a purely rational one and factors as comfort, performance and status are important to many car buyers. In addition, consumers typically buy a car that caters for their largest 'requirement', for example one that is sufficiently large and powerful for their annual holiday. Current policies generally stimulate the sale of small cars already (owners of smaller cars generally pay less in taxes), and fuel costs, car insurance, maintenance etc. are often significantly lower. Still, the trend is towards heavier cars with more power (EMBARQ). Possible solutions to remove this barrier would be if consumers operate a smaller car for day to day use, and hire a larger car when needed, e.g., via specialised rental companies, car dealers or car clubs.

An indication of these emission reduction effects can be seen in Figure 6 (IEEP, 2005). In this graph, the $CO_2$-emissions of all the passenger cars that were sold in 2002 in the EU are indicated, against a hypothetical measure of the vehicles utility: $V^{2/3}$ x $P^{1/3}$, where V = volume and P = engine power. Car buyers can reduce their fuel consumption by buying smaller, lighter end less powerful vehicles (the green arrow in the graph), or by choosing a fuel efficient vehicle within a given vehicle class (indicated by the orange arrow)

**Figure 6: $CO_2$-emissions of new passenger cars in Europe, in 2020 (IEEP, 2005).**




*Source: Derived from Polk Marketing data*

Price based policies would have to be very large indeed to bring about the full theoretical potential. A prudent estimate of the potential is given in (CE, 2007). There a maximum reduction of 10-20% is assumed.

It is difficult to predict the long term potential of this option, but we expect that it may be much smaller than in the current situation. First of all, if regenerative braking and hybridization becomes standard technology in future vehicles, the effect of weight reduction and the potential for smaller engine size is reduced. Second, if EU regulation continues to reduce the average $CO_2$ emissions of cars, car makers may be forced to use only the most fuel efficient engine technologies in their cars. This might reduce the diversity of the car park and thus limit the range of $CO_2$-emissions of cars that consumers may choose from. However, this depends on the developments in engine technology in the coming decades, which is currently difficult to predict.

# 3 Operational options for rail and inland shipping

## 3.1 Introduction

This chapter provides an overview and assessment of the operational measures that can reduce $CO_2$ emissions of rail and inland shipping. A number of options could be identified for these modes, but evidence on potential effects and costs are very limited.

## 3.2 Overview of measures

### 3.2.1 Inland shipping

A number of operational measures can contribute to a reduction of GHG emissions in inland shipping: improved maintenance, speed optimisation and just in time routing. However, very few studies are available on this topic.

**Improved maintenance**
Improved maintenance of inland ships may result in some GHG reduction. Here there are three main technical components:

1. The resistance of the ships hull may be reduced through the use of high quality coatings for the hull.
2. The efficiency of the ships propeller may be improved and
3. The operation of the ships engine will be enhanced.

No systematic studies about the subject of improved maintenance and GHG reduction in inland shipping are known.

**Speed optimisation**
Through the use of speed reduction significant amounts of fuel can be saved. Because energy required for propulsion of inlands ships is (mathematically) proportional to speed by a power between 2 and 3, therefore a 10 percent reduction in speed can save about 20 percent fuel. In practice, while decreasing the travelling speed of inland ships can have a significant effect on the fuel consumption, it also adds to the trip duration. The economical impact of a ship’s speed thus ties in with a variety of complex cost components, such as the fuel costs, a ship’s depreciation, wages of employees and the number of possible transports in a given time. Options to improve the fuel economy will only be employed if they remain cost effective in view of all the other cost components. The likelihood of an optimization with respect to fuel efficiency increases for increasing fuel costs, either direct or as a result of emission trading. Computer assisted trip planning and speed management (discussed in paper 5) can be used to facilitate the cost assessment including a GHG emission component.

**Just in time routing**
Just in time routing has to be considered as a form of speed optimisation within the constraint of the required delivery time of the cargo (see speed optimisation and computer assisted trip planning). Lower travelling speeds are acceptable when the recipient of the cargo does not immediately need to use the shipment. For just in time routing to function, therefore, the logistic requirements of the recipient need to be integrated within the logistic system of the ship-owner. Given the strong speed dependency of fuel consumption the extra time that may become available in principle offers a great opportunity for extra reduction of GHG-emissions. However, because slow transport conflicts with ‘just in time production’ and since the latter has the most impact on the costs (because of the relatively low contribution of transport to overall production costs), it is likely that most recipients will continue to demand transport that is as speedy as possible.

### 3.2.2 Rail

Even the most cursory literature review reveals numerous options for energy savings in the rail sector. This section will focus on operational opportunities to reduce GHG rather technical measures, which are covered in Paper 3. In a recent (2008) submission to the UK's Committee on Climate Change the UK rail sector estimated short to medium term measures could reduce carbon emissions up to 14% below the "do nothing" scenario by 2022 (CCC, 2008).

In its 2007 research the Rail Safety and Standard Board (2007) [10] identified a suite of significant energy saving (and hence GHG saving) opportunities for Great Britain (GB). Twelve of these options are summarised in the remainder of this section. The first nine options consider the potential savings from traction energy use, where the final three opportunities highlight the savings that could be achieved from non-traction energy use.

**Run shorter trains when extra capacity not required**
In GB the average load factor ranges from 20% up to a maximum of 50%. There is significant scope for running shorter trains off-peak. Some trains may also benefit from 'splitting' where load at one end of the route is higher than at the other end. Besides reduced energy costs benefits also include reduced train maintenance costs and reduced track wear.

Splitting multiple unit trains off peak, however, also involves a range of additional costs. The coupling and uncoupling procedures require additional staff to oversee the activities and the timetables need to be adjusted to allow time for these additional activities. In addition, depending on the location of the stabling, additional empty coaching stock miles may be accrued. Furthermore, additional train crews may be required. Finally, additional stabling space (i.e. space to store rail vehicles that aren't in use) will be required, which could have considerable cost implications.

**Energy efficient driving and train regulation**
Inefficiencies in the rail network can originate from a number of sources: poor train regulation and driver techniques, running ahead of time, unnecessary speed checks and sub optimal timetabling. There are a number of improvements that can be made without impacting journey times:

- **Coasting boards, route cards.** Coasting boards along the route denote the point at which the driver may shut off power. It has to be noted that these are route and train specific and are more practical on routes that do not have mixed fleets or inconsistent stopping patterns. A (more short-term oriented) alternative would be to use improved route cards, with the intention to provide accurate information enabling the driver to decide whether power could be reduced or more power is required. Route cards show a break down of departure times at the origin, destination, other station stops intermediate reporting points, such as junctions and passing points. This provides the driver with accurate information at a glance.

- **Improved driver training & driver advice systems.** There is scope to improve driver training to equip drivers with specific energy efficient driving techniques and an increased awareness of driving in an energy efficient manner.

  There are new technologies being developed, which can constantly provide the train driver with information related to the current driving technique. This can be taken a step further and combined with a knowledge of the timetable requirements to advise the driver on where power can be reduced without impacting on the journey time.

- **Changes to Speed Restrictions.** If speed restrictions are more cautious than necessary or their removal is delayed then this has an energy penalty. This is because trains are forced to brake to comply with speed restrictions and then

[10] For diesel traction, potential financial saving is based on a fuel cost figure of €0.37 per litre. For electric traction, a figure of €66 per MWh was used to account for the current cost of electricity from the electricity generating companies.

accelerate to return to their favoured speed. Acceleration uses far more energy than cruising at a given speed.

In Great Britain it is estimated that a restriction from 132km/h to 72km/h on a theoretical line, which operates High Speed Trains (7 trailers), 2 per hour for 18 hours per day will use an additional 3000 litres of diesel (£1000 and 7,900Kg of CO2) for every week that the restriction is in place.

- **Timetabling**. Train paths need to be integrated in a way that allows energy efficient driving strategies to be implemented, whilst also juggling the competing needs of differing service types and meeting the customer's journey time aspirations.

  The Swiss SBB is currently focusing on making better use of reserves in train scheduling to add greater robustness to its integrated national timetable. The major role is taken by real-time management of train services to maintain connections and more detailed passenger information provision. To improve operational performance while satisfying customer expectations, SBB has started to re-engineer its operational process through a 'Co-Production' concept. This approach allows intelligent reserve allocation by combining Japanese-style process control with real-time scheduling (Railway Gazette, 2008a).

**Reduction in empty stock movements**

Rationalisation of infrastructure has meant that many historical stabling and maintenance locations no longer exist. This has forced train operators to run an increased number of empty miles in order to get units to and from depots or stabling points. It is anticipated that train operators will seek to minimise empty cost stock moves, although it acknowledged that there will not be an easy solution to this issue. However, further consideration could be given to optimising depot locations and routing of diagrams.

**Intelligent engine control**

Given that some engines do not efficiently at low loads there is potential to selectively shut down engines on multi-engine trains whilst the train is in operation. Engines could be shut down and re-started according to train utilisation, i.e. shut downs could occur during long periods of coasting, down hill travel, standing at signals or in stations. The whole process could be controlled by intelligent software, programmed to identify periods of low demand and manage the supply of power according to the demand by starting and shutting down engines.

Examples of this intelligent software are already in service abroad. In Australia these systems provide drivers with advice on the optimum speed profile to reduce energy / fuel consumption while maintaining the train's scheduled timetable. The systems advise where and when to throttle and brake for a particular route, taking advantage of the known terrain and local characteristics of the route, as well as the mass of the train to give the optimal train handling.

Siemens Mobility and TransPennine Express initiated the Eco-Mode programme to maximise the energy efficiency of the Class 185 fleet in the UK in July 2007. Part of the programme was to introduce the 'eco-cruise' concept, a driver-selectable facility that maintains the speed of the train automatically on two engines, allowing the third to be shut down to save on fuel and lifecycle costs. The driver is able to select the function as soon as the desired cruise speed is reached (Railway Gazette, 2008b).

**Better recording of diesel engine fuel / power consumed**

A better awareness of how much energy individual trains are using will help focus attention on to areas where improvement can be made. Monitoring vehicle consumption will also allow any rogue vehicles to be identified where for one reason or another, energy consumption is higher than expected.

While there is no robust/accurate method for measuring energy usage on electric traction most modern traction systems can provide some figures from the traction package.
Electricity meters on electric trains are an option; however the cost and time to fit high integrity equipment suitable for electricity charging are significant. For diesel trains accurate records of how much diesel have been put in each tank would provide useful information on a per vehicle basis. Some operators do record fuel by unit number, however, the integrity of these records is generally considered to be questionable.

**Reduced traction maximum demand (25kV & 750V)**
Both traction demand and the total load on the National Grid system vary during the day. Currently the peak load from the Network Rail system in the UK occurs at a similar time to the peak overall load, which increases current in the National Grid and as a result increases losses. One way to meet the costs arising from peak load times is to introduce operational measures, such as extra coasting and lower top speeds. This would reduce the energy losses, but the cost of increasing journey times has to be weighed against the predicted savings. Though calculations show that any reduction in peak demand has only a relatively small impact on transmission losses it is likely to reduce the Network Rail electricity bill substantially. This is because the electricity bill includes a £/MW maximum power component, which reflects the extra generation and transmission plant in which the electricity companies must invest to meet the marginal demand.

**Disconnecting electric vehicles from supply when stabled**
In GB figures indicate that for some passenger operators as much as 15% of the total energy drawn from the substations occurs when electric trains are stabled and no service is running. Significant savings could be made by:

- Getting the incoming driver to drop the pantograph on stabled units or
- Employing someone on the depot at nights to manually manage the auxiliaries on stabled trains so that trains only remain live when they need to be.
- Load shedding. The simplest of load-shed systems are activated by a load-shed relay, which feeds the non-essential loads. This relay is de-energised once auxiliary voltage drops below a certain level. A simple modification could be implemented whereby the relay is manually de-energised, i.e. via an override switch. The installation cost of fleet fitment would not be insignificant however, as every vehicle would require modification.

**Reducing diesel engine idling**
Excessive idling may result from engines left running:

- At stations to supply auxiliaries
- If there is a concern that if engines are shut down, there is a risk that they may not be reliably restarted when required;
- Overnight to protect equipment against frost damage and to avoid coolant leakage as the pipes and joints contract;
- Overnight to supply ‘hotel services’ and maintain train heat;
- During refuelling, servicing and running maintenance; and

Some options to consider which will reduce idling time are:

- Intelligent software can identify when engine restarts are necessary and the duration of running. One example for an intelligent software reducing diesel engine idling was developed by Siemens Mobility and TransPennine Express through its Eco-Mode programme. Train services using it now arrive at terminal stations with only two engines running, and one of these is automatically shut down one minute after arrival. These are then re-started just prior to departure (Railway Gazette, 2008c).
- Re-scheduling of diagrams (i.e. timetables) can avoid long layovers, e.g. use slower journey times to arrive ready for the next scheduled departure time.
- When locomotives or units are brought onto the fuel point they could be shut down immediately after any running checks required for maintenance are completed - all subsequent movements could be made by a pilot or shunting locomotive.

- Shore supplies could provide all overnight train supply and battery charging. Similar supplies could be provided at terminal stations to avoid the need for engines idling for train supply.
- Large engine coolant and oil systems may be maintained warm and at near operational temperatures by using separate systems using intelligent software.
- Modify fluid systems to reduce the likelihood of leakage when cool, so that engines can be shut down with confidence

**Energy Monitoring**

Accurate metering provides accurate data on energy usage and can assist the user in identifying energy wasted. A widespread use of the energy meters could result in significant cost savings to the rail sector:

- Depots and facilities can use Automatic Meter Reading, which automatically collects data half-hourly from the electricity company for billing. Rather than relying on estimates this data would then be based on actual readings, which can then be used to develop profiles of energy use at depots and stations and hence identify opportunities for savings.
- Sub-metering could also be a useful tool in the rail sector where more than one party operates from a single site. Sub-metering allows the electricity used by certain pieces of equipment or parts of a building to be measured independently of the total electricity use. In turn this will allow the operator of the building to bill each party separately, which gives all parties the incentive to save energy individually and reduces the potential for so-called ‘free-riding’.

**Control and Command Signalling.**

The aim of the European Train Control System (ETCS) is to minimize track side infrastructure requirements (such as track circuits and cabling) by relying on the increasing ability of trains to manage themselves will lead to the greater use of cab-signalling. Eventually each train is supposed to provide its own localisation data back to a small number of control centres which will manage train regulation to minimise delay and reduce energy consumption.

# 3.3 Assessment of measures

## 3.3.1 Inland shipping

**Improved maintenance**
Improved maintenance of the hull, propeller and engine of inland ships may result in some GHG-reduction, but very few studies have quantified this.
The resistance of ships hull may be diminished by good quality painting, de Grave [3] mentions 3% in a single case. Regarding efficiency improvements of the ships propeller and the ships engine, no systematic studies about this subject in inland shipping are known.

Depending on the status of the individual parts of the individual ship about 3 - 5 percent for each component may be feasible. By the lack of systematic studies no indication can be given for the total GHG saving potential for the current or future inland shipping fleet.

**Speed optimisation**
In theory, a speed reduction of 10 percent can save about 20 percent fuel. Whether this speed reduction is feasible for an operator will depend on the balance of fuel cost saving and other complex cost components such as ships depreciation, wages of employees and time to win for other transports. Automating this process through “Computer assisted trip planning and speed management” (paper 5) can help optimize the speed for a given trip. More comprehensive speed optimisation could be evoked when GHG-emissions of shipping were integrated part of the economics of shipping for instance by the introduction emission trading.

The ultimate potential of speed optimization in terms of GHG-reduction is currently unknown, and will strongly be dependant on fuel pricing or the possible future introduction of CO2-emission trading.

**Just in time routing**
The benefits of speed optimization and possibly computer assisted trip planning can be further enhanced by using just in time routing. When the real time constraint of the ultimate users of freight to be delivered can be integrated within the logistic system, extra time may become available for shipment or travelling, offering an opportunity for extra reduction of GHG-emissions. However, the potential will be limited in practice, as this extra time very often will be consumed by the upstream producers: Just in time production.

The possibilities in the end will be dependant on the ratio of upstream production and sales prices against transport prices. For maritime transport a reduction potential between 1 and 5 percent is suggested (Henningsen, 2000).

## 3.3.2 Rail

The following table 1 lists the potential energy savings from the options resulting from traction energy use described in section 3.2.2 above, in Great Britain (Rail Safety and Standard Board (2007)). Where possible these results show quantified estimations for electric energy consumption, potential savings in diesel fuel, energy savings and the timescales for achieving these savings.

| Savings Option | Electric (MWh) | Diesel Fuel (litres) | Energy Saving (in £) | Energy Saving (in kg CO2) | Timescale | Cost/Benefit |
|---|---|---|---|---|---|---|
| **1. Run shorter trains when extra capacity not required** | 280,000 | N/A | £16.8m | 127.6m | Short | £17k / unit / yr.<br>Reduced track damage, reduced maintenance cost<br>Typical costs per unit per year:<br>Additional train crew to stable trains £12,250 / unit / yr.<br>Increased coupler maintenance £240 / unit / yr |
| **3. Energy efficient driving and train regulation *** | 141,000 | 33.5m | £19.9m | 152.3m | Short to medium | Typical benefits for a fleet of 40 trains:<br>-£270k per year.<br>Typical costs for a fleet of 40 trains:<br>-Route cards, negligible.<br>-Simulator modification £10k.<br>-Train drivers on simulators £105k to train 150 drivers.<br>-Fit driver advice system £900k<br>Payback period in 3 to 4 years |
| **4. Reduction in empty stock movements** | 9,000 | 2.2m | £1.3m | 10.2m | Short | Cost will depend on train operating company logistics, maintenance and cleaning. Also linked to franchise commitments and penalties. |
| **5. Shutting down some engines on distributed power trains (intelligent engine control)** | N/A | 15.4m | £5.2m | 40.4m | Medium term to Long | Typical benefits for a fleet of 40 trains: (£1.5m/yr)<br>-£2.8m for a fleet of 40 diesel trains.<br>Typical costs for a fleet of 40 trains: (£4.2m)<br>-One off development of systems £200k.<br>-Modify each train £100k.<br>Payback of about 3 years |

* The savings calculated are based on an overall 7.5% reduction in traction energy use while it is estimated that about 5% of this reduction can be achieved through efficient driving techniques and around 2.5% through improved train regulation.

| Savings Option | Electric (MWh) | Diesel Fuel (litres) | Energy Saving (in £) | Energy Saving (in kg CO2) | Timescale | Cost/Benefit |
|---|---|---|---|---|---|---|
| **6. Better recording of diesel engine fuel / power consumed** | | | | | Short to Medium | Low to Medium (low for diesels, record what goes in the tank). Higher to fit electric meters to trains. Fit electric watt meters to 10% of each fleet to monitor performance at a cost of £10k per train fitted. |
| **7. Reduced traction maximum demand (25kV & 750V)** | 1,000 | N/A | £0.1m | 0.4m | | It is questionable whether this is a realistic option without fundamental changes to the passenger service provided. |
| **8. Disconnect electric vehicles from supply when stabled** | 321,000 | N/A | £19.3m | 146.3m | Short to Medium | Typical benefits for a fleet of 40 trains:<br>-£283k/yr based on 11% saving on 40 train fleet.<br>Typical costs for a fleet of 40 trains:<br>-Annual cost of £70k per year to employ additional staff, or<br>-Modify trains to provide intelligent control £630k. |
| **9. Reduced diesel engine idling** | N/A | 36.1m | £12.3m | 95.1m | Short | Typical benefits for a fleet of 40 trains:<br>-£2.3/yr based on 40 x 5 car diesel trains.<br>Typical costs for a fleet of 40 trains:<br>-Improve procedures for shutdown, negligible cost.<br>-Some train modifications to improve cold weather performance £10k x 40 x 5 = £2m.<br>-Provision of hybrid shunting locomotive = £2m,<br>-Annual cost of £70k per year to employ additional staff, or<br>-Modify trains to provide intelligent control £630k. |

**Energy Monitoring**

Accurate metering provides accurate data on energy usage and can assist the user in identifying energy wasted. A widespread use of the energy meters could result in significant cost savings to the rail sector: However, there is no data the effects of this measure.

**Control and Command Signalling.**

There are currently no estimates available of costs or effects of this measure.

# Operational options for aviation and maritime shipping

## 3.4 Introduction

The following section considers operational options for aviation and maritime shipping. Key overarching themes covered include improvements in management practices, training of crew, increased maintenance and the use of electricity when at land.

## 3.5 Overview of measures

### 3.5.1 Aviation

A number of operational options are available for aviation including: training of crew; air traffic management; aircraft performance; and airport operations. These are discussed in turn below.

**Training of crew**
Training crew in environmental issues and how their actions can help reduce the level of emissions will have a positive impact on an airline's performance. A well-informed and environmentally aware crew will foster a long-term culture of sustainability and enable the efficient use of aircraft equipment and systems. This measure underpins a number of the operational options identified below.

**Air Traffic Management**
There are a number of air traffic management approaches which can be used. These include:

*Continuous Descent Approach*
The Continuous Descent Approach (CDA) is used when landing the aircraft. Here the aircraft stays higher for longer, than the conventional approach, descending continuously from around 7000 feet it therefore avoids any level segments of flight prior to intercepting the glide path. CDA requires significantly less engine thrust than prolonged level flight and this can result in significant emission savings.

*Open airspace*
National airspace is generally divided in order to separate civil aircraft from military aircraft. This fragments the use of airspace which can result in non-optimised routing and air traffic control issues.

Open airspace encourages the flexible use of military and civil airspace potentially allowing for more direct and therefore more fuel efficient flight paths. When the military need to use airspace, they alert the civil air traffic controller who temporarily sets aside the required area. When the military work is complete, the airspace is returned to civil use, giving both civil and military operators access to more airspace when the critically need it. This enables optimum routing and therefore reduces fuel burn and emissions.

*Reduced vertical distance between airplanes*
The Reduced Vertical Separation Minimum (RVSM) reduces the vertical separation of aircraft from the current 2000 to 1000 feet (at altitudes between 29,000 and 41,000 feet), thus providing access to more efficient cruising levels when responding to changing operating conditions (ICAO, 2005). This leads to reductions in emissions and fuel use. It also increases the number of aircraft that can safely fly in a particular volume of airspace.

**Aircraft performance**
*Aircraft capacity*
The load factor of an aircraft has an impact on emissions per passenger km. The configuration of an aircraft (for example the number of seats, distribution between seating and cargo capacity) also has an important influence on fuel burned per passenger km.

The aircraft capacity differs between airlines and is based on market considerations. For example Japan Airlines[11] configures its Boeing 747-400 in different ways. The 747-400 in long-range full passenger configuration has 262 seats, whereas the 747-400D used in high-density local Asian service has 568 seats, even when used in similar lengths of flights.

*Reduced weight*
Aircraft carriers can reduce weight through controlling the intake of water, the weight of equipment (including food trolleys), and, increasingly, luggage.

However, the most effective way of reducing the aircraft's weight is to reduce the amount of fuel carried. A key way of reducing fuel carried is to minimise the opportunities for tankering. Tankering is when aircrafts carry fuel for more one journey and is often carried out to avoid paying a higher price for refueling in a different country. Steps to avoid this include agreements between airlines and airport operators whereby the former commits to refueling at given airport provided discounts on the cost of fuel are provided.

Aircraft also carry 'contingency fuel', if this can be reduced (provided appropriate safeguards are in place) weight and emissions will be reduced.

More fuel efficient flying could also help reduce the amount of fuel which needs to be carried.

*Improved maintenance*
Aircraft which are well maintained are more fuel efficient and therefore have less detrimental impact on the environment. The maintenance of an aircraft to the highest possible standard will ensure that it is running at its optimum fuel efficiency providing both carbon and cost savings.

**Airport Operations**

*Electricity at the gate*
Electricity and air conditioning service can be provided for aircrafts at airport gates. This can permit a reduction in the use of aircraft auxiliary power units (FAA, 1997). This can, particularly if renewable electricity is used, result in significant emission reductions.

### 3.5.2 Maritime shipping

**Voyage optimisation**

Voyage optimisation includes the selection of optimal routes with respect to weather, currents and selection of speed with respect to tides, queues, and laycan windows. Several types of weather routing systems, technical support systems, monitoring and automation systems can be used to help achieve this.

[11] Intergovernmental Panel on Climate Change Aviation and the Global Atmosphere

Traffic management and control systems; including queue prioritisation on criteria other than 'first in' can play a role in reducing emissions. While reducing time in port through more efficient cargohandling, berthing and mooring can also help.

Ballast (water) helps stabilise the ship in the sea. The reduction of unnecessary ballast can reduce GHG emissions. However, determining optimal ballast can be a difficult consideration because it also effects the comfort and the safety of the crew. In addition trim optimisation – finding and operating at the correct trim can also reduce emissions.

**Energy management on the ship**

Energy is used (and associated emissions produced) in the day to day running of the ship. Measures to improve management include: avoidance of unnecessary consumption of energy; avoidance of parallel operation of electrical generators; optimisation of steam plant (tankers); optimisation of the fuel clarifier/separator; optimized HVAC operation on board; cleaning the economiser and other heat exchangers; and detection and repair of leaking steam and compressed-air systems.

Key means of facilitating these measures are the training and motivation of the sjips crew. The impact of improvements in terms of energy consumption should be monitored and here it is important to have a benchmark for energy consumption figures. Automation of certain processes for example automatic temperature control and automatic lights can also help save energy.

**Fleet management – optimisation of fleet**

Optimisation of operational performance is dependent on utilising ships that are suitable for the specific jobs they are required to undertake. For cargo ships, efficiency could be increased by using larger ships to carry larger amounts of cargo. This is likely to reduce energy consumption per tonne-km, but the total impact on overall door-to-door logistics performance may be negative unless this move is supported by the use of smaller ships that can assist in efficiently distributing cargo.

There also needs to be sufficient cargo available, larger ships are not efficient if not enough cargo is available.

*Improved maintenance for shipping*

Improved maintenance for shipping includes more frequent cleaning of hulls and propellers; the use of more efficient coatings for hulls (including future technologies such as nanotechnologies); and improved engine maintenance.

*Reductions in speed*

Fuel consumption, and thus the greenhouse gas emissions will mainly be a function of the ship speed. The fuel consumption per distance sailed will approximately increase proportionally with (at least) the square of the speed (Marintek, 2000). Whether this reduction in speed is a viable option depends on a number of issues. If the optimal speed of the ship is lower than the maximum speed of the ship, the ship owner may select a "Just in time" or "Slow Steaming" strategy. In this case the ship will be operated at a reduced speed. From an economical point of view, slow steaming is normally of interest only if the number of ships, and then transport capacity, is high in relation to a given market.

It should be noted that if more ships are required to 'offset' the reduction in speed the GHG reduction benefit would reduce.

*Electricity in ports*

Electricity can be provided to ships at berths in ports from the national grid instead of ships producing electricity using their own engines. Depending whether the source of emissions is renewable electricity this can reduce or even eliminate carbon emissions from ships' engines while at berths in port.

## 3.6 Assessment of measures

### 3.6.1 Aviation

**Training of crew**
Ensuring that flight crew are fully trained in fuel efficient procedures will ensure the long-term sustainability of an airline.

The costs of training crew will vary greatly on how it is administered and on what scale. However, investing in staff awareness of environmental issues has the potential to reduce fuel consumption and therefore reduce costs.

As well as contributing to more fuel efficient performance, a more environmentally competent crew could boast the green credentials of an airline, making them more attractive to potential passengers and investors.

The main barriers to the training of crew are funding and ensuring that the training is relevant, robust and reflects the current best practice. If new technologies or policy instruments are introduced which change how crew should act, this would require additional training at additional cost to the airline. A clear and accessible set of flexible resources would need to be developed to ensure that any best-practice changes could be easily incorporated into the training of crew.

Crew awareness of other greenhouse gas reduction options is essential to ensure that other operational options and technologies are used effectively. This could include training in more fuel efficient flying for pilots, improved maintenance methods for ground support staff and how to use electricity at the gate.

**Air Traffic management**
The Intergovernmental Panel on Climate Change (IPCC) estimate that Air Traffic Management could reduce fuel burn and emissions by between 6 to 12%. While the ACARE targets for ATM are a 5 to 10% reduction by 2050.

Contributing measures are discussed below.

*Continuous Descent Approach*
CDA, because less engine power is required, can result in significant fuel and emission savings. In trials conducted by EUROCONTROL and others savings of up to 40% during the approach phase have been demonstrated (NATs et.al., 2007). This could be equivalent to 300kg of $CO_2$ per flight (Eurocontrol, 2008).

Information on costs of implementation were not available, however, there are financial benefits through the saving of fuel. It is estimated that the 40% fuel saving estimated above could equate to between 50 to 150 kg of fuel (depending on the level at which CDA is commenced and the aircraft type). This is equivalent to between 50 and 100 million euros annually (at June 2007 prices).

The main additional benefit to CDA is noise reduction. Aircraft using CDA are higher above the ground for a longer period of time therefore the noise impact is reduced in certain areas under the approach path. Noise on the ground is also reduced further because the CDA eliminates the period of flight when additional engine thrust would be used. Depending on the location and aircraft type, the noise benefit from a CDA compared to a conventional approach could be up to about 5 decibels (CAA).

Barriers to use of CDA include airspace constraints or overriding safety requirements. In addition, when flying CDA an aircraft may still require a short segment of level flight in order to reduce speed or to reconfigure. A number of steps are being taken to implement CDA at the

European level. These include a European Joint Industry Action plan[12], whereby 100 airports for the introduction of CDA will be targeted by 2013 and the production of supporting materials. These include an ECAC CDA training package and an ICAO CDA manual.

*Open airspace*
Work by the UK National Air Traffic Services (NATS)[13] suggests that, through the use of optimal routes, $CO_2$ reductions of around 5% per flight are plausible.

Europe's Flexible Use of Airspace (FUA) programme has championed open airspace as a aid for the more efficient use of airspace and a tool for reducing emissions by making certain flight routes shorter. It started in 1996 and by 2007 it had been adopted by thirty European countries resulting in annual $CO_2$ savings of around 410, 000 tonnes. (SBAT, 2008)

The necessary evolution of the FUA Concept during the next ten years is described in the "EUROCONTROL Airspace Strategy for the ECAC States" under the Enhancement of European Airspace Management initiative. The 2015 target is to move towards a more demand-responsive and integrated function to support the ECAC States' collective responsibility for European airspace planning and management[14].

Open airspace and wider ATM will benefit from SESAR (the Single European Sky ATM Research Programme). This ATM improvement programme involves key aviation stakeholders (civil and military, legislators, industry, operators, users, ground and airborne) in defining, committing to and implementing a pan-European programme, and supporting the Single European Sky legislation

*Reduced vertical distance between airplanes*
RVSM has increased the airspace capacity above Europe by around 14%. By taking advantage of new cruising levels, the Air Traffic Management Panel conservatively estimate a saving of 80kg of fuel per flight in RSVM. With 10,000 daily flights in the Europe RVSM, this resulted in a yearly $CO_2$ saving of 913,500 tonnes (RSVM, 2002). While research by Eurocontrol (Jeleinek, 2002) suggests that the use of RVSM in European Airspace could reduce fuel burn and $CO_2$ in the order of 1.6% to 2.3%.

Reductions in NOx, $H_2O$ and SOx are also achieved.

The cost/benefit analysis in the North Pacific showed a 0.5% to 1.0% reduction in fuel cost for a saving of approximately US $8 million per year for aircraft using this airspace. In Europe, it was estimated that airlines would save close to €60 million annually.

RVSM was first implemented in 1997 in the airspace of the North Atlantic and applied successively thereafter over Europe, the Pacific, Asia, the Middle East and in the Europe/South America corridor. On the same basis of regional agreements, it will be expanded progressively to eventually cover all airspace around the world.

One issue which needs further exploration is that the introduction of capacity and efficiency enhancing measures could attract additional air traffic – through what is known as the rebound effect[11]. Here, efficiency gains would benefit aircraft operators to the extent that they may to decide to introduce new routes and more planes which would incur increased fuel use and GHG

[12]http://www.eurocontrol.int/environment/gallery/content/public/documents/CDA%20JointActionPlan_Final.pdf

[13] The UK National Air Traffic Services (NATS) is working with aircraft operators and the Ministry of Defence to plan 'Conditional Routes' (CDRs). CDrs are routes that become available on the day due to the cancellation of military activity. NATS estimates that the total number of air miles has been reduced by around 7,560 by using CDRs rather than alternative routes. This equates to a CO2 reduction of around 5% per flight

[14] EUROCONTROL. Flexible Use of Airspace.
http://www.eurocontrol.int/airspace/public/standard_page/1481_Overview.html

emissions, Further research is required is this area but it also highlights the importance of 'locking in' the benefits of measures through appropriate emissions caps.

**Aircraft performance**

*Reductions in weight*
Estimates from British Airways suggest that additional fuel burn as a result of tankering is around 0.5% of total aircraft fuel consumption (UNEP).

Methods to reduce tankering include European airports offering lower price fuel on a volume basis. For example Thomsonfly[15] has increased the volume of fuel it purchases at Coventry airport and as a result a reduction of 138 tons of $CO_2$ over a 12 month period will be achieved.

There are several key barriers in trying to reduce the amount of tankering (UNEP):
- High fuel costs abroad because of expensive distribution infrastructure and local taxes. For example Government-imposed fuel pricing at some Eastern European airports means that the price of aviation fuel can be over 50% more at these airports than at Western European.
- Fuel availability at some remote airports
- Monopoly distribution of fuel, which can involve cross-subsidies from large to small airports and expensive manpower practices
- Concern over fuel quality (e.g. water content) at particular locations
- Limited slot availability means that aircraft turnaround time may not allow sufficient time for refueling, thus incentivising tanker to minimize the risk of losing slots.

The inclusion of aviation into EUETS may also act as a 'barrier' to reductions. Emissions trading in aviation could potentially be avoided by airlines increasing refuelling beyond EU boundaries (Cames, Martin, 2007). The attractiveness of tankering depends substantially on the relationship between fuel prices and allowance prices. Tankering can be attractive up to a radius of about 4,000 km, at an allowance price of around €30/EUA and a kerosene price of €600/t. Emissions trading could, under unfavourable conditions, be evaded for up to 20% of the total fuel consumption in aviation with the help of tankering.

Other factors also impact on tankering decisions – the amount of fuel carried on a flight is decided by the pilot based on weather conditions, the route and perceived risk. Reducing tankering may be perceived as limiting the decision making skills of pilots to ensure adequate back-up fuel on flights which are perceived to be 'high-risk'.

This is linked to the contingency element of tankering. If this can be reduced the benefits could be significant Air India has seen cost and emissions reductions as a result of reducing their contingency fuel from five to three percent (The Economic Times, 2009).

*Improved maintenance*
Ensuring that aircrafts and equipment are well maintained and cleaned to a sufficient standard will ensure that the work more efficiently.

A clean engine is shown to reduce fuel consumption up to 1% which will amount to 250 kg less fuel consumed for a jumbo jet on a long haul flight. With the reduced fuel consumption follows reduced carbon dioxide emissions; 3.1 kg of carbon dioxide is avoided for every kg of fuel saved[16]

**Airport operations**

Electricity at the gate operates at a greater energy efficiency than auxiliary power units, thus contributing to a reduction in emissions for an aircraft whilst at an airport. A reduction between 75-95% can be achieved compared to the use of traditional systems (Sustainable Airport

[15] http://www.enviro.aero/Aviationindustryenvironmentalnews.aspx?NID=84
[16] Gas Turbine Efficiency. http://www.gtefficiency.com/compressor-cleaning.asp Accessed on 01/06/09.

Environments, 2008). For example APU uses 6000 kWh (fuel) to produce 250 kWh cooling power while using electricity (for Cavote PCAir) uses 450 kWh (electric) to produce the 250 kWh.

There can be additional benefits through – for example reductions in noise and fuel use and costs.

Even though electricity at the gate enables aircrafts to turn off their auxiliary power units while maintenance and cleaning crews prepare for the next flight, it is at the discretion of the air carriers as to whether they will be used.

Air carriers are not required to use the electric gates, and some choose not to use because they delay the efficiency of their procedures. Time efficiency is therefore a barrier in using electricity at gates, particularly for airlines that specialise in quick turn arounds of 20 minutes or less (GAO).

Replacing conventionally fueled ground support equipment with alternatively fueled equipment has been endorsed by the FAA as the most cost effective way of reducing emissions at airports (FAA, 1997).

### 3.6.2 Maritime shipping

There are a number of overarching policy measures which could be introduced to encourage take up of the following options. Since, they are overarching they are summarised at the end of the section.

**Voyage optimisation**
Weather routing can result in substantial savings for ships on certain routes. However, weather routing systems are not uncommon, and the incremental saving was not assessed in the latest (2009) study for IMO (Marintek, 2009). In the 2000 study (Marintek, 2000) savings in the region of 2-4% were suggested.

The low cost estimate for weather routing is US$800 and high cost US$1,600 pa (Marintek, 2009). With Cost efficiency in the range of - 100 US$/tonne of $CO_2$ to –165 US$/tonne of $CO_2$ (Marintek, 2009).

In terms of savings from ballast and trim optimisation the saving have been estimated in the range of 0 to 1% for each option (Marintek, 2000). In a recent specific case study of tanker operations done by DNV savings of 0.6% were estimated for ballast and trim optimisation. In addition, higher figures may be relevant for specific ship types that carry significant ballast during much of their optimisation.

**Energy management on ships**
A saving of 10% on auxiliary power may be realistic for many vessels. This corresponds to ~1-2% of total fuel consumption, depending on circumstances. For RoPax/cruise ships, it is anticipated that improvements in auxiliary energy consumption of up to 15% could be achieved.

Research suggests that the low cost estimate for a fuel consumption meter is US$46,000 while the high cost estimate is US$55,200 (purchase costs for a meter). In terms of cost efficiency the range is from –40 to 330 US$/tonne of $CO_2$.

Low energy/low heat lighting cost efficiency is estimated to be in the range of –85 to 440 US$/tonne of $CO_2$. While power management is in the range of –125 to 130 US$/tonne of $CO_2$.

**Fleet management –optimisation of fleet**
Fleet management, logistics and incentives can lead to a reduction in carbon emissions of between 5% and 50% (Marintek, 2009).

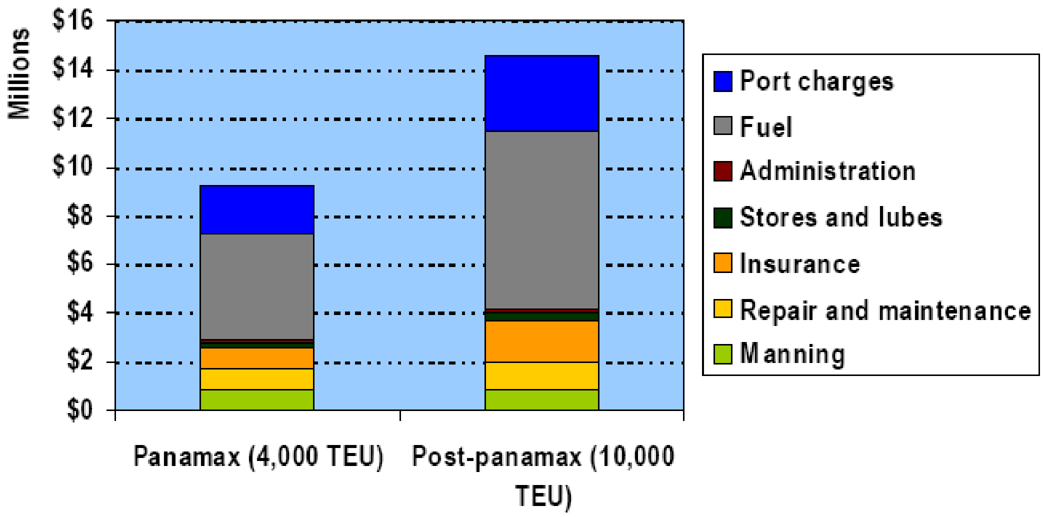
*Larger ships*

By employing larger vessels, the number of ship movements can be reduced. Research into the optimal ship size suggests that the following savings can be achieved:

- A reduction in TEU-miles of up to 17%
- A reduction in fuel consumption of up to 10%

Research on costs suggests that while wages and administration stay fairly constant. Fuel consumption will vary with the size of the ship, however this is not proportional.

**Figure 7: The cost of operating a Panamax and a post Panama x ship[17]**




This measure is currently being developed (AEA, 2007) - with bulk cargo operators, such as those dealing with oil, coal, and iron ore responding by designing Ultra Large Crude Carriers (ULCCs) and extra large bulk carriers. Vessels which deal in other forms of cargo such as container vessels have measures in hand to increase their capacity. The sizes of these vessels have been increasing over the last few years.

*Planning and management*

The type, style and the degree to which transport management can be effectively implemented depends on the type of cargo and vessel that the company is working with. The size of the fleet also has a bearing, since the larger the fleet, the more options that are available to an operations manager when trying to effectively place the company's vessels. Smaller general cargo vessels tend to be easy to configure to carry different cargos, for example wheat from Canada with a return cargo of beer and spirits, but larger, dedicated vessels such as oil tankers are not so easily configurable.

A co-benefit, as with many of the measures, is a reduction in fuel use.

A potential barrier is the level of resources that a company is prepared to out into their transport management systems. A further barrier is that some of the 'easy' wins in fleet management may already have been achieved because of the associated reductions in fuel use and costs.

**Reductions in speed**

The emissions savings associated with the speed depend on a number of factors. If 'just in time' strategy is possible then fuel savings and carbon savings in the region of 1 to 5% are possible (Marintek, 2000). The highest potential saving would be expected where economic considerations (incentives from contractual arrangement) presently favour inefficient operational arrival. More

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[17] Jean-Paul Rodrigue, Claude Comtois, and Brian Slack (2006) The Geography of Transport Systems in **Error! Bookmark not defined.**

TEU stands for 'twenty foot' equivalent and this is the standard size of container.

recently, the potential for energy saving by just-in-time arrival has been estimated to be 1% (Marintek, 2009), based on the Japanese domestic fleet.

Analysis on the potential for savings in a wider context, and taking into account that emissions from a vessel are roughly related to the square of a vessel's speed, suggests that a speed of 10% can lead to a reduction of emissions of 19% on a tonne-kilometre basis. Analysis on the costs efficiency associated with the 10% reduction suggest a figure of 110 US$/tonne of $CO_2$ (central figure)[18].

If a 'just in time' strategy is considered then economic considerations would have been factored in. For most ship engines, running at a reduced speed may cause problems such as increased vibrations and depositing of soot in the exhaust gas channel. Sooting problems are normally coincident with incomplete combustion and increased fuel consumption. For ships permanently operating at slow speeds, engine modification/ de-ratings may be a solution.

In terms of implementation again complexities of ship operation may be a potential barrier.

In introduction it is important to note the importance of consistency if steady power can be maintained, then the saving potential is estimated to be between 0 – 2% compared to normal practice. It is also worth noting that speed or power variations during a voyage will, compared to steady running, increase the fuel consumption and costs. A steady engine speed will normally be the simplest option to implement and the most economical. Steady power (minimum engine speed variations) during a voyage will keep the total fuel consumption to a minimum.

**Improved maintenance for shipping**

Research (Marintek, 2000) suggests that optimal hull maintenance could reduce fuel and $CO_2$ emissions by between 3 to 5%. Hull maintenance can include the use of more effective hull coatings, which may reduce resistance. Future technologies may include hull coatings based on nano technology. These coatings have the potential for substantially reducing the resistance of the underwater hull and delay the onset of marine growth for an extended period. While this technology is still in early stages power reductions of perhaps 15% may be expected.

Propeller maintenance could reduce emissions by between 1 to 3%. The effect will be greatest for propellers with large area ratios and for propellers running at high rates of rotation.

Optimal maintenance of main engines and ensuring that these are operating at the most effective (highest) pressures is also important. Savings of 1-2% of the fuel consumption of the main engine through "tuning" have been observed, with even more in extreme cases, although the average potential may be around 1%.

Research (Marintek 2009) suggests that hull coating and maintenance cost efficiency would be 105 US$/ tonne of $CO_2$ (central value). Propeller maintenance would be 75 US$/ tonne of $CO_2$ (central value). Detailed information on costings is also available (Marintek, 2009).

Barriers include the complexities of ship operation. For example - the ships may be operated by a company, which is different to the commercial operator. The technical operator may wish to minimise time in dry dock (to minimize off-hire cost) and other maintenance costs (e.g., painting costs). The impacts on energy and fuel of these steps are not taken into consideration because it is the commercial operator who is responsible for paying these bills.

Other barriers include a lack of drydock capacity – therefore the facilities are not in place to ensure that maintenance can be carried out. There may also be port restrictions on the brushing

[18] It should be noted that this figure is conservative and does not take into consideration the potential use of overcapacity – it is assumed that the speed reduction is corrected for by the purchase of new ships. It is also a fleet wide average figure and therefore masks higher and lower figures. In general, faster ships and larger ships demonstrate a better cost efficiency than smaller and slower ships.

of hulls, due to concerns that this may results in the transfer of invasive species from one country to another.

**Electricity in ports**

The carbon savings that could be achieved using shore side electricity have not been quantified but it is estimated that large vessels on average spend 700 hours a year at berth with their engines operating. However, it is important that the electricity mix includes low carbon sources since it is suggested (SEAAT, 2009) that the $CO_2$ emissions arising from shoreside power generation, including transmission and distribution losses, can be greater than those of an efficient on-board diesel generator, particularly if coal plays a significant role in the generator mix.

Additional benefits, and a key driver for the introduction of electricity at ports is the abatement of emissions which have a negative impaction on air quality.

Within the EU context a key policy instrument is the European Commission adoption of the “Recommendation of the promotion of shore-side electricity for use by ships at berths in EU ports”. The objective is to promote the consideration of shore-side electricity as a means of abating ships emissions in EU ports, particularly in populated areas which suffer from poor air quality. The recommendation is not legally binding and it aims to achieve the objective through providing information on practicalities, benefits and costs; by calling for harmonized international standards; and by highlighting the possible use of electricity tax reductions as an incentive to ship operators to use shore-side electricity

The key interaction with other GHG reduction options is the requirement for low carbon, potentially renewable, electricity.

**Policy Options**

The policy options to limit or reduce GHG from ships through operational efficiency include the use of an Energy Efficiency Operational Indicator (Marintek, 2009), here the emission index expresses the ratio between the cost (i.e. the emission) and the benefit, with the unit being grams of $CO_2$ per capacity mile. The EEOI would be allocated by ship category. Trials are currently taking place, and a number of issues have been identified with regard to the establishment of a baseline.

This EEOI could be complemented by a Ship Efficiency Management Plan (SEMP) (Marintek, 2009). The SEMP would provide a framework for a ship to address energy efficient operation by monitoring performance and considering possible performance in a structure fashion. The SEMP would consist of four phases – 1) Planning 2) Implementation 3) Performance monitoring and 4) Self improvement. The EEOI could be used to monitor performance within the SEMP.

These measures could be implemented through market based instruments such as a EEOI levy, through command and control instruments such as mandatory EEOI limits and reporting and mandatory SEMP or voluntary measures for example voluntary agreement to improve EEOI, and implement SEMP.

In addition, there are overarching policy instruments for example the introduction of Emissions Trading and/or the introduction of an emissions levy that will take forward emissions reductions across operational, design, and fuel life cycle GHG reduction options.

# 4 Summary of key findings and issues for discussion/research

## 4.1 Key findings

There are opportunities in all transport modes to reduce fuel consumption and thus GHG emissions by operational, non-technical measures. However, the potential varies strongly between modes. Data on potential and cost are scarce, especially for the non-road modes, and for the longer term.

In **road transport**, the transport mode with the largest share in the greenhouse gas emissions of Europe's transport sector, the following measures can be taken:
- fuel efficient driving
- tyre pressure monitoring
- vehicle downsizing.

The short term potential of the first two measures is significant, up to more than 10%, but they are expected to diminish over the coming decade as new vehicle technology that automates these behavioural changes will become standard. The potential for further operational measures in the longer term (2020-2050) is therefore expected to be limited.
Vehicle downsizing currently has high potential, as smaller engines and lighter vehicles directly reduce $CO_2$ emissions. However, this potential will also reduce in the future due to technological developments.

In **inland shipping**, the following operational measures were identified:
- Improved maintenance of ship hulls, propellers and engines
- Speed optimization
- Just in time routing

There is very little evidence on the GHG reduction potential of these measures. A rough estimate of the GHG reduction potential of the first option is about 3-5% for each component, for the third option a potential between 1 and 5%. The total potential of the second option is unknown, but may be large: a speed reduction of 10% can save about 20% fuel.

Quite a large range of operational measure were found for **rail transport**:
- Run shorter trains when extra capacity is not required
- Energy efficient driving and train regulation
- Reduction in empty stock movements
- Intelligent engine control
- Fuel additives to increase diesel engine fuel efficiency
- Better recording of diesel engine fuel/power consumed
- Reduced traction maximum demand
- Disconnecting electric vehicles from supply when stables
- Reducing diesel engine idling
- Energy monitoring
- Reducing energy use for heating
- Control and command signalling

Some of these measures can be implemented in the short term, others are technically more complex and need more time for implementation. Running shorter trains, energy efficient driving, disconnecting electric trains from the grid and reducing idling of diesel engines seem to have the largest potential for fuel savings and thus $CO_2$ reduction, with reasonable cost/benefit ratios. However, data on potential and cost of these measures is limited, and may vary between countries and rail operators.

The following operational measures were identified **for aviation**:
- Training of the crew,
- Measures in air traffic management

- Measures to improve aircraft performance
- Measures at the airport: electricity at the gate

The potential of crew training has not been quantified. Measures in air traffic management (use of the Continuous Descent approach, open airspace and reduced vertical distance between airplanes) could reduce fuel consumption emissions by 6-12% in 2050. Many initiatives are already in place to implement these measures and harvest a large part of that potential.
Measures to improve aircraft performance (reductions in tankering and improved engine maintenance) have much less reduction potential, about 0.5 and 1% respectively  The potential of electricity at the airport gate is expected to be relatively low, but cost effective.

There are quite a number of operational measures that may reduce emissions of maritime shipping:

- Voyage optimization (weather routing)
- Energy management on ships
- Fleet management and optimization
- Improved maintenance of hulls, propellers and engines
- Speed reduction
- Electricity in ports

Evidence on potential effects are quite limited, but we conclude that especially improvements in fleet management and special hull coatings have the highest potentials for reduction: fleet management between 5 and 50% (the high estimate especially if significant speed reductions can be achieved), coatings can achieve up tot 15% reduction. Speed reductions, perhaps in combination with just in time strategies, also have significant potential, of about 1-5%.

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