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# Achieving a sustainable transport sector in the UK: the effect of UK transport reform and change in population's travel decisions on the reduction of energy consumption and CO2 emission within the transport sector

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# **Achieving a sustainable transport sector in the UK: the effect of UK transport reform and change in population's travel decisions on the reduction of energy consumption and CO<sub>2</sub> emission within the transport sector**

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## **Abstract**

With the onset of climate change and diminishing global energy supplies, it is a concern that global fuel demand, energy consumption and carbon release are increasing. The transport sector is one of the largest contributors to environmental pressure and degradation, yet it is making a very limited contribution to carbon emission and energy reliance reduction. This paper presents a critique of the UK approach to transport sustainability, focusing mainly on aspects of an unsuccessful transport scheme; Transport 2010, whilst analysing three reform approaches stated in Haan et al (2007) study; reducing demand, energy intensity and carbon intensity to conclude with an improved transport strategy. Reform methods are tested through various models where fuel used, energy consumed and CO<sub>2</sub> released are calculated for each mode of available transport for a sample UK short and long distance route. The best reform techniques are deliberated, where a mixture of schemes proved appropriate for typical short distance travel and increased rail use for long distance travel is deemed the most environmentally beneficial. To conclude all three approaches will reduce environmental impact somewhat, however it is a combination of technological alternatives, stringent policy and substantial behavioural change, along with sufficient political and public support, that will result in even the arduous reduction targets being met. Essentially a modal shift is required, away from economic development onto social and environmental sustainability.

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## Chapter 1

### Introduction

#### *1.1 Worldwide Transport Sustainability*

Energy is central to worldwide social and economic wellbeing; it provides personal comfort and mobility and is essential to industrial, commercial and societal wealth generation (Taylor *et al* 2005; Yu 2008). Yet, excessive fuel production and consumption place considerable pressure on both the environment and human health, only intensifying alongside rapid world development and diminishing global oil supplies. The global transport sector is the largest contributor to such universal strain (Cherp *et al* 2003), responsible for about 25% of total anthropogenic CO<sub>2</sub> emissions and 14% of GHG emissions (Hensher 2008), equating to 1113 billion tons of carbon release, per annum (Olsthoorn 2009), while the latest predictions state such values are set to rise by 50% under a 'business as usual' scenario, by 2050 (Baars 2009).

The 1973 and 1979 oil crises and recent global warming phenomena focused the world's attention on limited fuel reserves and the impact on the environment (Fronk *et al* 2009; 2010). Subsequently, rising fuel prices, concerns about climate change and national energy security offer further incentives for the search for alternative transport fuels and methods (Musti *et al* 2011). In developed countries, where the transport sector is responsible for the majority of total energy consumption and a considerable amount of CO<sub>2</sub> emissions, it is the passenger car that is accountable for 50-60% of the transport sectors' total environmental impact (Ahmen *et al* 2001). Furthermore, this is becoming an evident problem in developing countries due to rapid economic growth and increased car ownership (Todoc *et al* 2005).

Government strategies to reduce passenger car traffic, improve fuel efficiency, meet CO<sub>2</sub> reduction targets and assure energy security vary worldwide. A study in Australia (Hensher 2008) concludes the most effective method for transport reform is a combination of technology and pricing, hence fuel efficiency improvements and the introduction of carbon tax and variable user charges. In Sweden a combination of engine development, hybrid technology, smaller more efficient cars and an improved public transportation system led to a 65% reduction of CO<sub>2</sub> emission in the urban Mälardalen region (Dahlquist *et al* 2007).

#### *1.2 The UK Transport Sector*

The transport sector in the UK has been increasingly responsible for mass fuel consumption and is currently accountable for 69% of total energy use (DfT 2010) and 20% of total CO<sub>2</sub> emission (Fullerton and West 2010); yet of these values, private road transport is responsible for 76.9%, whereas rail is only responsible for 1.4%; when considering total domestic transport, cars and taxis contribute the greatest to GHG emission (DfT 2010), therefore cutting private transport use, in particular the passenger car is the focus of the investigation.

However, the UK government was very positive about being able to meet its share of the EU Kyoto Protocol targets set in 2000, to reduce CO<sub>2</sub> emission by 12.5% by 2010, and it has gone further by committing to a self imposed 20% target reduction of 1990 levels; there are no explicit targets for the transport sector itself, but it is expected to make a major contribution to the national reduction targets (Banister

2007). Thus, local authorities, the government and Transport Research introduced the nation's transport legislation, comprising of numerous targets, policies, agreements and programmes (DfT 2010), summarised in Banister (2007, p. 4).

There are two main market based measures within the transport sector to achieve the aforementioned targets; the fuel duty escalator, an annual increase in fuel duty above the rate of inflation, and road pricing, like congestion charges found in London and Durham (DfT 2010; Hensher 2008). The fuel duty, introduced in 1993, saw the price of a litre of fuel increase from 56 pence to 85 pence in 2000, yet it was abolished in that year due to industry pressure, then introduced again in 2007, as evidence suggested the previous duty escalator showed signs of success (Banister 2007), whilst congestion charges saw large decrease in local air pollution (Nel and Cooper 2009).

One of the least successful schemes was Transport 2010, unveiled by Deputy Prime Minister John Prescott on July 20<sup>th</sup> 2000, it involved eight public service agreement targets (DfT 2010), designed to deliver UK Government priorities: reduced congestion, better integration, and a wider choice of quicker, safer, sustainable, more reliable travel on road, rail and other public transport (Railways Archive 2005). The scheme was funded from both the public and private sectors and a total of £180 billion was set to benefit all transport modes between 2000 and 2001 (BBC News 2010), to achieve the following targets (DfT 2010):

- Reduce road congestion on the inter-urban networks and in large urban areas in England below current levels by 2010 by promoting integrated transport solutions and investing in public transport and the road network.
- Increase rail use in Great Britain (measured in passenger kilometres) from 2000 levels by 50% by 2010, with investment in infrastructure and capacity, while at the same time securing improvements in punctuality and reliability.
- Increase bus use in England (measured by the number of passenger journeys) from 2000 levels by 10% by 2010, while at the same time securing improvements in punctuality and reliability.
- Double light rail use in the UK (measured by the number of passenger journeys) by 2010 from 2000 levels.
- Cut journey times on London Underground services by increasing capacity and reducing delays. Specific targets will be agreed with the Mayor after the Public Private Partnership has been established.
- Improve air quality by meeting our National Air Quality Strategy targets for carbon monoxide, lead, nitrogen dioxide, particulates, sulphur dioxide, benzene and 1-3 butadiene.
- Reduce greenhouse gas emissions by 12.5% from 1990 levels, and move towards a 20% reduction in carbon dioxide emissions by 2010.
- Reduce the number of people killed or seriously injured in Great Britain in road accidents by 40% by 2010 and the number of children killed or seriously injured by 50%, compared with the average for 1994-98.

The plan boasted vast renovation of the transport sector, yet there has been much doubt in the scheme's success and evidence states it has had to backtrack on many of its targets (BBC News 2010; Banister 2007); predictions in population and car ownership growth are not often taken into consideration when strategies to achieve the targets are made (Todoc *et al* 2005) and the recent economic downturn has

meant some developments have been unable to take place (Boretti 2010). Subsequently, UK rail use has only increased by 2% and public bus use has decreased by 1% (National Transport Statistics 2009). Despite local air pollution declining as a result of improved engine technology, it is estimated, due to increased car ownership and road traffic, CO<sub>2</sub> emissions will continue to increase. It is deliberated the UK needs greater integration between the environment and transport procedure, especially concerning the impact of the passenger car (Begg and Gray 2004); Hensher (2008) expresses policy objectives must consider efficiency, sustainability and equity, focusing on social surplus in addition to cost effectiveness; but in particular the ability to reduce CO<sub>2</sub> emission.

### *1.3 Transport Reform Methods*

Haan *et al* (2007) suggests there are three main approaches to attain a sustainable transport sector and reduce the passenger car effect; firstly, reducing demand, the number of passenger kilometres; secondly, by reducing the energy intensity per passenger kilometre; and lastly by reducing the carbon intensity, implicating the use of alternative energy sources.

This report will critically analyse the Transport 2010 projections, whilst testing the potential of the three transport reform approaches from Haan *et al* (2007). In order to gain the best reform methods to reduce UK oil dependence and adverse environmental impact of the transport sector, a comprehensive analysis into sustainability is needed for short distance and long distance travel by comparing the possible transportation modes available for each. Using the results from such analysis a suitable conclusion will be made to determine the best reform methods for the UK transport strategy and recommendations will be given.

#### *1.3a) Reducing Demand of the Passenger Car*

In the UK the passenger car is responsible for the majority of fuel consumption and CO<sub>2</sub> release; therefore reducing the number of passenger kilometres in such mode, hence lessening reliance on private fuelled transport, would be a viable option for sustainability. Encouraging reducing demand would involve increased car tax dependant on efficiency, energy consumption or CO<sub>2</sub> release of the vehicle (Fullerton and West 2010). Currently in the UK vehicles are rated from band A, green and most efficient, to band G, which is red and the least fuel efficient, with stages in between (Direct Gov 2011); a development on this to widen the band gap and focus on the associated CO<sub>2</sub> emitted.

Similarly, increasing road user charges; for example, more tolls and congestion charges or increased inner-city parking fees would have a similar effect (DfT 2008), additionally reducing inner-city traffic which would naturally encourage the use of the public transport, without needing to enhance services. In reverse to increasing expenditure, incentives for commuters to car-pool is an option, for example closer parking spaces at work, high occupancy vehicle lanes or a carbon savings point system enabling monetary incentives to drive more sustainably, would offer reform of the transport sector. Equally, charges could be enforced if individuals do not partake in an energy saving or reduced carbon travel option.

Furthermore, subsidizing mass transit to improve public transport would have effect; decreased prices or a points system to encourage the use of public transport, enhancement of bus and train service timetables i.e. more frequent transport,

especially at peak times and development of the routes so that it reaches more people in suburbs and surrounding towns and villages to cities (Essen *et al* 2009). A universal pre-paid ticket, like London's Oyster Card, would make paying for public transport easier and more efficient (Banister 2007). Upgrading speed and capacity of existing rail lines, for example adding new lines of high-speed rail and new major stations like parkways would make rail travel more appropriate, accessible and popular (DfT 2008).

### 1.3b. Reducing Energy Intensity of the Passenger Car

The reduction of car use will have effect; however, there will continuously be necessity for private transport, due to ownership, comfort and convenience (Begg and Gray 2004). Subsequently, reduction in the energy intensive travel is imperative. Methods of reducing energy intensity involve a cutback on high speed driving, above 90 km h<sup>-1</sup>; the most efficient driving speed is 45-50mph for most cars and 25% more fuel is used at 85mph than the national speed limit, 70mph (Dahlquist *et al* 2007). Similarly, reduction in the size of the car, or the size of the engine, has an energy saving effect, Haan *et al* (2009) suggests using more efficient cars by lowering the weight has a 15% reduction potential on fuel consumption. This can be achieved by influencing consumers to buy smaller and lighter cars by a different taxation policy. Likewise, the age of the vehicle typically determines how much fuel it uses per kilometre, figure 1.

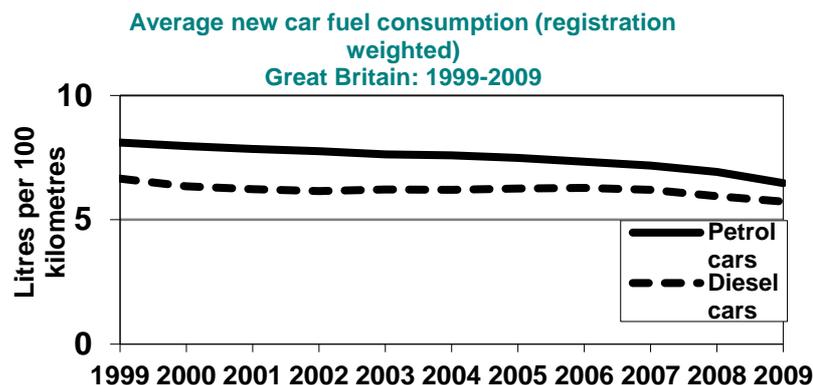


Figure 1: Fuel Consumption against Age of Vehicle (National Transport Statistics 2009)

A more efficient system can also be achieved by improvements to the internal combustion engine itself, or switch to other concepts like fuel cell technology, viable within the next few decades (Boretti 2010). The principal, and perhaps the most viable, approach to reducing energy intensity is the use of hybrid powertrains to recuperate braking energy; a combination of combustion engines and electric motors, seen in many new cars on the market today, which reduce fuel consumption in city traffic by 10–20% (Dahlquist *et al* 2007). The study will test and compare Turbo Direct Injection (TDI) hybrid cars, where a fuel injector sprays atomised fuel directly into the main combustion chamber as opposed to the pre-combustion chamber prevalent in older diesel vehicles (Boretti 2010), and kinetic energy recovery systems, or regenerative braking (KERS); an energy recovery mechanism that slows a vehicle by converting its kinetic energy into a useful energy form, as opposed to conventional braking systems, where excess kinetic energy is converted into heat by friction in the brake linings and therefore wasted (Baars 2009; Dahlquist *et al* 2007; Hensher 2007 & 2008).

### *1.3c. Reducing Carbon Intensity*

Reducing carbon intensity implicates the use of alternative energy resources such as nuclear, renewable, hybrid, fuel-cell, and battery powered electric vehicles, and alternative fuels such as hydrogen, methanol and biofuel; all of which are viable energy resources (Kerr and Service 2005; Ahmen *et al* 2001). Vehicles with new powertrains using alternative fuels can cut energy use in half and reach low or near-zero emissions of carbon dioxide and regulated pollutants (Ahmen *et al* 2001). The US department of energy states using biodiesel as an alternative to petroleum diesel reduces CO<sub>2</sub> emissions by 58.5% (NBB 2009). Despite, alternative fuels having immense potential (Adelekan 2010), technology will not be ready to the most efficient degree until several decades time and substantial cost reductions are needed for widespread deployment (Ahmen *et al* 2001). Consequently, quantitative analysis cannot be undertaken within the study, yet it will be considered.

## **Chapter 2**

### **Literature Review, Aims and Objectives**

#### *2.1 Literature Review*

Globally transport is a massive contributor to environmental pressure and in most countries rising fuel prices, concerns about climate change and national energy security offer incentives for an alternative transport strategy (Cherp *et al* 2003), only intensifying alongside rapid world development (Machado 2009). Van Mierlo and Maggetto (2007, p. 167) and Hu *et al* (2010, p. 4291) illustrate the current and projected increase in global demand for transport oil, as well as the corresponding decrease in world oil supply.

Ahmen *et al* (2001) and Fronk *et al* (2009 & 2010) give evidence that the 1973 and 1979 oil crises focused the world's attention on the issue of oil dependence; limited oil reserves have motivated the search for alternative transport fuels and methods. Similarly, VanMierlo and Maggetto (2007) and Olsthoorn (2009) state the transport sector is responsible for about 25% of total CO<sub>2</sub> emissions, offering a further incentive for transport evaluation.

Rising fuel prices, concerns about climate change and national energy security are forcing reanalysis of the transport sector (Musti *et al* 2011; Oum and Yu 2004), Haan *et al* (2007) suggests there are 3 main approaches to attain sustainable fuel consumption; firstly, reducing demand, the number of passenger kilometres; secondly, by reducing the energy intensity per passenger kilometre; and lastly by reducing the carbon intensity of energy generation and use, implicating the use of alternative energy sources.

A comprehensive analysis into sustainability, comparing all transportation modes is required to gain the best reform methods to reduce oil dependence (Steenhof *et al* 2007). Initially, an accurate and current energy consumption value should be ascertained for each form of transport; road, rail, aviation and maritime, as previous studies show much contradiction and discrepancy. Hu *et al* (2010) predicts a 400 million ton increase in total transportation energy use by 2030, of the projected increase, road vehicles account for nearly 70% and air, rail, and marine transportation modes account for 14%, 12%, and 5% respectively, whereas, Ahmen

*et al* (2001) suggests road vehicles use 79% of the total transport energy demand with the remaining 21% divided equally among air, rail and maritime transport. Despite sharing equivalent value for 2006 road transportation consumption share as Ahmen *et al* (2001), Mazraati (2010) considers the aviation sector is the second major consumer, with 11.2% share in total oil demand in the transportation sector.

Basic fuel consumption data for a sample trip is the principal method to establish foundation values from where the true social and environmental impact of a transport form in the UK can be derived from (DfT 2010), much like Rothbauer and Sieg (2010) study which calculated 'A sample rail trip from Berlin to Paris produces 33 kg CO<sub>2</sub> per passenger compared to 115.4 kg for the same trip by car, or 203.5 kg by air'. Similarly, Liimatainen and Pöllänen (2010) takes an average journey to determine the fuel consumption and energy efficiency for each vehicle and trip in the Finnish goods transport sector, and suggests such unique methods can be applied to other transport scenarios.

Chester *et al* (2010) estimates inventories from modal vehicle kilometres travelled (VKT), and passenger kilometres travelled (PKT). Chester and Horvath (2009) provides a generalized formula for determining component energy or emissions (Equation. 1), which suggests the appropriate units and method in which to evaluate the influencing factors for each transport mode.

Equation 1: Formula for Calculating Component Energy or Emissions (Chester and Horvath 2009)

$$EM = \sum_c^C \frac{EF_{M,c} \times U_{M,c}(t)}{PKT_M(t)}$$

where *EM* is total energy or emissions per PKT for mode *M*;  
*M* is the set of modes {sedan, train, aircraft, etc};  
*c* is vehicle, infrastructure, or fuel life-cycle component;  
*EF* is environmental (energy or emission) factor for component *c*;  
*U* is activity resulting in *EF* for component *c*;  
*PKT* is PKT performed by mode *M* during time *t* for component *c*.

Odhams *et al* (2010) and Perez-Martinez (2007) unearth questions such as 'during peak travel is it environmentally better to take a bus or a train, or does a five-passenger bus outperform a two-passenger car?' and 'public transport can improve efficiency levels by 35%, is it the answer to rising competitive energy demand?' They can be answered by assessing energy consumption and emissions for each transport option considering the many influencing variables.

A key influencing factor in discovering transport's true environmental impact is vehicle capacity and occupancy, therefore calculating fuel utilisation, per person, per kilometre. Studies (Van Mierlo and Maggetto 2007; Ballis and Golias 2002) used occupancy data (35% for cars, 1.4 persons per vehicle, 40 to 70% for trains, 60% for intercity buses and national flights) to conclude, for passenger transport; 'the train uses 15 to 50% less primary energy than the car; the intercity bus, lighter than the train, reaches about 70% of the energy consumption of the train and 42% of the consumption of the car. The aeroplane is at 60% of the car but at 300% of the fast

train but for air travel, time and practicality obviously plays an important economic role (Chiung-Wen *et al* 2010).

The load factor for freight transport has a similar influence (Browne *et al* 2007); Mazraati (2010, p. 44) gives evidence for occupancy and load percentage for aviation.

Van Mierlo and Maggetto (2007), using load factor data, concluded; the boat used for inland transport can reach 200% of the consumption of rail because of its diesel motor and rail transport reaches 40–50% of road transport consumption. However, for a true evaluation the duration of the trip has significant importance (Lindsey *et al* 2011).

Similarly, the size of vehicle, coinciding with capacity, affects the efficacy (DfT 2010); Morell (2009) states increasing the size of aircraft will increase efficiency, whereas size of road vehicles may lessen it (Galachoir *et al* 2009). However, that is mainly due to the weight, power and efficiency relationship (Chen and Ren 2010), and many technical advances are being carried out in order to address vehicle size issues (Haan *et al* 2009).

One of the main influencing factors is fuel efficiency and traffic congestion; Mazraati (2010) and (Rothbauer and Sieg 2010) both state that when vehicle speed lowers in city traffic the energy efficiency of a car falls below 15%. Amongst today's fuels, diesel is the most efficient, followed by gasoline and natural gas (Musti *et al* 2011). Similarly, Bai *et al* (2009) states 'it is possible to save 6.8% energy under the rigorous restriction of schedule time by keeping train speed uniform'.

Vehicle age can also determine fuel efficiency (Zachariadis 2006) and operational CO, NO<sub>x</sub>, PM<sub>10</sub> and VOC emissions (Chester *et al* 2010; Lelli *et al* 2010). In the United States, Corporate Average Fuel Economy (CAFE) standards have been implemented since the late 1970s, requiring that the sales-weighted average fuel economy of newly registered cars do not exceed a limit value, which was set at 18 miles per gallon in 1978 which increases with current improvement in efficiency (Zachariadis 2006; Popp *et al* 2009), Fullerton and West (2010) state a 71% efficiency gain can be achieved by enforcing such taxes on gas, size, and vintage.

Despite considering the global influencing factors, a foremost complexity is the difference in development rate in each country (Nel and Cooper 2009). Ahmen *et al* (2001) states North American, Western European and Pacific OECD countries accounted for 64% of the total world energy demand for transport in 1995, but by 2020, this fraction is expected to decrease to 53%, with a growing share taken up by non-OECD countries in Asia and the Pacific. Todoc *et al* (2005) gives evidence for vast independent transport intensification in Thailand and Khanna *et al* (2011) explains Delhi has around 4.4 million vehicles, which account for about 70% of the city's energy consumption, and the number is rapidly increasing.

Timilsina and Shrestha (2009) and Heffner *et al* (2010) suggest the main driver for such increase is the economic growth of developing countries and change in transportation options. The issue of different development rates should be addressed in a full analysis of transport efficiency, because due to technology in developed countries, fuel efficiency values can be very different; China an average

of 9.5 L/100 km, Japan 7.15 L/100 km, Europe 6.89 L/100 km and US 9.97 L/100 km (Hu *et al* 2010), however, that is mainly due to the weight of the vehicles (Chen and Ren 2010). In addition, other influencing factors will vary from country to country and subsequently reforms on transport modes should be addressed from a bottom-up approach (Boretti 2010), considering each nation as individual.

Chester and Horvath (2009) encompasses the most comprehensive study into the true environmental impact as it uses non-active operation data. Similarly, Vihermaa *et al* (2006) give resource data for rail in material input per service input-unit to produce lifecycle assessments for each transport mode. Both studies take into account a variety of influencing factors to produce a thorough evaluation of transport modes and their influenced scenarios.

Despite much literature analysis on current efficiency influencing factors, there proves to be little investigation into influencing factors of proposed mitigation. Using data from studies on future scenarios (Hu *et al* 2010; Ahmen *et al* 2001; Hensher 2007 & 2008; Baars 2009), which examine the use of electric, hybrid and fuel cell vehicles, alternative fuels (Borjesson 1999), enforced government and global policy, for example taxes and 'cap and trade' (McCollum and Yang 2009) and enhancing public transport, an absolute study incorporating current influencing factors, expanding on Haan *et al's* (2007) study and including alleviation techniques, should be concluded. This would finally attain an evaluation of a current efficient transport mode and the principal mitigation proposal in order to reduce global dependence on diminishing oil supplies.

## *2.2 Aims of the Report*

The aims of the project are to complete a comprehensive analysis into sustainability aspects, considering factors such as fuel use, energy consumption and CO<sub>2</sub> emission, which compare all transportation modes for a typical short distance trip and long distance trip, in the UK. Using capacity analysis, the potential of 100% transport reform will be shown in terms of energy and CO<sub>2</sub> saved. Similarly, the increased public transport usage targets of the Transport 2010 will be critically examined and the reform approaches from Haan *et al* (2007) applied to give alternative options. The third initiative is to compare reducing energy intensity techniques with conventional systems and alternative transport modes. To conclude with the use of Haan *et al* (2007) strategies to manipulate the Transport 2010 agenda to a more appropriate scheme and achieve full potential with existing infrastructure and budget.

## *2.3 Objectives of the Report*

To achieve such aims, current consumption and emissions for each mode of transport will be calculated, using an example UK route. These foundation values will then be manipulated according to the specific approach method or Transport 2010 target to give potential savings in fuel, energy and CO<sub>2</sub>. The reducing energy intensity systems will then be compared against conventional systems for the passenger car and other forms of transport available. The conclusion will come from finding the best 'mode-neutral' approach to a sustainable transport sector by manipulating the results. The conclusion should assess consumption and emissions, consider medium and long-term forecasts, be able to inform policy and be robust enough to inform government agendas.

## **Chapter 3**

### **Methodology**

#### *3.1 Short and Long Distance Travel*

To determine fuel use, energy consumption, CO<sub>2</sub> emission, frequency and capacity data for each mode of transport, a theoretical trip in the UK is used for the basis of calculations. Fuel, energy and CO<sub>2</sub> are analysed. When new technology, such as a hydrogen-fuelled bus, is entered into the market, with a dedicated supply of hydrogen produced directly from nuclear power, could be considered to have zero CO<sub>2</sub> emissions, but may have very large energy demands; In such a case, it is appropriate to compare both total energy use and CO<sub>2</sub> emission (DEFRA 2008), making the model accessible in the future.

Short and Long distance trips are analysed separately, as time, distance and availability differs for both route types. It is important to investigate short and long distance travel separately when exploring the best reform strategies for UK transport for each mode (DfT 2010), as there are varied transport options, fuel efficiency, capacity values and frequencies for each travel type.

Short Distance travel in the UK is based predominately on frequent, convenient trips; a journey under 50km or taking less than 60 minutes and usually for the purpose of commuting to work or local shopping. Across Great Britain, such journey takes an average of 33 minutes (DfT 2010).

UK long distance journeys are over 50km or take more than 60 minutes, where the purpose is classed as 'leisure' i.e. visiting friends and relatives, UK tourism, day trips, business trips, sports/entertainment, holidays, students travelling between university and home etc.; 84% of leisure activities are of the designated distance (National Transport Statistics 2009), the remaining 16% are 'leisure trips' which have the short distance classification. Similarly there is an element of uncertainty when it comes to classification e.g. a journey that is 40km but takes 70 minutes, these two factors can be categorised at the analyst's discretion.

Despite long distance travel obviously occurring less frequently than short distance, it still has a great effect; just 2.3% of trips are long distance, yet such trips represent 30.2% of total kilometres travelled, higher still on strategic routes, for example 44% of traffic on the M1, 68% of traffic on the M6 and 89% of trips on West Coast Mainline, are long distance (DfT 2008).

Long distance travel is analysed using a sample route from Plymouth to Glasgow, the route is typical of long distance transport within the UK, as it includes road, rail and aviation and can be applied to any other journey. Short distance travel, due to variability over the country, is analysed using average route distances for short distance travel from the Department for Transport (2010).

### 3.2 Comparing the Environmental Impact of Transport Modes at Current use rates

#### 3.2a) Comparison of Fuel Used, Energy Consumed and CO<sub>2</sub> Released per Journey at Full Capacity:

Basic data for each mode is shown in tables 1 and 2, and these values are manipulated to compare current environmental impacts of each mode. The basic data allows for calculation of fuel used, energy consumed and CO<sub>2</sub> released per person per long or short distance journey (Journey Impact: JI) and per kilometre (Kilometre Impact: KI), at full capacity for each transport mode. Subsequently allowing to test the sustainability potential of the Transport (2010) directive and the approaches of Haan *et al* (2007).

**Table 1:** Basic Values for Short Distance Travel (National Transport Statistics 2009; 2010; DFT 2010; Rail Performance Society 2011) – For full analysis of values, see Appendix

Short Distance Transport Mode	D Average Route Distance /km	V <sub>F</sub> Fuel Used L/km	V <sub>E</sub> Energy Consumed J/km	V <sub>C</sub> CO <sub>2</sub> released g/km	C <sub>1</sub> Full Capacity
Car	18.1	0.076	95996	205	5
Motorcycle	20.0	0.042	1324512	84	1
Bicycle	6.9	0	0	0	1
Local Bus	10.8	0.28	2718	896	57
Inner City Bus	14.0	0.27	2621	864	57
Rail non-peak	30.0	0.34	168	330	254
Rail Peak	30.0	0.34	168	330	254
Walk	1.5	0	0	0	1

**Table 2:** Basic Values for Long Distance Travel (Google Maps 2010; Car Fuel Data 2006; The World Bank 2010; National Transport Statistics 2010; Virgin Trains 2010; CCT 2010; Rail Performance Society 2011; DfT 2010; Air Southwest 2010) – For full analysis of values, see Appendix

Long Distance Transport Mode	D Route Distance /km	V <sub>F</sub> Fuel Used L/km	V <sub>E</sub> Energy Consumed J/km	V <sub>C</sub> CO <sub>2</sub> released g/km	C <sub>1</sub> Full Capacity
Car	780	0.076	95996	205	5
Train	514.3	0.34	90.2	330	347
Internal Flight	676	2.019	25466	2150	50

In order to calculate the environmental impact; fuel used, energy consumed and CO<sub>2</sub> emitted per passenger in a particular journey (J<sub>F</sub>/J<sub>E</sub>/J<sub>C</sub>), manipulation of the following equation is used.

#### Equation 2: Calculating the Environmental Impact per Passenger per Journey (JI)

$$J_{F/E/C} = \frac{D \times (V_F/V_C/V_E)}{C_1}$$

J<sub>F</sub>/J<sub>E</sub>/J<sub>C</sub>= Impact: Fuel/Energy Consumed/CO<sub>2</sub> released per passenger per theoretical journey.

D = Distance /km

V<sub>F</sub> = Fuel Used per km

C<sub>1</sub> = Full Capacity

V<sub>C</sub> = CO<sub>2</sub> Emitted per km

V<sub>E</sub> = Energy Consumer per km (V<sub>F</sub> x 8.76 x 3.6 x 10<sup>6</sup>)

### 3.2b) Comparison Using Relative Frequency

The data is then put in context using a relative frequency value; a percentage of usage for a specific mode of transport, calculated from total passenger kilometres per year (National Transport Statistics 2009); tables 3 and 4 show, for example if 100 people were to undertake a long distance trip, 90.8 of them would use a car. The relative frequency is multiplied by the consumption and emission values to show the proportional environmental impact per passenger per kilometre (KI). KI is calculated using equation 3:

Equation 3: Calculating the Environmental Impact per Passenger per Kilometre (KI)

$$KI_F/KI_E/KI_C = \frac{(V_F/V_C/V_E)}{C_1}$$

$KI_F/KI_E/KI_C$  = Impact: Fuel/Energy Consumed/  
 CO<sub>2</sub> released per passenger per kilometre.  
 $C_1$  = Full Capacity  
 $V_F$  = Fuel Used per km  
 $V_C$  = CO<sub>2</sub> Released per km  
 $V_E$  = Energy Consumed per km

**Table 3:** Relative Frequencies for Each Mode of Transport for Short Distance Travel

Short Distance Transport Mode	Relative Frequency % Derived From Total Passenger km	KI <sub>F</sub> Fuel Used Per Passenger/km / L	KI <sub>E</sub> Energy Consumed Per Passenger /km / J	KI <sub>C</sub> CO <sub>2</sub> released Per Passenger/km / g	C <sub>1</sub> Full Capacity
Car	59.6	0.015	479978	0.0409	5
Motorcycle	2.4	0.042	1324512	0.084	1
Bicycle	1.3	0	0	0	1
Local Bus	6.3	0.0049	154914	0.0157	57
Inner City Bus	3.4	0.0047	149381	0.0152	57
Rail non-peak	2.1	0.0013	42760	0.0013	254
Rail Peak	2.1	0.0013	42760	0.0013	254
Walk	22.7	0	0	0	1

**Table 4:** Relative Frequencies for Each Mode of Transport for Long Distance Travel

Long Distance Transport Mode	Relative Frequency % Derived From Total Passenger km	KI <sub>F</sub> Fuel Used Per Passenger /km / L	KI <sub>E</sub> Energy Consumed Per Passenger /km / J	KI <sub>C</sub> CO <sub>2</sub> released Per Passenger /km / g	C <sub>1</sub> Full Capacity
Car	90.8	0.0152	479978	0.0409	5
Train	8.14	0.0010	31300	0.00095	347
Internal Flight	1.07	0.0404	1273285	0.043	50

Therefore, Relative Environmental Impact (RKI) is calculated by multiplying Relative Frequency by KI<sub>F</sub>/KI<sub>E</sub>/KI<sub>C</sub>. Albeit this is not fully comprehensive to show the true environmental impact for everyday travel, but it does show the comparative impact for a theoretical journey.

### 3.3 Reducing the Demand of the Passenger Car

#### 3.3ai) Testing the Reducing Demand Approach From Haan et al (2007) - Comparing Full Capacity with Current Capacity

Using *equation 2*, where  $C_1$  is replaced by the actual capacity,  $C_2$ , *table 5*, the same analysis is done to conclude the true environmental impact per passenger at existing average capacities, and the results are compared with the environmental impact of transport modes at full capacity.

**Table 5:** Current and Actual Capacity Values for Each Mode of Transport and Number of Services per Day. Adapted from: Air Southwest (2010); Van Mierlo and Maggetto (2007); DfT (2008) and DfT (2010) \*Only applicable to Long Distance Travel Calculations. For full analysis of Values, see Appendix.

Short Distance Transport Mode	$C_1$ Full Capacity	$C_2$ Actual Capacity % of $C_1$	$C_2$ Actual Capacity	N Number of Services per Day*
Car	5	33.5	1.675	/
Motorcycle	1	100	1	/
Bicycle	1	100	1	/
Local Bus	57	42	23.94	/
Inner City Bus	57	60	34.2	/
Rail non-peak	254	40	101.6	/
Rail Peak	254	70	177.8	/
Walk	1	100	1	/
Long Distance Transport Mode				
Car	5	33.5	1.675	/
Train	347	40	138.8	9
Internal Flight	50	80	40	1

#### 3.3aii) Testing the Reducing Demand Approach from Haan et al (2007) - Using Remaining Seat Phenomenon to Calculate Full Potential

Such analysis allows for the “filling empty seats” investigation; where the remaining seats on the theoretical public transport are filled with people who would alternatively drive their car at a 33.5% capacity rate, *equation 4*. This analysis tests the reducing demand technique to its fullest potential, i.e. achieving 100% public transport capacity with current infrastructure.

#### Equation 4: Calculating the Potential Savings of Full Capacity Travel

$$*S_{(F/E/C)} = N \times C_2 \times (I_F/I_E/I_C) \times (C_1 - C_2)$$

$S_{(F/E/C)}$  = Savings per transport mode in Fuel/Energy/ $CO_2$   
 N = Number of services per day (only applicable to long distance calculations)

\*NB.  $S_{(F/E/C)}$  for long distance travel calculations is savings per service (excluding N) and  $S_{(F/E/C)}$  for long distance is savings per day (when incorporating N).

As long distance travel calculations are based on a sample route, from Plymouth to Glasgow, with timetabled services, potential savings per day can be calculated,

$S_{(F/E/C)}$ ; there are 9 opportunities to take the train a day and 1 to take a flight, this is  $N$  for each mode of transport. This is obviously for a specific route and not all long distance journeys are as far as Plymouth to Glasgow, but it does show the magnitude of savings increased public transport use can make. Also, the formula to obtain these values can be applied to any route.

Short distance travel can also be analysed this way however due to the data being based on average short distance trips not timetabled services, only the savings per journey can be calculated,  $S$ .

3.3b) Testing points 2 and 3 of Transport 2010 to Achieve Point 7 - Comparing Current Capacity and Transport 2010 Target Capacities  
Points 2, 3 and 7 of Transport 2010 were:

2. Increase rail use in Great Britain (measured in passenger kilometres) from 2000 levels by 50% by 2010, with investment in infrastructure and capacity, while at the same time securing improvements in punctuality and reliability.

3. Increase bus use in the UK (measured by the number of passenger journeys) from 2000 levels by 10% by 2010.

7. Reduce greenhouse gas emissions by 12.5% from 1990 levels, and move towards a 20% reduction in carbon dioxide emissions by 2010.

As UK rail use has increased by 2% and public bus use has decreased by 1% from 2000 to 2010 (National Transport Statistics 2009), the increases in capacity tested in the analysis will be 48% and 11% respectively, *table 6*;  $C_3$ . Using such values with the manipulation of *equation 1* gives the potential 2010 savings of fuel used, energy consumed and  $CO_2$  released, according to the 10-year plan, if its proposal in 2000 had been successful. The results will be critically analysed according to proposed capacities, potential savings and comparison to Haan *et al* (2007) approaches.

**Table 6:** Proposed Capacity Values using the targets from Transport 2010 (National Transport St.) \*Increasing peak rail capacity by 48% actually increases the rate to over the full capacity, however the value is still deemed valid as many peak commuter trains have standing space.

Short Distance Transport Mode	$C_2$ Actual Capacity	% Capacity Increase	$C_3$ Proposed 2010 Capacity
Local Bus	23.94	11	26.6
Inner City Bus	34.2	11	38.0
Rail non-peak	101.6	48	150.4
Rail Peak	177.8	48	263.1*
Long Distance Transport Mode			
Train	138.8	48	205.4

Point 3 of Transport 2010 is a measure in passenger journeys, thus *equation 2* will be used with the substitution of  $C_3$  for  $C$ , however point 2 is measured in passenger kilometres therefore a manipulation of *equation 2* will be used, *equation 5*, where

distance of journey is not accounted for and Impact is measured in value per passenger/km:

Equation 5: Calculating Value Per Passenger/km for Actual Capacities

$$I_{2F}/I_{2E}/I_{2C} = \frac{(V_F/V_C/V_E)}{C_3}$$

$I_{2F}/I_{2E}/I_{2C}$  = Impact: Fuel/Energy Consumed/CO2 released per passenger per km.

$V_F$  = Fuel Used per km

$V_C$  = CO<sub>2</sub> Emitted per km

$V_E = V_F \times 8.76 \times 3.6 \times 10^6$

$C_3$  = Capacity

Using *equation 2 and 5*, the same analysis is done to conclude the true environmental impact per passenger at proposed capacities, and the results are compared to the environmental impact of transport modes at existing capacities; environmental impact of  $C_3$  is compared to those of  $C_2$  to give the proposed percentage reduction, hence the test of point 7 of transport 2010.

*3.4 Reducing Energy Intensity of the Passenger Car - Testing the Reducing Energy Intensity Approach from Haan et al (2007).*

Comparing the environmental impact from current transport with impacts from more efficient vehicles tests reducing energy intensity. Testing this approach involves comparing energy consumption and CO<sub>2</sub> release values for numerous reducing energy techniques, *table 7*; the data is manipulated to give impact value per passenger/km for current capacity  $C_2$ , and this is compared to other modes of transport available.

**Table 7:** Basic Data for Reduced Energy Intensity Methods; TDI – Turbo direct Injection, KERS – Kinetic Energy Recovery System (Regenerative Breaking). Adapted from: (Boretti 2010; Van Mierlo and Maggetto 2007; Ballis and Golias 2002) \*with traditional powertrain. For analysis of values see Appendix A.

Reduced Energy Car	$V_E$ Energy Consumed MJ/km	$V_C$ CO <sub>2</sub> Released g/km	$C_2$ Actual Capacity
Average Car	2.40	204.5	1.75
Compact*	1.38	99	1.75
Compact Hybrid	1.26	89	1.75
Electric	1.38	99.2	1.75
1.6 TDI Engine Car	1.15	82.4	1.75
1.6 TDI + KERS	1.33	95.4	1.75
1.2 TDI Engine Car	1.1	79.2	1.75
1.2 TDI + KERS			

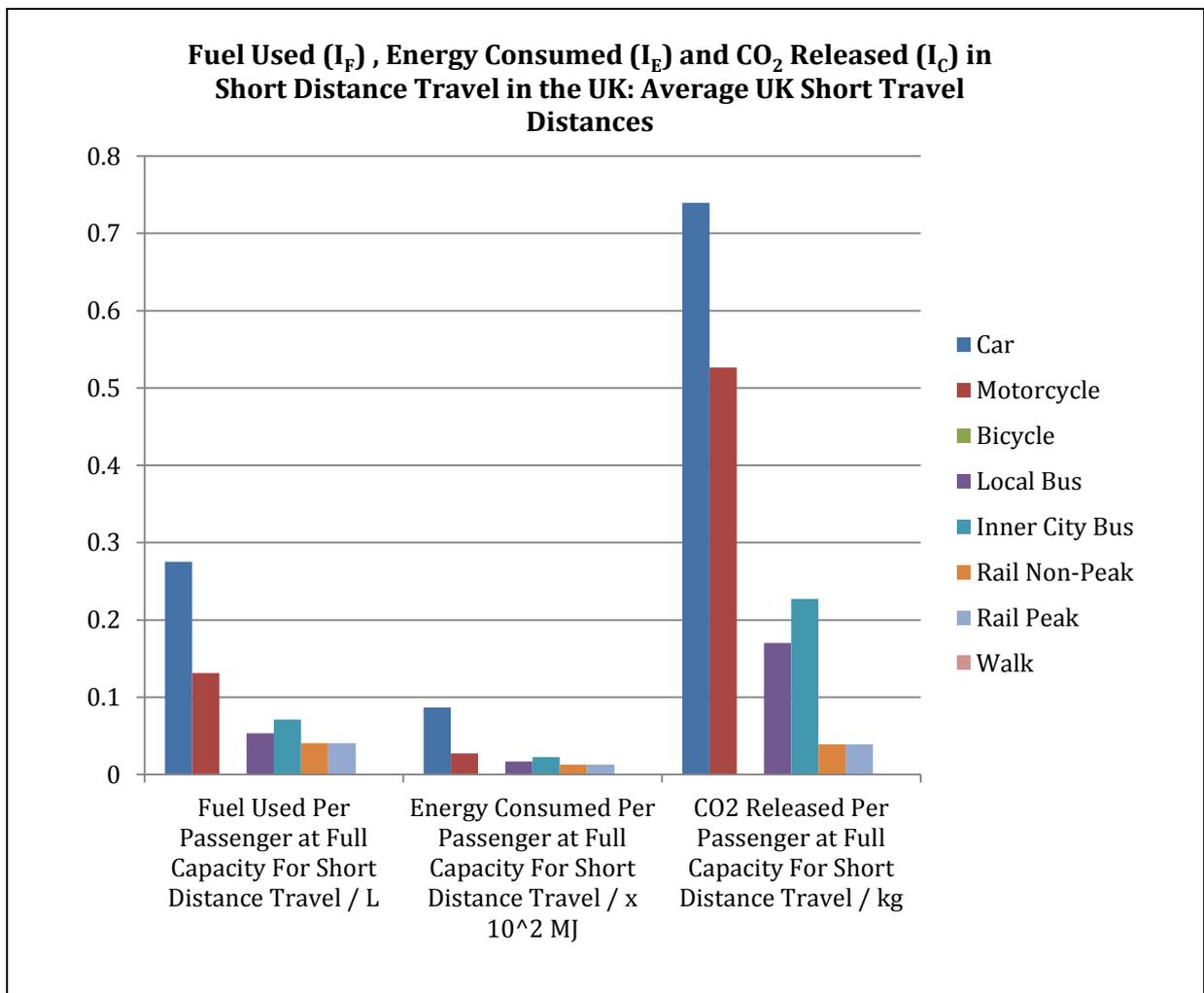
## Chapter 4

### Results

#### 4.1 Comparing the Environmental Impact of Transport Modes at Current Use Rates

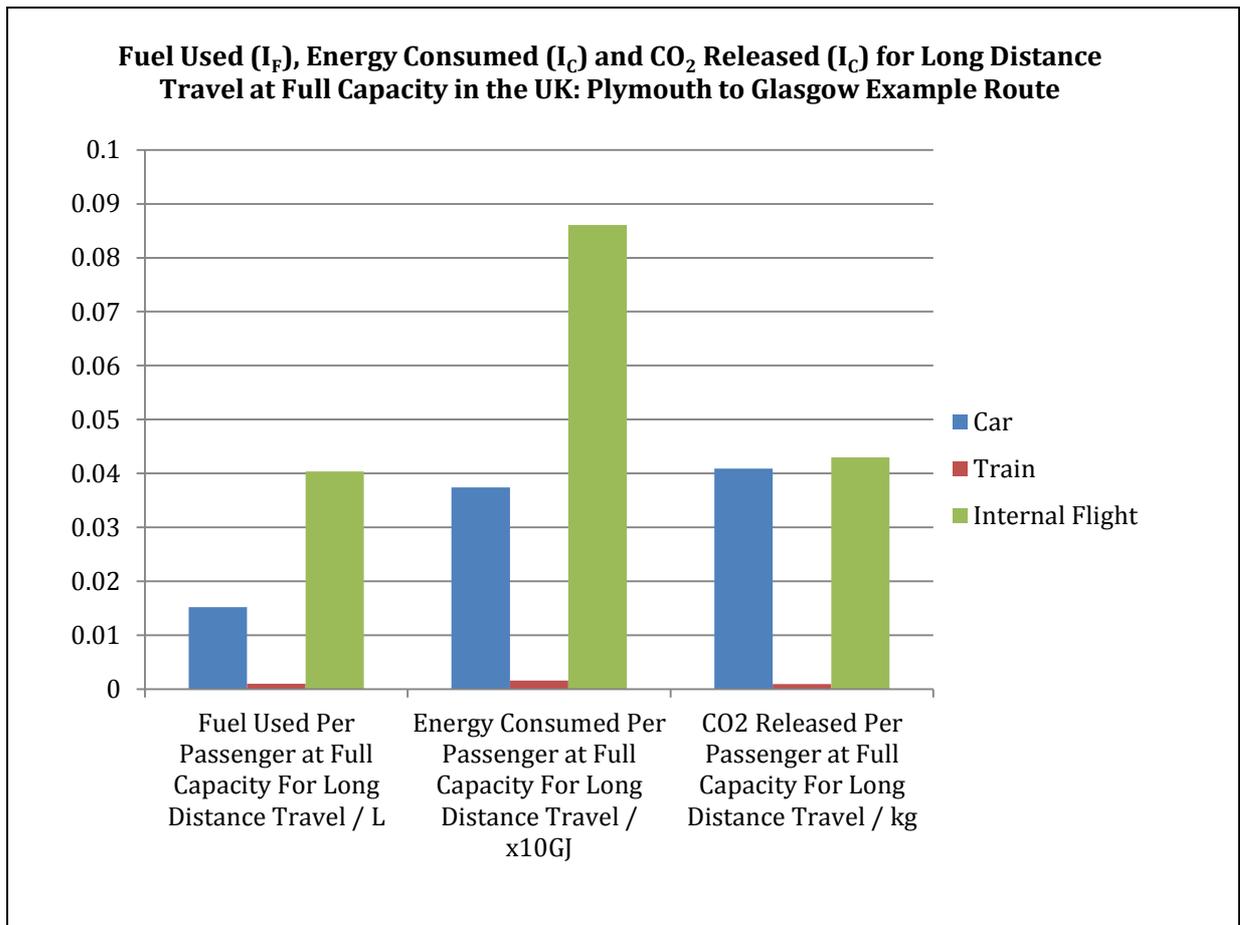
##### 4.1a) Comparison of Fuel Used, Energy Consumed and CO<sub>2</sub> Per Journey at Full Capacity.

Figure 2 shows the passenger car has considerably greater environmental impact per passenger, followed by the motorbike, the bus and then the train at full capacity for a typical short distance travel route in the UK. The bicycle and walking show zero energy and carbon impact; they are the least effecting however; such journeys are rare and inappropriate at distances over 7km.



**Figure 2:** Fuel Used ( $I_F$ ), Energy Consumed ( $I_E$ ) and CO<sub>2</sub> Released ( $I_C$ ) in Short Distance Travel in the UK: Average UK Short Travel Distances.

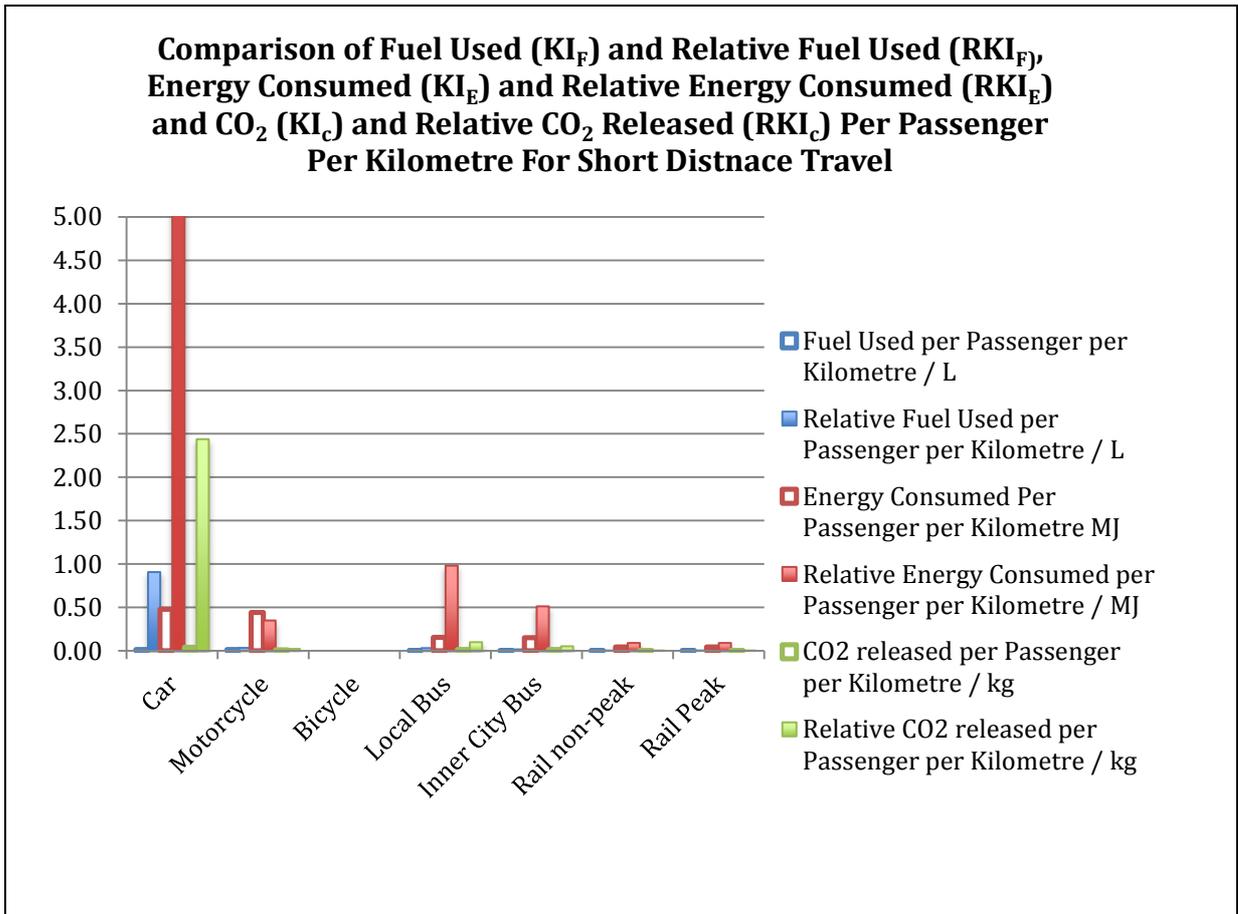
Similarly, figure 3 shows the Internal flight has considerably greater environmental impact per passenger, concerning fuel used and energy consumed, than the car and the train at full capacity for a typical long distance travel route in the UK. The CO<sub>2</sub> released per passenger is almost equal for the car and internal flight and considerable less for the train.



**Figure 3:** Fuel Used ( $I_F$ ), Energy Consumed ( $I_C$ ) and CO<sub>2</sub> ( $I_C$ ) Released for Long Distance Travel in the UK: Plymouth to Glasgow Example Route.

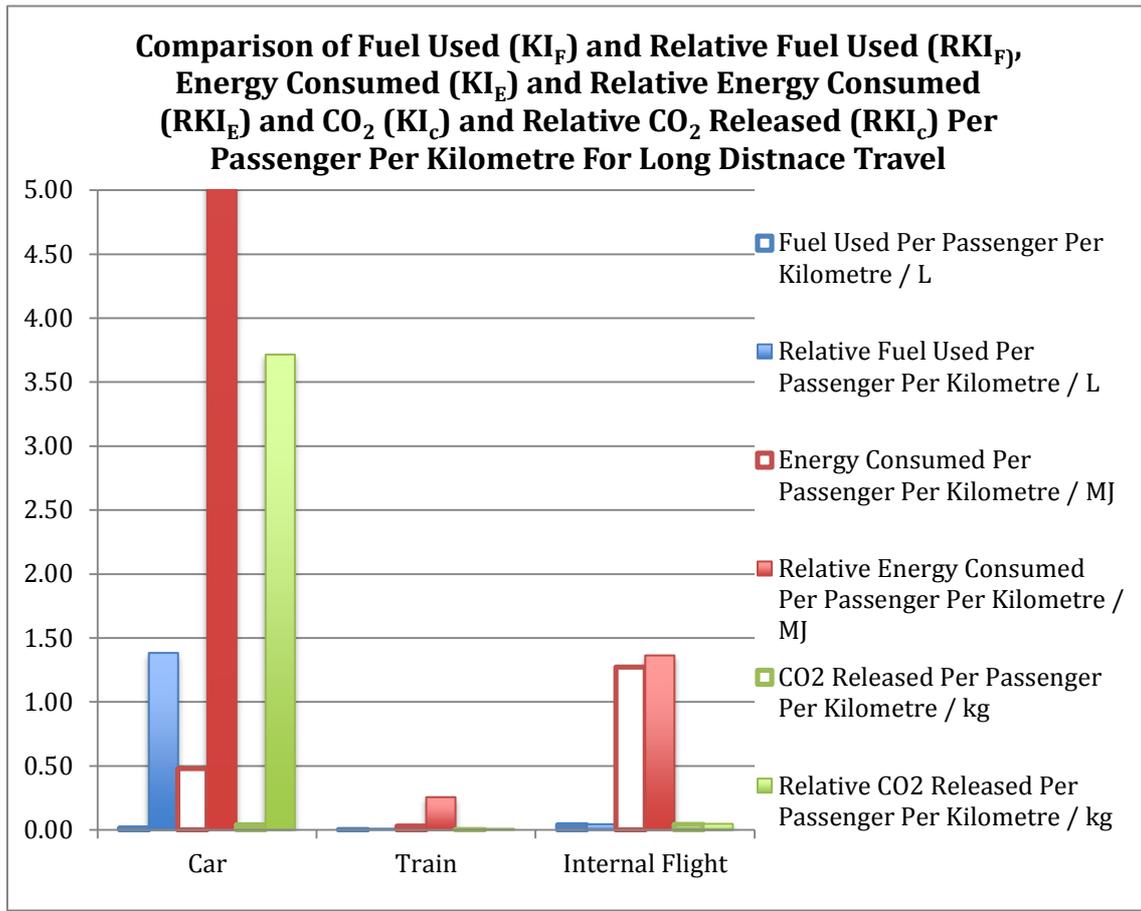
4.1b) Comparison Using Relative Frequency

The relative frequency is a theoretical value, thus does not reflect actual values of travel, yet it does demonstrate the proportion of travel usage, and how the population's decisions can affect the environmental impact; *figure 4* shows the passenger car has a much larger overall impact as 59.6% of short distance travel is undertaken by car.



**Figure 4:** Comparison of Fuel Used ( $KI_F$ ) and Relative Fuel Used ( $RKI_F$ ), Energy Consumed ( $KI_E$ ) and Relative Energy Consumed ( $RKI_E$ ) and  $CO_2$  ( $KI_C$ ) and Relative  $CO_2$  Released ( $RKI_C$ ) Per Passenger per Kilometre for Short Distance Travel. NB. Relative Energy Consumed for the passenger car in fact reaches 28.6 MJ.

Similarly *figure 5* shows, compared to the train and the internal flight the passenger car has a much larger effect due to its frequent use; 90.8% of long distance journeys are undertaken in a car. The relative environmental impact shows the passenger car, despite being the least efficient and the largest consumer of energy and emitter of  $CO_2$ , is the most frequently used. Thus, reducing such usage by a certain amount would decrease the environmental impact of the passenger car by an increased amount.

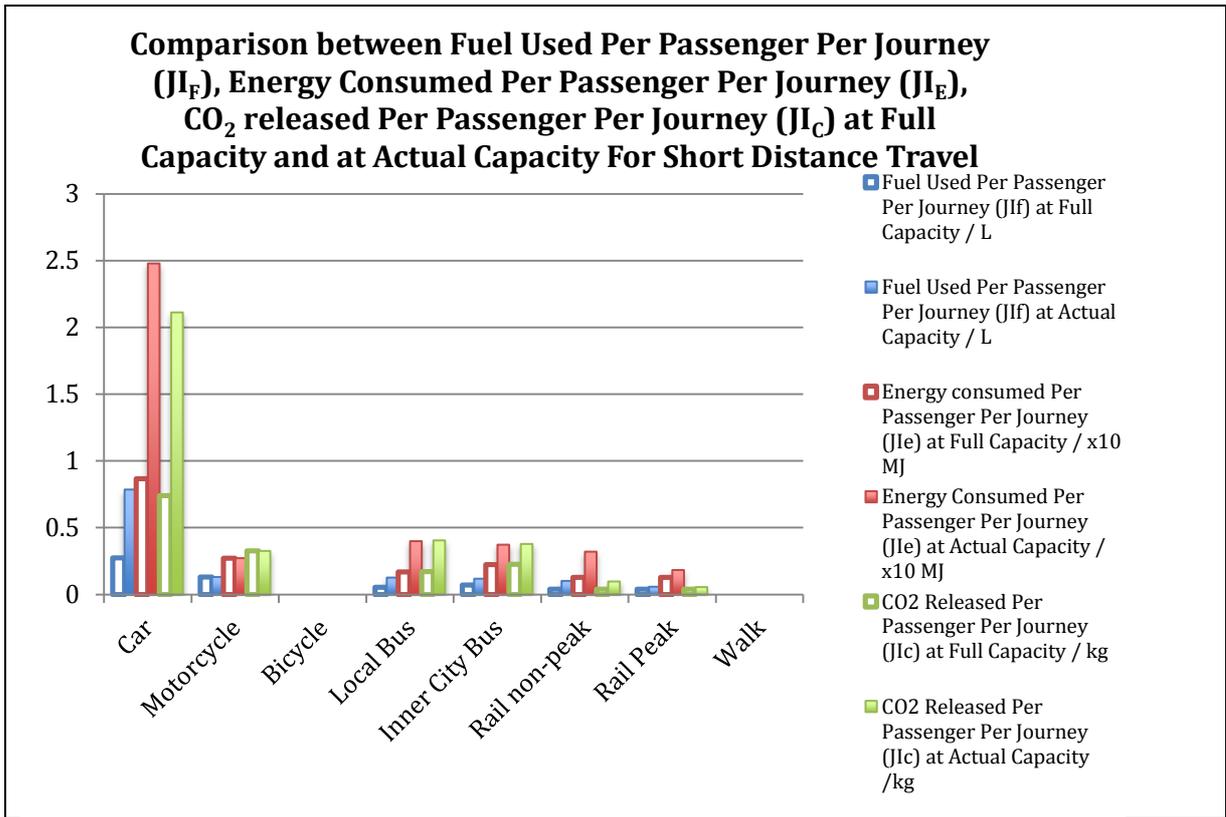


**Figure 5:** Comparison of Fuel Used ( $KI_F$ ) and Relative Fuel Used ( $RKI_F$ ), Energy Consumed ( $KI_E$ ) and Relative Energy Consumed ( $RKI_E$ ) and  $CO_2$  ( $KI_C$ ) and Relative  $CO_2$  Released ( $RKI_C$ ) Per Passenger per Kilometre for Long Distance Travel. NB. Relative Energy Consumed for the passenger car in fact reaches 43.6 MJ.

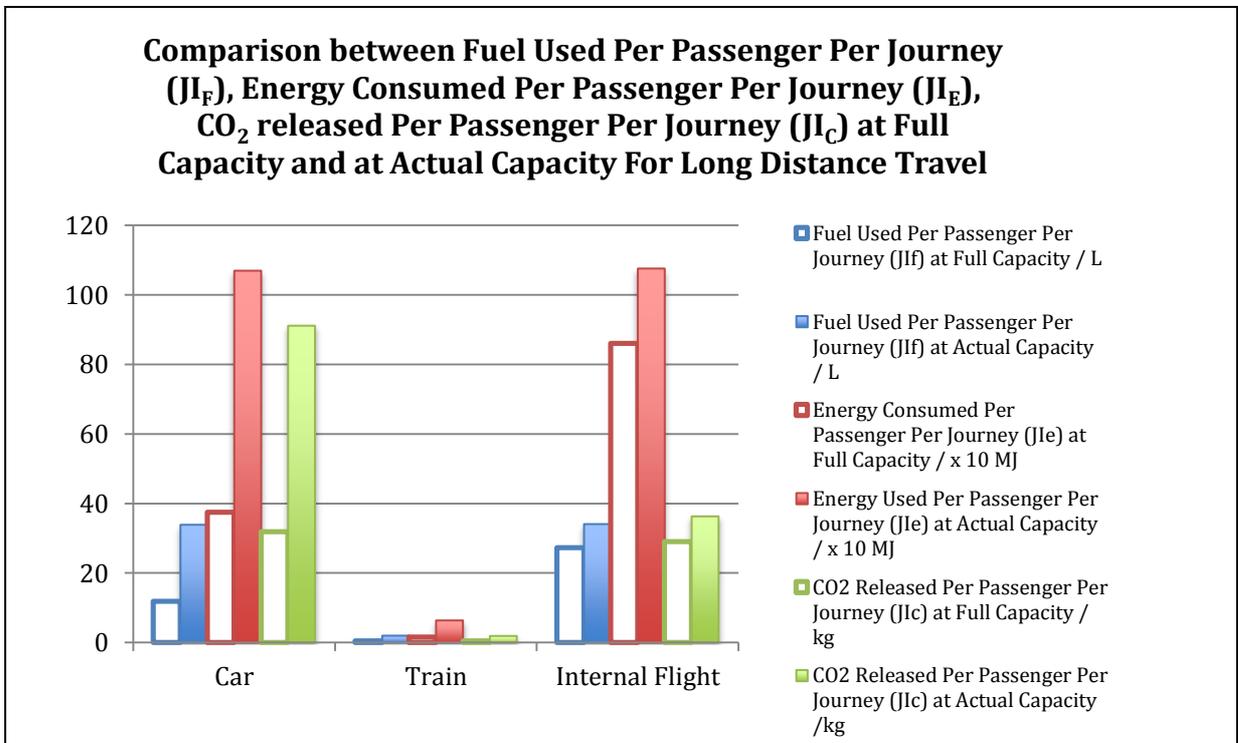
#### 4.2 Reducing the Demand of the Passenger Car

##### 4.2ai) Testing the Reducing Demand Approach from Haan et al (2007) - Comparing Full Capacity with Current Capacity

Figure 6 shows the comparison between the fuel used, energy consumed and  $CO_2$  released per passenger at full capacity and at actual capacity for short distance travel. When actual capacity is taken into account the effect per passenger is much greater, subsequently implying much wasted energy and unnecessary release of  $CO_2$ . Similarly, figure 7 illustrates that despite the car being smaller and requiring less fuel than a small plane, the environmental impact when actual capacity rates are taken into consideration for long distance travel, the passenger car has equal or greater negative effect. For the train, even with a relatively low capacity rate of 40%, the associated impact is comparatively low: never reaching above 5L of fuel, 100MJ of energy and 5kg of  $CO_2$  per passenger for a 514.3 km trip.



**Figure 6:** Comparison between Fuel Used per Passenger per Journey ( $J_{IF}$ ), Energy Consumed per Passenger per Journey ( $J_{IE}$ ),  $CO_2$  released Per Passenger per Journey ( $J_{IC}$ ) at Full Capacity and at Actual Capacity, For Short Distance Travel.



**Figure 7:** Comparison between Fuel Used per Passenger per Journey ( $J_{IF}$ ), Energy Consumed per Passenger per Journey ( $J_{IE}$ ),  $CO_2$  released Per Passenger per Journey ( $J_{IC}$ ) at Full Capacity and at Actual Capacity, For Long Distance Travel.

4.2a) Testing the Reducing Demand Approach from Haan et al (2007) - Using Remaining Seat Phenomenon to Calculate Full Potential

Using information from figures 6 and 7, the associated fuel, energy and CO<sub>2</sub> savings can be calculated, in terms of reduced car journeys, if the remaining seats on public transport were filled by people who would alternatively use a car at a 33.5% capacity; table 8 for short distance travel and table 9 for long distance. The associated savings are if 100% capacity is reached on public transport, obviously this is impossible, yet it gives the scale of potential increase in public transport use can have, using current infrastructure. Such model illustrates the effect car sharing can have; table 8 shows a full car saves almost two alternative journeys in 33.5% filled cars. Hence a saving, for an average UK short distance trip, of 5L fuel, nearly 150MJ of energy and 12kg of CO<sub>2</sub> per journey.

Subsequently a viable method for reduction of long distance transport impact is filling the remaining 60% of the train and 20% of the internal flight with passengers that would alternatively use a car at 33.5% capacity, table 9; demonstrating the potential fuel, energy and CO<sub>2</sub> savings filling remaining capacity on public transport would have.

**Table 8:** Associated Savings in Fuel, Energy and CO<sub>2</sub> in terms of Alternatives to Car Journeys, per Service of Public Transport, for Short Distance Travel.

Remaining Capacity	Associated Car Journeys	Associated Fuel Savings / L	Associated Energy Savings / MJ	Associated CO <sub>2</sub> Savings / kg
Car = 3.325	1.9	5	141	12
Local Bus = 33.06	18.9	46	1434	122
Inner-City Bus = 22.8	13.0	31	989	84
Train (Non-peak) = 152.4	87.1	210	6611	563
Train (Peak) = 76.2	43.5	105	3305	282

**Table 9:** Associated Savings in Fuel, Energy and CO<sub>2</sub> in terms of Alternatives for Car Journeys, per Typical Day, For Long Distance Travel.

Remaining Capacity	Associated Car Journeys	Journeys Per Day Saved	Associated Fuel Savings /L	Associated Energy Savings /MJ	Associated CO <sub>2</sub> Savings /kg
Train = 208	118.9	1070.7	63557	2004338	170794
Plane = 10	5.7	5.7	339	31919	911
<b>Total</b>	Total=	1076.4	63896	2015035	171706

4.2b) Testing points 2 and 3 of Transport 2010 to Achieve Point 7 - Comparing Current Capacity and Transport 2010 Target Capacities

Table 10 illustrates the decreasing effects the Transport 2010 objectives would have had if they had been successful. Increasing public bus use by 10% (target 2) would have had a 9.9% decrease in environmental impact from 2000 levels. Similarly, increasing rail use by 50% (target 3) would have had a 32.4% decrease in impact for non-peak and peak travel. However, proposed 2010 targets would exceed

holding capacity on peak trains; however, this may have a true reflection as many commuter trains have standing space, thus the percentage analysis remains the same for all train services.

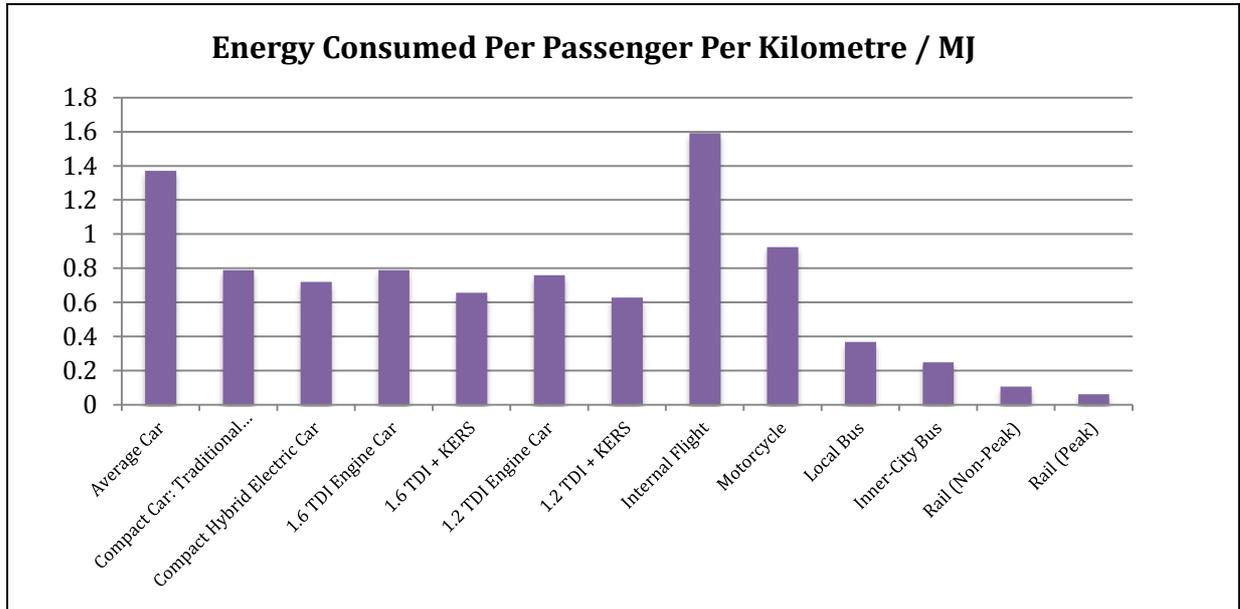
**Table 10:** The Potential Decrease in Fuel Used, Energy Consumed and CO<sub>2</sub> Released According to Transport 2010 Targets, For Short and Long Distance Travel. \*Including long distance values. \*\*Proposed 2010 exceed holding capacity, but are accounted valid due to standing space.

Transport	Fuel Used Per Passenger Per Journey (J <sub>F</sub> ) / L	Energy Consumed Per Passenger Per Journey (J <sub>E</sub> ) / MJ	CO <sub>2</sub> Released Per Passenger Per Journey (J <sub>C</sub> ) / kg
<b>Local Bus at Proposed 2010 Capacity, C<sub>3</sub></b>	0.114	3.600	0.365
<b>Local Bus at Actual Capacity, C<sub>2</sub></b>	0.127	3.996	0.406
<b>Inner City Bus at Proposed 2010 Capacity, C<sub>3</sub></b>	0.107	3.361	0.341
<b>Inner City Bus at Actual Capacity, C<sub>2</sub></b>	0.118	3.730	0.379
<b>Percentage Decrease in Environmental Impact</b>	0.099 (9.9%)	0.099 (9.9%)	0.099 (9.9%)
	Fuel Used Per Passenger Per Kilometre (K <sub>F</sub> ) / L	Energy Consumed Per Passenger Per Kilometre (K <sub>E</sub> ) / MJ	CO <sub>2</sub> Released Per Passenger Per Kilometre (K <sub>C</sub> ) / kg
<b>*Rail Non-Peak at Proposed 2010 Capacity C<sub>3</sub></b>	0.0023/*0.00168	0.072/*0.05287	0.0022/*0.00256
<b>*Rail Non-Peak at Actual Capacity, C<sub>2</sub></b>	0.0034/*0.00248	0.107/*0.07825	0.0032/*0.00379
<b>**Rail Peak at Proposed 2010 Capacity, C<sub>3</sub></b>	0.0013	0.043	0.0013
<b>Rail Peak at Actual Capacity, C<sub>2</sub></b>	0.0019	0.061	0.0018
<b>Percentage Decrease in Environmental Impact</b>	0.32432 (32.4%)	0.32432 (32.4%)	0.32432 (32.4%)

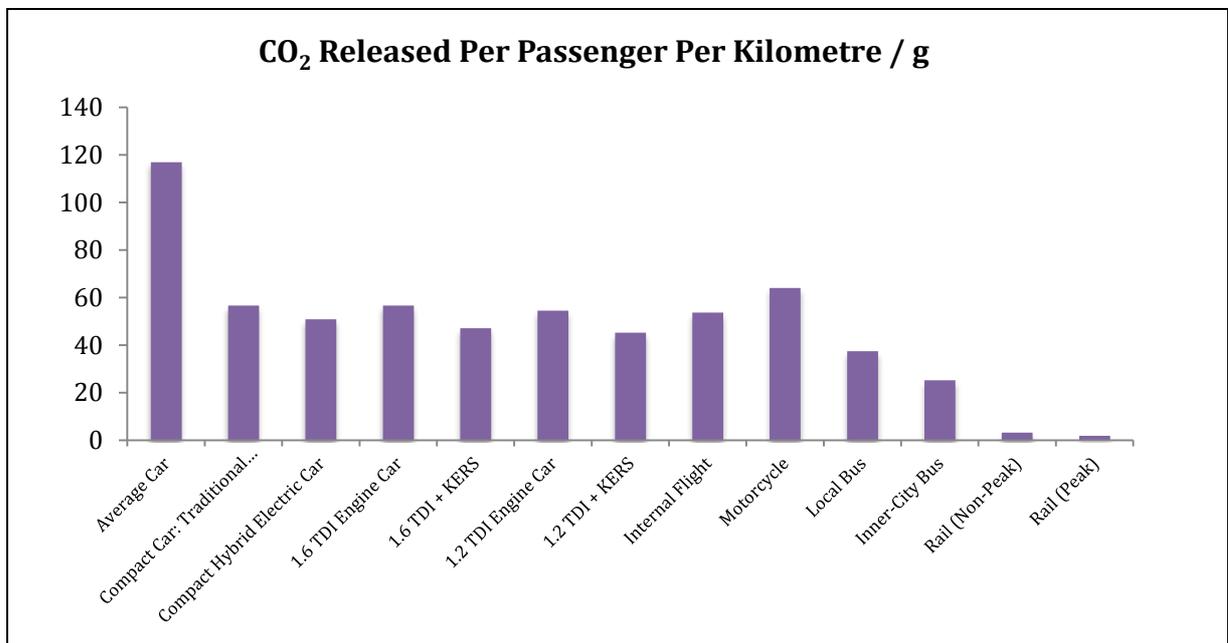
#### 4.3 Reducing Energy Intensity of the Passenger Car

Figures 8 and 9 compare all fuelled modes of transport, short and long distance, for energy consumed and CO<sub>2</sub> released per passenger per kilometre; illustrating reducing energy technology, especially hybrid and regenerative braking systems, have a large effect on decreasing energy consumed and a lessening effect on CO<sub>2</sub>

released. *Figure 9* very much highlights the need for reform of the transport sector as the average passenger car has a much larger environmental impact than any other available transport mode.



**Figure 8:** Comparison of Energy Consumed Per Passenger Per Kilometre Between Reducing Energy Intensity Methods and All Other Transport Modes Available.



**Figure 9:** Comparison of CO<sub>2</sub> Released Per Passenger Per Kilometre Between Reducing Energy Intensity Methods and All Other Transport Modes Available.

## Chapter 5

### Discussion

#### 5.1 Comparing the Environmental Impact of Transport Modes at Current Use Rates

##### 5.1a) Comparison of Fuel Used, Energy Consumed and CO<sub>2</sub> per Journey at Full Capacity.

The analysis of environmental impact of short distance travel modes, *figure 2* illustrates non-fuelled and public fuelled transport has considerably less environmental impact than private fuelled transport, hence a focus to improve bus and train services, as well as promotion of non-fuelled travel where appropriate, is necessary. In the UK, for a long distance journey, an internal flight has the largest environmental impact; followed closely by the car, *figure 3*, whilst the train vastly surpasses both modes in environmental benefit.

Thus initial analysis suggests the focus of reform should be on enhancing public transport, especially increasing rail use; coinciding with the Transport 2010 objectives. Similarly, increasing train usage over road or air transport would give investment for the energy strained future (CBI 2001), as such mode has the largest potential for improvement. Since 1995, passenger rail has improved its position substantially: average emissions per passenger kilometre falling by an estimated 22% compared to an 8% reduction from car traffic and a 5% increase from domestic air (ATOC 2007).

Furthermore, in the longer term, it is estimated that rail can provide additional passenger capacity at a carbon intensity of about half the current figure due to electric regenerative braking technology, biofuel trials and more efficient driving techniques (ATOC 2007). Hence, using data from *figures 2 and 3*, an average UK short distance journey would only release 19.5g of CO<sub>2</sub> per rail passenger as opposed to 739g per passenger in a full car. Similarly, for the sample long distance route, Plymouth to Glasgow, 31902g of CO<sub>2</sub> is emitted per passenger in a full car, yet by train, 245g is emitted per passenger, whilst providing additional capacity, according to longer term estimates (ATOC 2007).

In addition to the operational carbon reduction advances, the rail service can further contribute to omitting climate change and GHG emission by electric supply advances, whereby UK electricity generation is becoming less carbon intensive, *table 11*.

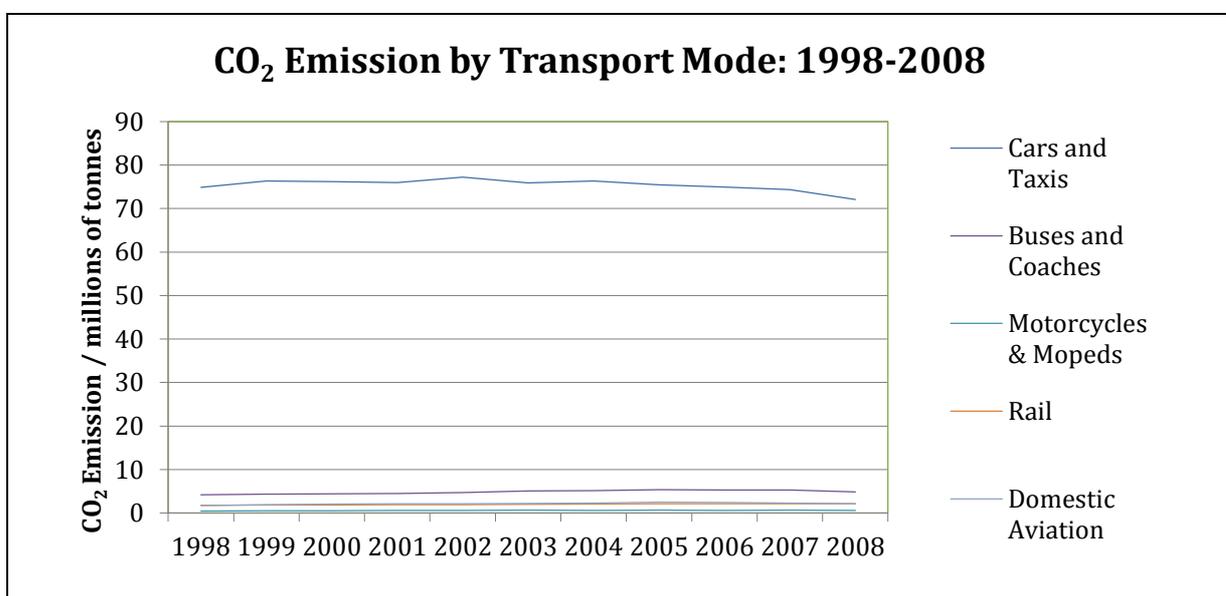
**Table 11:** Change in UK Electricity Generation Mix Since 1990 (ATOC 2007).

Year	Generation mix (%)						Carbon intensity (gCO <sub>2</sub> /kWh)**
	Coal/oil	Oil	Gas	Nuclear	Renewable	Other*	
1990	68	5	0	20	2	5	718
1995	46	3	18	26	2	6	551
1997	34	2	30	27	2	5	480
2000	32	1	37	23	3	5	472
2005	34	1	37	20	5	4	489

Looking ahead electric trains have the potential to be fully powered by electricity from renewable sources, thereby providing a carbon neutral form of transport. Conversely, the energy and carbon saving technical advances, as well as electricity supply and improvements in fuel for transport power are just as viable in road transport and aviation technology (ATOC 2007), yet it is the rail industry where it is more readily available and the relative advantage of rail is much higher (Rail Safety and Standards Board 2007).

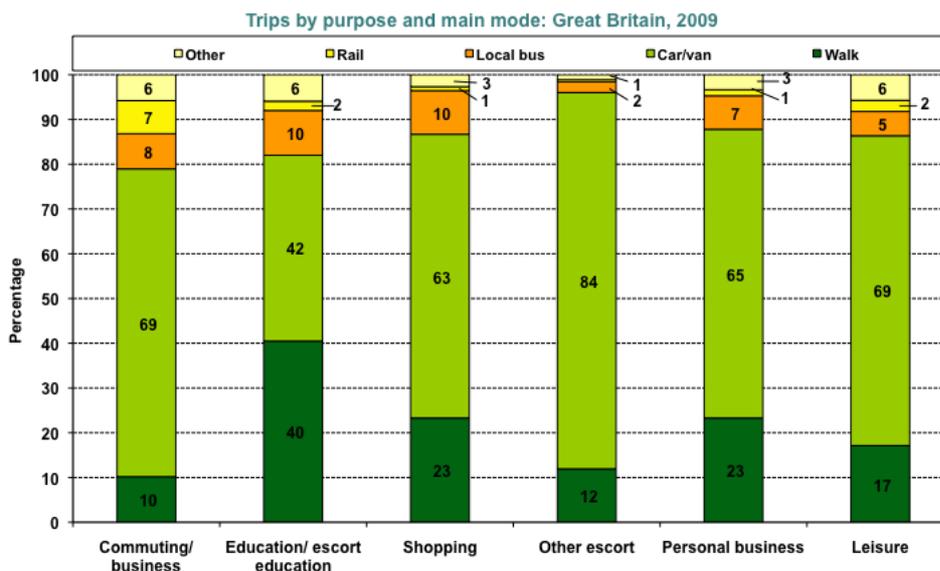
### 5.1b) Comparison Using Relative Frequency

The analysis of relative frequencies to calculate relative impact, *figures 4 and 5*, illustrate the passenger car has an average impact of 103 times that of the public transport, at full capacity. Therefore, suggesting the excessive energy consumption and GHG emission is due to the extensive use of the motorcar over other modes of transport, as well as its individual impact, highlighted in *figure 10* where private cars have a much greater total CO<sub>2</sub> emission than domestic flights, yet in *figure 3*, the analysis of one journey, the emission rates were very similar.



**Figure 10:** CO<sub>2</sub> Emission by Transport Mode: 1998-2008 (National Transport Statistics 2008).

The nearly 200-fold environmental impact the car has over the train, both due to the large CO<sub>2</sub> output and energy consumption per journey and the frequency of use of such transport mode, can be manipulated to give suggestions for reform. Due to the disproportional impact of transport modes, decreasing private fuelled transport by increasing the use of public fuelled transport, especially rail use, will have 103-fold average positive environmental effect. Hence, decreasing car and motorbike use in favour of trains, buses and in some circumstances planes by 10%, in theory will have a 1030% effect on environmental enhancement of the transport sector. *Figure 11* shows a break down of the transport sector's impact, and highlights the area of focus for reform; long distance travel, commuting, shopping, leisure and personal business is dominated by the use of the passenger car. Thus such areas would be the focus of increasing public transport use.



**Figure 11:** Trips By Purpose and Mode of Transport (DfT 2010). Where other escort equates to aspects of long distance travel.

A positive influencing factor on transport sector emission and consumption diminution is the establishment of the Internet. Between 1995 and 2009 the number of commuting trips has decreased by 16% (DfT 2010) and the last two years have seen a large fall again, highlighted in *figure 10* by a slight dip in private fuelled transport from 2008; believed to be due to the ability to work at home, due to the Internet. Similarly, the average number of shopping trips per person fell by 18% (DfT 2010) between 1995 and 2009 due to the ability to shop via the Internet. Yet, increased car ownership outweighs such phenomenon; the growth in emissions from passenger cars reflects growth in activity, whilst the influence of technological change is great, the impact is minuscule in the overall passenger car fleet (Galachoir *et al* 2009).

For short distance travel the choice of modes are vast and, exclusive of the substantial effect of the passenger car, the environmental impact between each mode are somewhat nebulous (*figure 2*), mostly due to many other influencing factors; time, route distance, accessibility and location to name a few. Yet for long distance travel, the environmental aspects are much clearer cut. *Figure 3* illustrates the environmental effect of rail transport to be significantly less than other modes, yet *figure 11* illustrates it is the mode that is used the least. However, developments have occurred in the UK to promote rail use; the introduction of high-speed rail in recent years has meant trains have cut heavily into the road and air markets for strategic routes, for example London to Manchester (ATOC 2007). In the short term at least, modal shift to rail where practicable, is a realistic way to reduce energy consumption and carbon emissions from such journeys (Rail Performance Society 2011).

## 5.2 Testing the reducing demand approach from Haan et al (2007)

### 5.2a) Comparing Full Capacity with Current Capacity and Using Remaining Seat Phenomenon to Calculate Full Potential

A decrease in environmental impact is possible if capacity was increased on public transport; *figures 6 and 7* show the true fuel used, energy consumed and CO<sub>2</sub> released per passenger at actual capacity rates; where the difference between the outlined and blocked lines show the potential savings if such mode ran at full capacity. For short distance travel in the UK the car, by nearly 10 times, has a larger environmental impact than public transport at their normal capacities, even when the public transport capacity is lower, *figure 6*. Subsequently, a model can be used to calculate the potential, using existing infrastructure, to mitigate release of GHGs and reduce the reliance on oil, *table 8*. It demonstrates the associated fuel, energy and CO<sub>2</sub> savings full capacity public travel can have per service. Consequently, multiplying the numbers by how many services run per day, would have a large impact. The DfT (2010) states a UK citizen makes an average of 973 short distance trips per year, equating to 2.7 trips per day, with an average trip length of 11km, the average of short distance travel. Thus using the relative frequencies from *table 3* it can be calculated that on average, a person in the UK theoretically makes 1.6 trips by car, 0.06 by motorcycle, 0.17 by local bus, 0.09 by inner-city bus and 0.11 by peak and non-peak trains each day, which is vastly disproportionate. Whilst considering the total associated car journeys from public transport savings in *table 8*, 162.5, there theoretically over 150 public transport options, which are wasted, at each point in the day to make the 2.7 trips.

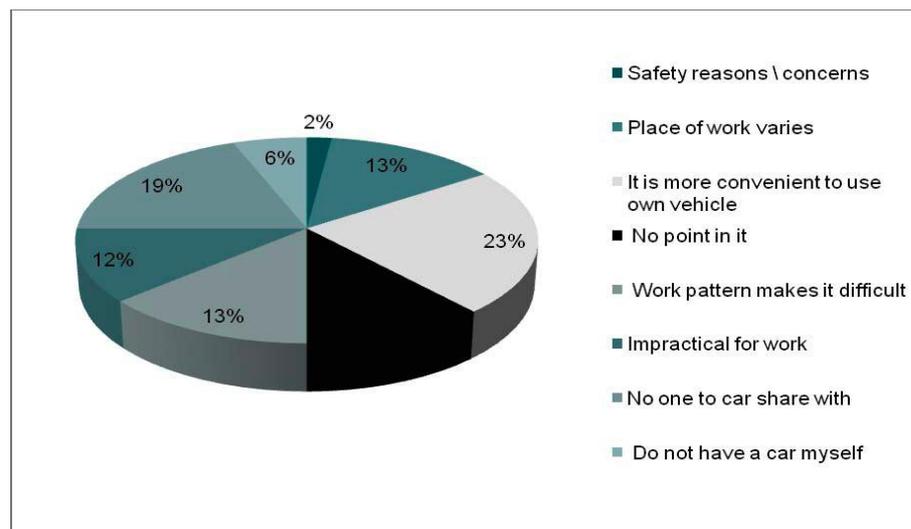
The car is accounted for in this model as it reflects the impact car-pooling can have; 5L of fuel, 141MJ, and 12kg of CO<sub>2</sub> is saved by driving a full car for an average UK short distance trip, instead of 33.5% full. Thus, if 5 commuters car-pooled for an average business year 2300L of fuel, 64.9 GJ and 5520kg of CO<sub>2</sub> would be saved.

Reducing demand for the passenger car for frequent, short distance travel can be achieved through a number of methods; increase the band gap for car tax in conjunction with focussing it more on the amount of CO<sub>2</sub> the vehicle releases, to encourage the purchasing of more efficient vehicles. The existing banding appears too relaxed; as the environmental impact of the passenger car has increased (Fullerton and West 2010). However, the prospect of change is oncoming; car showrooms display fuel economy labels as well as car road tax payable each year (Direct Gov 2011), making such values more accessible on purchase. Increasing the cost of owning a car promotes the use of public transport, yet is disproportionate to use; frequent drivers pay the same as occasional drivers. Similarly, widening the tax band gap would encourage scrapping older, less efficient, cars for newer, less expensive, greener band cars, which is unsustainable in itself (Chester and Horvath 2009). Therefore, along with the introduction of increased taxes there would need to be incentives for responsible scrapping (Lelli et al 2010).

To make driving expenses impartial to car use, incremental charges whilst driving is perhaps an improved method from car tax; tolls, congestion charges or increased inner-city or town parking fees would have a similar effect but focusing on the frequent driver. Additionally, this initiative would reduce inner city traffic somewhat and encourage the use of the public transport without enhancing its service. In

reverse to increasing expenditure, incentives for travellers to drive more efficiently and environmentally aware is an additional approach; equally, charges could be enforced if individuals do not partake in an energy saving or reduced carbon travel option (Begg and Gray 2004).

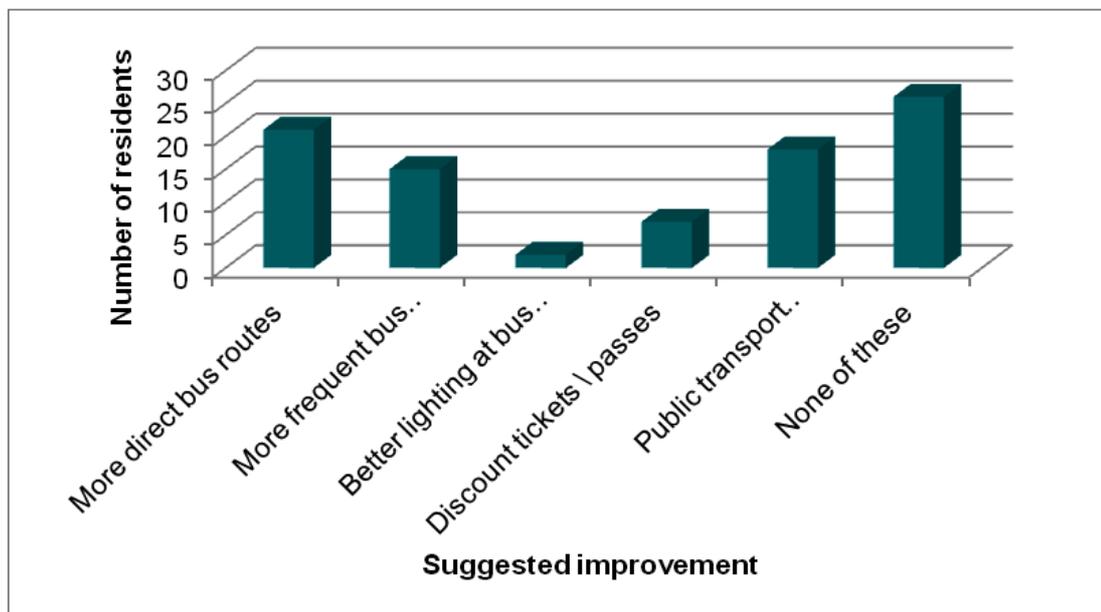
Incentives to car share are advantageous, reflected in *table 8* where carpooling has the effect of up to 65% on reduction of environmental impact. Schemes such as closer parking spaces at work or at shops, high occupancy vehicle lanes or a carbon savings point system could enable financial incentives to encourage more sustainability and help mitigate the effects of climate change (Banister 2007). The benefits to car sharers would be less road congestion, quicker journeys, reduced fuel and parking fees and increased personal security for the travellers. In the UK, high occupancy vehicles are currently seen in areas with high congestion (DfT 2010). The UK's first motorway car sharing lane was opened in March 2008, it links the southbound M606 near Bradford to the eastbound M62 towards Leeds, allowing car sharers to avoid congestion at junction 26, and get priority entry onto the M62 eastbound and as well as cars with at least one passenger the lane can be used by coaches, buses and taxis when carrying passengers (Direct Gov 2011). However, *figure 12*; results from a survey in Milton Keynes UK, suggests there are many negative attitudes towards car sharing.



**Figure 12:** Reasons For Not Participating In Car Sharing (DfT and Milton Keynes Council 2010)

*Figure 12* gives evidence for the need for an established car-sharing scheme. Another viable system is car clubs; car clubs provide their members with quick and easy access to a car when required, bookings can be made in advance or a few minutes before required and collection is made from local designated parking bays. It's a good thing for travellers if you only need a car occasionally, and would save you money if you owned and ran a car but only drove it 8000 miles per year (Direct Gov 2010); such scheme would very much discourage convenience use of the car. Furthermore, subsidising mass transit to improve public transport would have effect; decreased prices or a points system to encourage the use of buses and trains, enhancing service timetables i.e. more frequent services, especially at peak times and development of the routes so that it reaches more people in suburbs and

surrounding towns and villages to cities (Hensher 2009; Musti *et al* 2011). Furthermore, a universal pre-paid ticket, like London's Oyster Card, would make paying for public transport more efficient and possibly cheaper for the traveller. The main concern for public transport is accessibility, reliability, price and quality of service (*figure 13*) and thus these need to be addressed alongside the introduction of targets.



**Figure 13:** Suggested Improvements For Public Transport (DfT and Milton Keynes Council 2010).

The analysis of long distance travel, *figure 7*, illustrates that despite the internal flight consuming more energy and releasing more CO<sub>2</sub> than the car per passenger, per journey, when actual capacity is taken into consideration the environmental impact per passenger is considerably more for the car. Correspondingly, the environmental impact of the train remains minimal, in spite of its low actual capacity. Hence, encouraging use of public transport as opposed to the car would be a viable approach, verified by *table 9*; where 6.4 x 10<sup>4</sup>L of fuel, 2 TJ and 1.7 x 10<sup>5</sup>kg of CO<sub>2</sub> can be saved a day, with full use of public transport for a theoretical long distance route in the UK.

The reducing demand techniques have the potential to lessen the transport sector's fuel consumption and GHG emission; Chester *et al* (2010) highlight the need for increasing bus and especially train use in favour of the motor car for commuting and shopping and *figure 7* emphasizes the potential enhancement increasing train use over the passenger car can make. Such aspects are reflected in objectives 2 and 3 of Transport 2010 and are tested in *table 10*.

It is clear from the analysis of long distance travel the train consumes the least energy and releases the least amount of CO<sub>2</sub> per passenger than any other fuelled mode, even at low capacity rates. Thus transport strategy in the UK should be based, fundamentally, on increasing train use in favour of other transport modes. For long distance, infrequent travel increased train usage is a viable option as it is fast, direct and sufficiently flexible, however, for short distance travel rail may only be an option in some cases.

One of the main barriers for conversion to rail for long distance travel is the price; fourteen percent of an average UK families' revenue is devoted to transport (Van Mierlo and Maggetto 2007), consequently the cost of travel is a huge aspect, as well as the relative importance of cost and time (Musti *et al* 2011). To undertake the example journey in this investigation it costs on average £62 in fuel, by car, £96 for an internal flight and £178 by train, whilst a return journey is £124, £192 and £183 respectively, for standard off peak travel (AirSouthWest 2010; Car Fuel Data 2006; The Trainline.com 2010). Despite the return journey being £9 less for train than the internal flight, the flight takes 324 less minutes. Even though the train takes a similar time than the car, it is on average, double the price. The price and time aspects reflect the fact the train is the least popular method of long distance travel and in order to achieve transport reform this should be addressed. Additionally, a group of travellers will be disinclined to use public transport, as it becomes 21% less economic per passenger to get a train instead of travelling in a full capacity car. Hence, group save schemes should be enforced to essentially make it cheaper to travel by public transport than it would by car (Essen 2009).

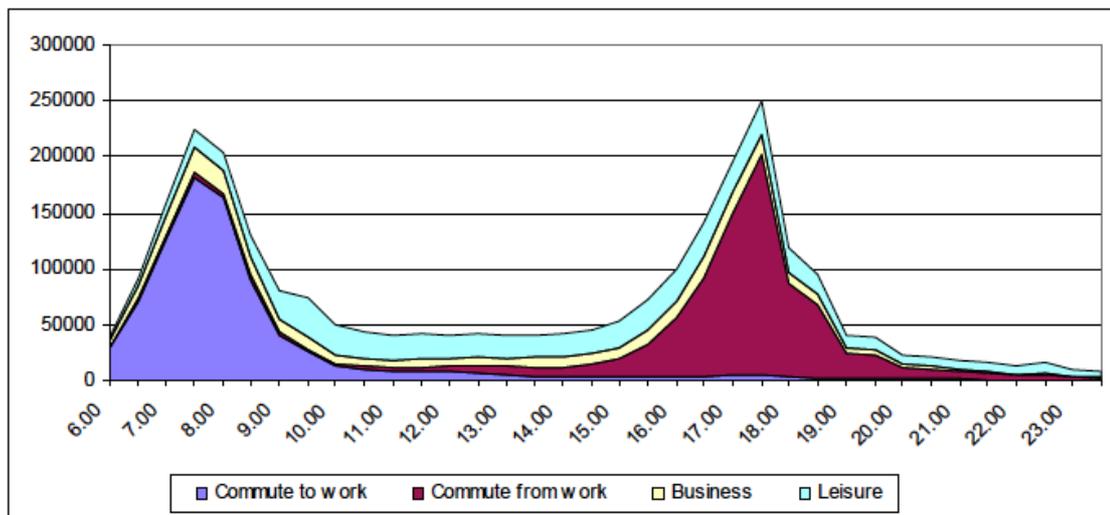
Furthermore, a consumer survey revealed rail is the only transport mode by which less than 50% of the respondents are satisfied and about 25% of the respondents have experienced problems with this service in the last 12 months. In contrast, only about 15% of the respondents have had problems with new motor vehicles or air transport (Rothbauer and Sieg 2010). Thus suggesting an enhanced quality regulation is an appropriate policy to increase the modal share of rail transport.

To increase the quality options for travellers and to reduce anthropogenic greenhouse gas emissions a noteworthy alternative is a policy to support entry into the rail passenger transport market. Increased competition increases the output, and more passengers will use trains instead of other transport modes with higher emissions (Chung-Wen and Lee 2010).

#### 5.2b) Testing Points 2 and 3 of Transport 2010 to Achieve Point 7

After performing a reducing demand analysis on the Transport 2010 proposed capacity rates, a total of 41.1% decrease in environmental impact would have been achieved if points 2 and 3 were successful, 9.9% for bus and 32.4% for rail. Albeit the objectives are somewhat flawed; point 7 endeavours to reduce GHG emission by 12.5%, whilst reducing CO<sub>2</sub> emission by 20%, deeming the first statement irrelevant as of the total greenhouse gas emissions from transport, over 85% are due to CO<sub>2</sub> emissions (Hensher 2008). The remaining greenhouse gases; water vapour, methane, ozone and nitrous oxide have decreased by 20% (Department for Energy and Climate Change 2011) due to improved engine systems (Banister 2007). Thus, considering the greenhouse gases separately, it is only CO<sub>2</sub> that requires the 12.5% reduction, which is covered as point 7 states a 20% reduction target. Similarly, achieving points 2 and 3 would in fact have a 41.1% reduction in CO<sub>2</sub> release, a significantly greater amount than stated in point 7. Furthermore, when considering reduction targets 1 and 4 the percentage increase would be higher still, therefore, integration between targets is necessary. Furthermore, Transport 2010 does not include incentives for car-pooling and measures of reducing energy intensity, which, from *table 8 and figures 4 and 5*, prove viable approaches.

Irrespective of whether the objectives of Transport 2010 were relevant, the targets concerning climate change and energy consumption were not achieved; UK rail use has only increased by 2% and public bus use decreased by 1% (National Transport Statistics 2009), necessitating for a more deliberated transport strategy in the UK. In order for Transport reform schemes to be successful, the targets need to be more associated with location and time of travel, as *figures 14 and table 12* show at different locations in the UK and at different times across the day, travel can be diverse and therefore targets need to be according with this (Lindsey *et al* 2011). Occupancy of transport routes also changes at different times of the year; the highest traffic occupancy rates are during school holidays and bank holidays (Rail Safety and Standard Board 2007).



**Figure 14:** Number of Travellers and Reason for Travel Against Time, Across the UK (National Rail Travel Survey 2010).

**Table 12:** Rail Commutes Across the UK (National Rail Travel Survey 2010).

	Number and percentage	
	000s	%
Scotland	181	7
Wales	48	2
North East	26	1
North West	198	7
Yorkshire and Humberside	127	5
East Midlands	52	2
West Midlands	121	5
East of England	209	8
London	1,275	48
South East	373	14
South West	73	3
<b>Total</b>	<b>2,682</b>	<b>100</b>

Percentages do not sum to 100 per cent due to rounding

In Austin, Texas a study (Musti *et al* 2011) reveals the population are concerned about climate change yet only 60% are willing to change their behaviour according to transport decisions. Amongst women, younger people and higher income households there is support for taxing energy use and imposition of energy saving regulations, whereas other groups support energy caps and better transit access to promote public transport. The study reflects many of the UK population opinions (DEFRA 2008) and highlights some of the problems associated with reducing the demand for the passenger car.

Additionally, the recent recession has made both negative and positive impacts on UK transport infrastructure. As a result of the downturn in the economy there has been little or no funding for enhancing or improving transport initiatives (Fullerton and West 2010). There have not been investment opportunities to initiate or sustain some schemes that would have reduced the contributions of climate change. Conversely, the individual may as a result of necessity review their travel patterns and methods favouring more economical vehicles, greener public transport, walking or cycling. These lifestyle changes may be sustained into the future that would have a positive contribution. Initiatives such as Climate Week provide an opportunity for raising awareness and may impact on long-term public attitudes and opinions. Climate Week is a national occasion, taking place March 21<sup>st</sup>-27<sup>th</sup> 2011 that offers an annual renewal of our ambition to combat climate change, by reducing carbon emissions. It is for everyone wanting to do their bit to protect our planet and create a secure future; companies and many transport organisations, and local councils have signed up to share ideas and take action through schemes such as zero energy and carbon commute (Climate Week 2011).

*5.3 The Reducing Energy Intensity Approach from Haan et al (2007).* The methods which were tested, to reduce energy intensity of the passenger car in this investigation were Turbo Direct Injection and regenerative braking systems. *Figure 8* illustrates driving a compact car as opposed to the average UK car reduces energy consumption by almost 43% and reduced energy technology almost halves the energy consumption, whilst a further 20% reduction from this value when regenerative braking systems are introduced. Despite the potential savings reduced energy intensity can make, the comparison between all transport modes available show public transport still has the least energy consumption per passenger per kilometre, even at such low current capacity rates.

*Figure 9* is the foremost illustration highlighting the need for UK transport sector reform; at current capacity rates, every other transport mode available, for short and long distance travel, has 50% less CO<sub>2</sub> release per passenger per kilometre. Considering the onset of climate change and the diminishing global oil supplies, such phenomenon is the grounds for critical reanalysis of UK transport strategy; enforcement of policy to encourage the use of alternative viable transport modes other than the average passenger car are insufficient and ineffective.

Although increased public transport use has the potential to reduce environmental impact by 41%, *table 10*, the accessibility of public transit will never be wholly adequate for the population's needs and society will always demand private transport at some points in time (Boretti 2010). Thus, reducing energy intensity and CO<sub>2</sub> release of the passenger car is an essential technological development.

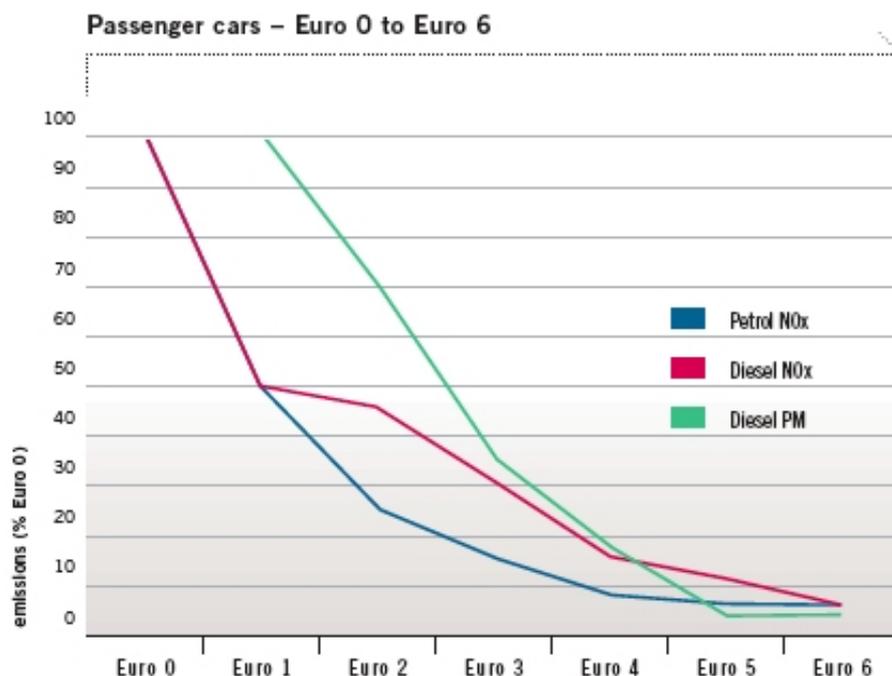
The KERS and the diesel TDI engine concept are potential enablers of dramatic improvements in vehicle fuel economy. Furthermore, hydrogen energy technology, H<sub>2</sub>ICE is able to deliver better than diesel part load efficiencies (Boretti 2010). Synergies of the three technological engines, coupled with H<sub>2</sub>ICE may be considered a benchmark for fuel efficiency use with today's technology and H<sub>2</sub>ICE with KERS, not readily available yet, furthers this benchmarking (Boretti 2010).

Increasing the efficiency of the passenger car is a viable reducing energy intensity method; Ahmen *et al* (2001) illustrates a comparison between the powertrain and vehicle efficiencies in future techniques compared to current efficiency of the average passenger car (ICEV). The battery driven powertrain reaches the highest efficiency and the hybrid and fuel cell follow second, driven by methanol.

The energy efficiency of the different means of transportation varies strongly as a result of the thermodynamic laws, type of technology, and power level (Van Mierlo and Maggetto 2007); the energy efficiency of a car in a city falls below 15%, and 80% of cars are driven in city traffic (Van Mierlo and Maggetto 2007; Dahlquist et al 2007), notwithstanding the fact from a 50 litre fuel tank only 7.5 litres are useful and the remaining 42.5 litres are transformed into heat and pollutants (Dahlquist 2005). By using hybrid technology the fuel consumption in city traffic can be lowered by 25% (Dahlquist et al 2007), and even more so with the development of fuel cell technology (Van Mierlo and Maggetto 2007). *Figures 8 and 9* also illustrate driving a compact car reduces environmental impact considerably; the best compact, C class, vehicle available today couples thermal engine, electric motor, generator, battery pack and drive wheels to power the vehicle with modulated thermal and electric motors and recovery of braking energy (Boretti 2010), and reduction of the weight of cars may contribute to 10–15% reduction of total fuel and energy consumption (Dahlquist et al 2007).

In order to achieve greater movement to more efficient, less energy consuming and CO<sub>2</sub> emitting cars, different taxation policy is necessary to direct consumers to buy smaller and lighter cars (Fullerton and West 2010). Currently in the UK there are tax band ratings from green or band A, the most efficient to red or band G the least efficient and how much road tax is payable each year is according to such band; recently, car showrooms are obliged to display fuel economy labels on every car which is an affirmative progression to energy tax awareness (Direct Gov 2011). Similarly, from this year onwards all new cars will have to meet Euro 5 standards; reducing particulate emissions of diesel cars to similar levels of petrol and from September 2015. New cars will have to meet Euro 6 standards *figure 15*; reducing carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxide (NO<sub>x</sub>) emissions ever more so (ACEA 2011).

Efficiency taxation policy is developing within the UK, however evidence of increased car ownership and increased passenger car emission indicates the need for more stringent taxations (DfT 2010). A system where the barriers between each efficiency grade are wider, hence further increasing tariffs for higher band cars, whilst decreasing tariffs for lower bands, is a viable option to achieve fleets of more efficient cars on UK roads. Similarly, directing taxation policy also on associated CO<sub>2</sub> release of the vehicle, as well as efficiency and energy consumption would contribute to the movement towards zero carbon intensity.



**Figure 15:** Passenger Car Emissions Against Euro 0-6 (ACEA 2011).

It is both an ecological necessity and a technological challenge to reduce the dependence on oil from the current level of 98%, by improving the energy efficiency of transport and the future development of alternative fuels (Van Mierlo and Maggetto 2007). However, there are a few obstacles to such advancements; vehicles which have decreased in weight and dimensions per load volume and the changes in multiple mechanical aspects to give energy savings through electric generation, lowers the effectiveness, as such cars are environmentally expensive to produce, maintain and dispose (Boretti 2010).

The introduction of more efficient products into the market is often accompanied by macroeconomic rebound effects (Borretti 2010). If a product or service becomes more efficient, regarding energy use or the use of other resources, it will also become cheaper: higher energy-efficiency in both production and operational phase would mean a lower sales price and lower running costs, hence increased demand (Haan *et al* 2007) and such phenomenon counteracts the positive effect of increased efficiency.

The definition, identification and quantification of rebound effects are areas of ongoing research, yet generally, three different rebound effects might be induced: a direct effect; increased demand for the same service as it has become cheaper, an indirect or secondary effect; increased demand for other services as more purchasing power has become available and a macro-scale effect; structural effects on larger parts of the economy due to changed demand, production and distribution patterns (Haan *et al* 2006). If this was to occur, the effect of relative frequency on the associated consequence of the passenger car figures 4 and 5 would be even greater, and thus environmental benefits will be counteracted.

In conjunction with this, increased car ownership plays a varying role and socio-

psychological costs of ownership might be regarded as possible driver for rebound effects; neighbourhood pressure, norms of peer group, wealth and social or cultural backgrounds may have effect on type of car purchased (Haan *et al* 2006; Van Mierlo and Maggetto 2007). A typical example of this is socio-psychological aspects preventing or encouraging the purchase of a sport-utility vehicle (SUV), owing to consideration for the environment or the expression of wealth, respectively; for every hybrid sold in the UK, there are 27 4x4 SUVs sold (Banister 2007).

Suggesting, the real problems have been that there are only a few vehicles that are available with the low emissions profile, and consumer-purchasing patterns still favour the larger cars (Banister 2007). However, the market entry of hybrid SUVs will omit previous socio-psychological preventions, having a rebound effect on the economy and the environment (Smith 2010).

In terms of reducing demand techniques car-pooling, as an official established scheme, is a useful option as it would be the most inexpensive, immediate and using existing infrastructure, whilst the development of reducing energy and carbon intensity techniques are formulated. Despite macroeconomic effects, reducing energy intensity methods essentially will decrease the effect the passenger car has on the environment if appropriate policy to cap car ownership is enforced, yet the development requires an initial capital influx. Boretti (2010) deliberates the roles of universities and research companies is to develop new concepts, but it is then the roles of original equipment manufacturers and their suppliers to develop new technologies and ultimately deliver new products, but the global financial melt down has left very little financial support to explore new technologies, and the development of the reduced energy concept.

Yet the recent recession may have a positive effect as people buying a new car may decide to get a smaller, less energy intensive one who would usually buy a bigger car, initiating the development of the reduced energy intensity industry. The recent recession also gives an incentive for the UK to partake in emissions cap and trade, where the UK government are considering the potential for including surface transport, along with aviation, in the EU Emissions Trading Scheme (EU ETS); the benefits would be emission savings may be traded with other nations and therefore leaves excess moneys to enter back into UK economy (ATOC 2007). Despite the reducing qualities such techniques have, the passenger car still has greater environmental impact than public transport, *figure 8 and 9*, however the reducing intensity analysis is calculated using actual capacity ( $C_2$ ) and therefore combining reducing demand techniques and reducing energy intensity will have an increased effect.

The comparative investigation; *figures 2 to 7* highlight the need for reform of the transport sector whereas the capacity models; *table 8 and 9* and reducing energy intensity comparisons illustrate there is potential for mitigation of climate change, through reduction of greenhouse gas emission of the transport sector, and there is also potential to decrease reliance on fossil fuels. Dahlquist *et al* (2007) states if realistic measures were taken, at the fullest completion with existing infrastructure and technology in both the reducing demand and reducing energy intensity categories, a 65% reduction in total environmental impact could be achieved.

The third approach of Haan *et al* (2007) study was reducing carbon intensity, therefore the use of alternative fuels. A more than viable approach, yet it is a

developing phenomenon, thus few objectives, and only general targets have been made according to this. Biofuels are making a limited impact with some diesel fuel now having 5% biodiesel added to it. The EU Biofuels Directive means that 5% of all fuel sold in the UK will have to come from renewables by 2010/11; this has taken the form of a Renewable Transport Fuel Obligation (RTFO) and became operational in 2008. It is now the main mechanism to achieve carbon reductions in the transport sector 1.7 MtC by 2010 (Banister 2007).

It is planned that the hydrogen economy will begin around 2020, at the earliest, and will be established by around 2050 (Fronk *et al* 2010). Fortunately, many of the electric drive technologies common with hydrogen drive systems are already in development today and implemented in battery or hybrid electric vehicles. Two transport technologies are currently ready to play a significant role in this context: the battery electric vehicle and the thermal hybrid electric vehicle; the missing links to a possible hydrogen transportation economy (Van Mierlo and Maggetto 2007). As alternative fuels are not widely used within the transport sector, there is little literature to support calculations and theoretical models and thus gives aspects for further analysis.

#### *5.4 Recommendations*

In order to achieve a sustainable transport sector in the UK, stringent targets and policy need to be enforced, much like the Transport 2010 strategy, yet more directed and focussed on certain aspects with associated incentives:

- “Increase train use by 50%” should be incorporated with reduced prices for regular rail commuters or people travelling as a group, a loyalty card scheme, improved services, increased charges for alternatively using a car etc.
- Fuel efficiency measures should be prioritised to contribute to economic recovery and to mitigate effects of climate change.
- Incentives to Internet shop, to make use of car-pooling and car club membership and to work from home should be adopted so that individuals use these methods as a preference over traditional choices.
- More rigorous efforts, through policy, to be made to encourage the purchase of reduced energy and carbon emitting private vehicles, with vigilant measures to prevent macroeconomic rebounds occurring.
- The Government, environment, education and trade organisations need to work together by demonstrating joined-up thinking in fostering new approaches towards sustainability within future transport initiatives.

#### *5.5 Limitations*

Despite the results showing expectant values from the previous literature there are many restraints to this investigation due to the broad scope, time constraints and data accessibility:

- The models of the short and long distance journeys only account for one way and do not include any terminal costs such as parking; the appropriate specification for a model would be a *tour*, rather than a one-way trip.
- Socioeconomic factors, such as age and presence of children, may influence the leisure travel models due to space and accessibility. Also, occupational status may influence the business models.
- Travel routes do not account for other influencing effects; traffic at certain

times of day and therefore speed.

- Capacity data only takes into account average vehicles for the model, and obviously there are many other sizes of buses and trains, similarly double decked, or 'bendy buses' are not considered, as well as metros and undergrounds.
- Also theoretical travel routes will most likely consist of more than one travel mode, i.e. a car or bus to get to the train station or airport.

## Chapter 6

### Conclusion

#### *6.1 Conclusion of Investigation*

In conclusion, the investigation, using comparative data and capacity model simulations, confirmed reducing demand and reducing energy intensity of the passenger cars are viable methods in lessening the environmental impact of the transport sector. It will be a lengthy process, especially due to economic climate, but it would be possible to achieve a total of 84.1% when both methods are undertaken to the full potential, considerably more than the 65% value given by Dahlquist *et al* (2007). Thus CO<sub>2</sub> reduction targets can be achieved by a combination of strong behavioural change and superior technological innovation, but only where there is no overall increase in UK travel.

Transport, as a large contributor to the nation's energy consumption and CO<sub>2</sub> emission, must have an instrumental role in achieving sustainable development in the UK. To achieve such a change requires a fundamental shift in policy thinking; for transport to achieve the levels of savings expected within a market that is rapidly expanding requires radical reform. On environmental grounds, there is a strong case for transferring passengers from road and air to electric railways, but the key role in tackling climate change remains the reduction of CO<sub>2</sub> emissions from cars (ATOC 2007).

The starting point for a major change that embraces reduced energy use, CO<sub>2</sub> reduction and sustainable development should begin at the travel decision process, by looking for opportunities for making fewer trips, encouraging modal shift away from the car, reducing trip lengths, and encouraging greater efficiency in the transport system (Banister, 2007).

Most of the current thinking revolves around the greater efficiency of the transport system through technological measures, but behavioural change must be seen as central to the debate (Musti *et al* 2011).

Subsequently, significant investment would have to be made into the industries to reduce prices and improve services. However, while market liberalisation and more price competition will benefit competitiveness, it may act as a disincentive to energy saving and even encourage energy consumption, thus external costs need to be fully internalised and energy demand managed (Taylor *et al* 2005).

Hensher (2008) states energy and carbon tax offers the most attractive way forward when balancing efficiency, equity and sustainability, as they send clear signals and

distort the economy less than any other approach. Whilst, a reduction in the energy and carbon intensity car purchase by strong legislative requirements could achieve arduous targets (ATOC 2007), yet will not be fully established for another 15 years (Banister 2007). In terms of reduction in carbon intensity it is believed the only effective measure could be the development of RTFO, yet much of the biofuels will have to be imported and will not be counted in the UK's renewables balance sheet (Banister 2007).

Essentially, to achieve substantial reductions in energy and carbon use in fuelled transport, we must travel less. It begins with understanding of the scale and importance of the CO<sub>2</sub> reduction; achieved by policy decisions, increasing public awareness and encouraging behavioural change, thus lifting some of the barriers to effective implementation.

Overall it appears that a mix of technology and pricing through a carbon tax or a variable user charge is the way forward, assuming continuing development of fossil fuels. An overriding concern is focus on economic growth rather than social and environmental priorities. In conclusion, implementations to reduce demand for energy and carbon intensive transport need to be put in place immediately, to bide time before alternative energy sources are established; if immediate action is taken the UK will be in a sustainable social, economic and environmental position to further develop the transport industry.

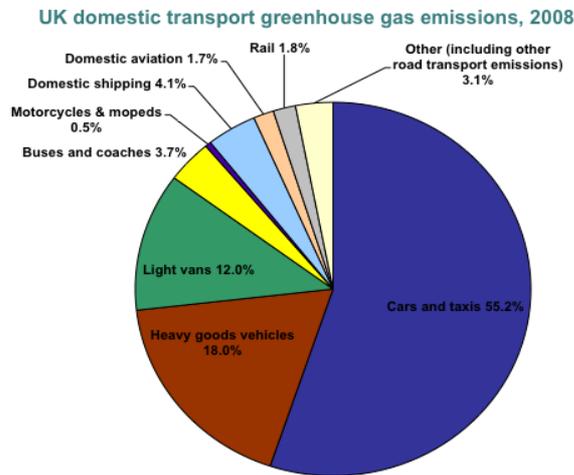
## *6.2 Further analysis*

The overall analysis shows reducing demand and reducing energy intensity of the passenger car facilitate reduction of environmental impact, yet in a broader outlook there are more aspects to consider when concerning the transport sector. Firstly, once the alternative fuel has developed into a viable source a similar analysis should be done to compare biofuel and hydrogen fuels in order to find the most efficient and develop the industry.

Secondly, the analysis has looked at energy consumption and CO<sub>2</sub> emission within the transport sector across the whole of the UK, types of transport mode are vastly dependant on geographical location *figure 11*; in rural areas private transport maybe the only option, whereas in cities an important factor is local pollution. Road transport is the main source of many local emissions including benzene, 1,3-butadiene, carbon monoxide (CO), nitrogen oxides (NO<sub>x</sub>) and particulates (PMs). Despite the recent improvements in engines, within urban areas the percentage of contributions due to road transport is particularly high, in London road transport contributes almost 80% of particulate emissions (Next Green Car 2011). There is growing concern that links vehicle pollutants to human ill health including the incidence of respiratory and cardio-pulmonary disease and lung cancer (Steenhof *et al* 2006); hence analysis into local air pollutants due to the transport sector is required. Subsequently a more geographically specific analysis is required, coinciding with point 4 and 5 of Transport 2010: analysing London Underground and local pollution.

Another investigation that is essential is a full lifecycle analysis (Chester and Horvath 2009), expanding on this investigation to give a comprehensive analysis including manufacture, breakdown costs and disposal.

Finally, an analysis is needed into other heavily contributing transport modes to environmental degradation; this investigation looked only into passenger travel and alternative modes than the passenger car, however, second to the passenger car is heavy goods vehicles as contributor to greenhouse gas emissions, *figure 16*. Similarly domestic shipping has a large sector; emissions from international aviation and shipping (outside Kyoto) have risen by 86% and 45% respectively, and accounted in 2004 for 22% of transport emissions (DEFRA 2008).



**Figure 16:** UK domestic Greenhouse Gas Emission, 2008 (National Transport Statistics 2008).

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## Chapter 7

### Bibliographic References

Ahman, M., Nilsson, L., Johansson, B., (2001). Cars and fuels for tomorrow: a comparative assessment. *NATURAL RESOURCES FORUM*: **25** (2) 109-120.

Air Southwest (2010). About Us and Flight Times [online]. Available: <http://www.airsouthwest.com/> [Accessed 27/12/10].

ATOC – The Voice of the Passenger Railway (2007). Baseline energy statement – energy consumption and carbon dioxide emissions on the railway [online]. Available: [www.atoc.org/clientfiles/File/.../npsB3A7\\_tmp.pdf](http://www.atoc.org/clientfiles/File/.../npsB3A7_tmp.pdf) [Accessed 12/12/10].

Baars, D., (2009). Promoting sustainable energy in the New Zealand transport system: policies, programmes and strategic directions. *URBAN TRANSPORT XV - URBAN TRANSPORT AND THE ENVIRONMENT*. 431-439.

Bai, Y., Mao, B., Zhou, F., Ding, Y., Dong, C., (2009). Energy-Efficient Driving Strategy for Freight Trains Based on Power Consumption Analysis. *JOURNAL OF TRANSPORTATION SYSTEMS ENGINEERING AND INFORMATION TECHNOLOGY*: **9**.

Ballis, A., Golias, J., (2002). Comparative evaluation of existing and innovative rail-road freight transport terminals. *TRANSPORTATION RESEARCH, PART A*: **36** (7) 593.

Banister, D., (2007). Reducing Energy Use in UK transport. *TRANSPORT STUDIES UNIT, OXFORD UNIVERSITY CENTRE FOR THE ENVIRONMENT*: Working Paper N° 1028.

BBC News (2010). What happened to the 10-year transport plan? [online]. Available: <http://news.bbc.co.uk/1/hi/magazine/8465383.stm> [Accessed 03/01/11].

Begg, D., Gray, D., (2004). Transport policy and vehicle emission objectives in the UK: is the marriage between transport and environment policy over? *ENVIRONMENTAL SCIENCE & POLICY*: **7** (3) 155-163.

Boerjesson, P., (1997). Energy analysis of biomass production and transportation. *BIOMASS & BIOENERGY*: **11** (4) 305-318.

Boretti, A., (2010). Comparison of fuel economies of high efficiency diesel and hydrogen engines powering a compact car with a flywheel based kinetic energy recovery systems. *INTERNATIONAL JOURNAL OF HYDROGEN ENERGY*: **35** (16) 8417-8424.

Browne, M., Allen, J., Atlassy, M., (2007). Comparing freight transport strategies and measures in London and Paris. *INTERNATIONAL JOURNAL OF LOGISTICS: RESEARCH AND APPLICATIONS*: **10** (3) 205–219.

Car Fuel Data (2006). CSV Data Part – Downloads 2006 [online]. Available: <http://www.vcacarfueldata.org.uk/downloads/may2006.asp> [accessed 30/11/10].

CBI (2001). Transport 2010 – On track or off target. Transport Brief July 2001 [online]. Available: [www.cbi.org.uk](http://www.cbi.org.uk) [accessed 02/12/10].

Chen, C., Ren, Y., (2010). Exploring the relationship between vehicle safety and fuel efficiency in automotive design. *TRANSPORTATION RESEARCH PART D-TRANSPORT AND ENVIRONMENT*: **15** (2) 112-116.

Cherp., A, Kopteva, I., Mnatsakanian, R., (2003). Economic transition and environmental sustainability: effects of economic restructuring on air pollution in the Russian Federation. *JOURNAL OF ENVIRONMENTAL MANAGEMENT*: **68** (2) 141-151.

Chester, M. and Horvath, A., (2009). Environmental assessment of passenger transportation should include infrastructure and supply chains. *ENVIRONMENTAL RESEARCH LETTERS*: **4** (2) 024008.

Chester, M., Horvath, A., Madanat, S., (2010). Comparison of life-cycle energy and emissions footprints of passenger transportation in metropolitan regions.

**ATMOSPHERIC ENVIRONMENT: 44** (8) 1071-1079.

Chiung-Wen, H. and Lee, Y., (2010). Competition between high-speed and conventional rail systems: A game theoretical approach. *EXPERT SYSTEMS WITH APPLICATIONS: 37* (4) 3162-3170.

Cross Country Trains – CCT (2010). Customer Service – Our trains [online]. Available: [http://www.crosscountrytrains.co.uk/Customer\\_service/Our\\_trains.aspx](http://www.crosscountrytrains.co.uk/Customer_service/Our_trains.aspx) [accessed 01/12/10].

Dahlquist, E. (2005). Sustainable Energy Systems. Mälardalen University Press: Västerås

Dahlquist, E., Thorin, E., Yan, J., (2007). Alternative pathways to a fossil-fuel free energy system in the Mälardalen region of Sweden. *INTERNATIONAL JOURNAL OF ENERGY RESEARCH: 31* (12) 1226-1236.

Department for Environment, Food and Rural Affairs – DEFRA (2008). 2008 Guidelines to Defra's GHG Conversion Factors: Methodology Paper for Transport Emission Factors [online]. Available: [www.defra.gov.uk](http://www.defra.gov.uk) [Accessed 18/12/10].

Department for Transport – DfT (2008). Modelling longer distance demand for travel feasibility study final report [online]. Available: [www.dft.gov.uk/.../longdistancemodelling/modellinglongerdistance.pdf](http://www.dft.gov.uk/.../longdistancemodelling/modellinglongerdistance.pdf) [Accessed 18/12/10].

Department for Transport – DfT (2010). Aviation, Rail, Roads, Shipping [online]. Available: <http://www.dft.gov.uk/> [accessed 18/10/10].

Department for Transport and Milton Keynes Council (2010). DfT New Growth Points Local Authority Support, Ashland Vale Residents Survey Results, Milton Keynes, March 2010 [online]. Available: <http://www.dft.gov.uk/> [Accessed 18/10/10].

Department of Energy and Climate Change (2011). Statistical release UK Climate Change Sustainable Development Indicator: 2009 Greenhouse Gas Emissions, Final Figures [online]. Available: [http://www.decc.gov.uk/en/content/cms/statistics/climate\\_change/gg\\_emissions/uk\\_emissions/2009\\_final/2009\\_final.aspx](http://www.decc.gov.uk/en/content/cms/statistics/climate_change/gg_emissions/uk_emissions/2009_final/2009_final.aspx) [Accessed 12/03/11].

Direct Gov (2011). The Environment and Greener Living [online]. Available: <http://www.direct.gov.uk/en/Environmentandgreenerliving/> [Accessed 12/03/11].

Essen, H., Rijke, X., Verbraak, G., Quak, H., Wilmink, I., (2009). EU Transport GHG: Routes to 2050? Modal Split and Decoupling Options: Paper 5.

European Automobile Manufacturers Association – ACEA (2011). AIR QUALITY: Cost-effectiveness must guide progress [online]. Available: [http://www.acea.be/index.php/news/news\\_detail/cost\\_effectiveness\\_must\\_guide\\_progress/](http://www.acea.be/index.php/news/news_detail/cost_effectiveness_must_guide_progress/) [Accessed 12/03/11].

European Federation for Transport and Environment – EFTE (2006). Greenhouse gas emissions from transport in the EU25 [online]. Available: [http://reports.eea.europa.eu/technical\\_report\\_2006\\_6/en/](http://reports.eea.europa.eu/technical_report_2006_6/en/) [Accessed 12/03/11].

Fronk, B., Neal, R., Garimella, S., (2009). Evolution of the Transition to a World Driven by Renewable Energy. *ES2008: PROCEEDINGS OF THE 2ND INTERNATIONAL CONFERENCE ON ENERGY SUSTAINABILITY – 2008*: 1147-153.

Fronk, B., Neal, R., Garimella, S., (2010). Evolution of the Transition to a World Driven by Renewable Energy. *JOURNAL OF ENERGY RESOURCES TECHNOLOGY-TRANSACTIONS OF THE ASME*: **132** (2).

Fullerton, D. and West, S., (2010). Tax and Subsidy Combinations for the Control of Car Pollution. *B E JOURNAL OF ECONOMIC ANALYSIS & POLICY*: **10** (8).

Galachoir, B., Howley, M., Cunningham, S., Bazilian, M., (2009). How private car purchasing trends offset efficiency gains and the successful energy policy response. *ENERGY POLICY*: **37** (10) 3790-3802.

Haan, P., Mueller, M., Peters, A., (2006). Does the hybrid Toyota Prius lead to rebound effects? Analysis of size and number of cars previously owned by Swiss Prius buyers. *ECOLOGICAL ECONOMICS*: **58** (3) 592-605.

Haan, P., Peters, A., Scholz, R., (2007). Reducing energy consumption in road transport through hybrid vehicles: investigation of rebound effects, and possible effects of tax rebates. *JOURNAL OF CLEANER PRODUCTION*: **15** (11) 1076-1084.

Haan, P. & Mueller, M., (2009). How much do incentives affect car purchase? Agent-based microsimulation of consumer choice of new cars-Part II: Forecasting effects of feebates based on energy-efficiency. *ENERGY POLICY*: **37** (3) 1083-1094.

Heffner, G., Maurer, L., Sarkar, A., Wang, X., (2010). Minding the gap: World Bank's assistance to power shortage mitigation in the developing world. *ENERGY*: **35** (4) 1584-1591.

Hensher, D., (2008). Climate change, enhanced greenhouse gas emissions and passenger transport – What can we do to make a difference? *TRANSPORTATION RESEARCH PART D, TRANSPORT AND ENVIRONMENT*: **13** 95–111.

Hensher, D., (2009). Bus transport: Economics, policy and planning. *RESEARCH IN TRANSPORTATION ECONOMICS*.

Hu, X., Chang, S., Li, J., Qin, Y., (2010). Energy for sustainable road transportation in China: Challenges, initiatives and policy implications. *ENERGY*: **35** (11) 4289–4301.

Kerr, R. & Service, R., (2005) What can replace cheap oil- and When? *Science*: **309** 101.

Khanna, P., Jain, S., Sharma P., and Mishra, S., (2011). Impact of increasing mass transit share on energy use and emissions from transport sector for National Capital Territory of Delhi. *TRANSPORTATION RESEARCH PART D, TRANSPORT AND ENVIRONMENT*: **16** (1) 65–72.

Kuo, C & Nicholls, G., (2007). A mathematical modelling approach to improving locomotive utilization at a freight railroad. *OMEGA-INTERNATIONAL JOURNAL OF MANAGEMENT SCIENCE*: **35** (5) 472-485.

Lelli, M., Pede, G., Valentini, M., Masoni, P., (2010). Car scrappage incentives policies: a life cycle study on GHG emissions. *ENVIRONMENTAL ECONOMICS AND INVESTMENT ASSESSMENT III*: **131** 121-131.

Liimatainen, H. and Pöllänen, M., (2010). Trends of energy efficiency in Finnish road freight transport 1995–2009 and forecast to 2016. *ENERGY POLICY*: **38** (12) 7676–7686.

Lindsey, M., Schofer, J., Durango-Cohen, P., Gray, K., (2011). The effect of residential location on vehicle miles of travel, energy consumption and greenhouse gas emissions: Chicago case study. *TRANSPORTATION RESEARCH PART D, TRANSPORT AND ENVIRONMENT*: **16** (1) 1–9.

Machado, H., (2009) 'Brazilian low-carbon transportation policies: opportunities for international support. *CLIMATE POLICY*: **9** (5) 495-507.

Mazraati, M., (2010). World aviation fuel demand outlook. *OPEC Energy Review*: **34** (1) 42-47.

McCollum, D. & Yang, C., (2009). Achieving deep reductions in US transport greenhouse gas emissions: Scenario analysis and policy implications. *ENERGY POLICY*: **37** (12) 5580-5596.

McCollum, D. & Yang, C., (2009)\*. Meeting an 80% reduction in greenhouse gas emissions from transportation by 2050: A case study in California. *TRANSPORTATION RESEARCH PART D-TRANSPORT AND ENVIRONMENT*: **14** (3) 147-156.

Morrell, P., (2009). The potential for European aviation CO<sub>2</sub> emissions reduction through the use of larger jet aircraft. *JOURNAL OF AIR TRANSPORT MANAGEMENT*: **15** (4) 151-157.

Musti, S., Kortum, K., Kockelman, K., (2011). Household energy use and travel: Opportunities for behavioural change. *TRANSPORTATION RESEARCH PART D, TRANSPORT AND ENVIRONMENT*: **16** (1) 49–56.

National BioDiesel Board – NBB, (2009). Benefits of Biodiesel.  
<http://www.tdot.state.tn.us/biofuel/docs/benefits.pdf>.

National Rail Enquiries (2010). Fares, Prices and Availability [online]. Available:  
<http://www.nationalrail.co.uk/> [Accessed 15/12/10].

National Rail Travel Survey (2010). Overview Report [online]. Available: [www.dft.gov.uk/pgr/statistics/datatablespublications/railways/nrtsupdate.pdf](http://www.dft.gov.uk/pgr/statistics/datatablespublications/railways/nrtsupdate.pdf) [Accessed 15/12/10].

National Transport Statistics (2008). Department for Transport: Policy Guidance and Research [online]. Available <http://www.dft.gov.uk/pgr/statistics/> [Accessed 03/01/11].

National Transport Statistics (2009). Department for Transport: Policy Guidance and Research [online]. Available <http://www.dft.gov.uk/pgr/statistics/> [Accessed 03/01/11].

National Transport Statistics (2010). Department for Transport: Policy Guidance and Research [online]. Available <http://www.dft.gov.uk/pgr/statistics/> [Accessed 03/01/11].

Nel, W., Cooper, C., (2009). Implications of fossil fuel constraints on economic growth and global Warming. *ENERGY POLICY*: **37** (1) 166-180.

Next Green Car (2011). Vehicle Emissions [online]. Available: <http://www.nextgreencar.com/caremissions.php#1> [Accessed 20/02/11].

Odhams, A., Lee, Y., Hunt, SW., Cebon, D., (2010). Factors influencing the energy consumption of road freight transport. *PROCEEDINGS OF THE INSTITUTION OF MECHANICAL ENGINEERS PART C-JOURNAL OF MECHANICAL ENGINEERING SCIENCE*: **224** (C9) 1995-2010.

Olsthoorn, X., (2003). Implications of globalization for CO<sub>2</sub> emissions from transport. *TRANSPORTATION PLANNING AND TECHNOLOGY*: **26** (1) 105-133.

Oum, T., Yu, C., (2004). Measuring airports operating efficiency: a summary of the 2003 ATRS global airport benchmarking report. *TRANSPORTATION RESEARCH PART E*: **40** (6) 515–532.

Owen, B., Lee, D., Lim, L., (2010). Flying into the Future: Aviation Emissions Scenarios to 2050. *ENVIRONMENTAL SCIENCE & TECHNOLOGY*: **44** (7) 2255-2260.

Perez-Martinez, P., (2007). Mobility and environment in Spain. *HIGHWAY AND URBAN ENVIRONMENT*: 35-43.

Popp, M., Van de Velde, L., Vickery, G., Van Huylenbroeck, G., Verbeke, W., Dixon, B., (2009). Determinants of consumer interest in fuel economy: Lessons for strengthening the conservation argument. *BIOMASS & BIOENERGY*: **33** (5) 768-778.

Rail Performance Society (2011). Email Contact – Lee Allsopp.

Rail Safety and Standards Board (2007). Engineering – Traction Energy Metrics. *RESEARCH PROGRAMME*: (2).

Railways Archive (2005). Document Archive – Transport 2010: The 10 year Plan [online]. Available: <http://www.railwaysarchive.co.uk/docsummary.php?docID=195> [Accessed 02/02/11].

Ricardo Consulting Engineers (2004). Motorcycle exhaust emissions factors and test cycles programme – final report [online]. Available: [http://dftsearch.dft.gov.uk/search?client=default\\_frontend&proxyreload=1&proxystylesheet=default\\_frontend&output=xml\\_no\\_dtd&q=motorcycle+fuel+consumption&pg=1](http://dftsearch.dft.gov.uk/search?client=default_frontend&proxyreload=1&proxystylesheet=default_frontend&output=xml_no_dtd&q=motorcycle+fuel+consumption&pg=1) [Accessed 04/01/11].

Rothbauer, J., Sieg, G., (2010). Quality standards for passenger trains: Political majorities and environmental costs. *TRANSPORTATION RESEARCH PART D, TRANSPORT AND ENVIRONMENT*: **15** 1-92.

Singer, B., Harley, R., (2000). A fuel-based inventory of motor vehicle exhaust emissions in the Los Angeles area during summer 19. *ATMOSPHERIC ENVIRONMENT*: **34** (11) 1783-1795.

Smith, M (2010). Addressing the limits to physical growth: prospects for an economic growth that is environmentally and socially sustainable. Australian National University.

Steenhof, P., Woudsma, C., Sparling, E., (2006). Greenhouse gas emissions and the surface transport of freight in Canada. *TRANSPORTATION RESEARCH PART D-TRANSPORT AND ENVIRONMENT*: **11** (5) 369-376.

Svensson, A., Møller-Holst, S., Glöckner, R., Maurstad, O., (2007). Well-to-wheel study of passenger vehicles in the Norwegian energy system. *ENERGY*: **32** (4) 437–445.

Taylor, P., Wiesenthal T., Mourelatou A., (2005). Energy and environment in the European Union: An indicator-based analysis. *NATURAL RESOURCES FORUM*: **29** (4) 360–376.

The World Bank (2010). By Country – United Kingdom [online]. Available: <http://data.worldbank.org/country/united-kingdom> [Accessed: 03/01/11].

The Trainline.com (2010). Train Times and Fares [online]. Available: [http://www.thetrainline.com/buytickets/?href=ppcg\\_trainline&WT.srch=1&WT.mc\\_ev=click&gclid=CliK-dmQkqgCFUdP4QodrXs6Cw](http://www.thetrainline.com/buytickets/?href=ppcg_trainline&WT.srch=1&WT.mc_ev=click&gclid=CliK-dmQkqgCFUdP4QodrXs6Cw) [Accessed: 03/01/11].

Timilsina, G. and Shrestha A., (2009). Factors affecting transport sector CO<sub>2</sub> emissions growth in Latin American and Caribbean countries: An LMDI decomposition analysis. *INTERNATIONAL JOURNAL OF ENERGY RESEARCH*: **33** (4) 396-414

Todoc, J., Todoc, M., Lefevre, T., (2005). Indicators for sustainable energy development in Thailand. *NATURAL RESOURCES FORUM*: **29** (4) 343–359.

Turgut, E. & Rosen, M., (2010). Partial substitution of hydrogen for conventional fuel in an aircraft by utilizing unused cargo compartment space. *INTERNATIONAL JOURNAL OF HYDROGEN ENERGY*: **35** (3) 1463-1473.

Van Mierlo, J. and Maggetto, G., (2007). Fuel Cell or Battery: Electric Cars are the Future. *FUEL CELLS*: **7** (2) 165-173.

VanWee, B., Janse, P., VanDenBrink, R., (2005). Comparing Energy Use and Environmental Performance of Land Transport Modes. *TRANSPORT REVIEWS*: **25** (1) 3–24.

Vihermaa, L., Lettenmeier, M., Saari, A., (2006). Natural resource consumption in rail transport: A note analysing two Finnish railway lines. *TRANSPORTATION RESEARCH PART D-TRANSPORT AND ENVIRONMENT*: **11** (3) 227-232.

Virgin Trains (2010). Train Specifications [online]. Available: <http://www.virgintrains.co.uk/trains/> [Accessed: 06/12/10].

Yu, M., (2008). Assessing the technical efficiency, service effectiveness, and technical effectiveness of the world's railways through NDEA analysis. *TRANSPORTATION RESEARCH PART A*: **42** (10) 1283–1294.

Zachariadis, T., (2006). On the baseline evolution of automobile fuel economy in Europe. *ENERGY POLICY*: **34** (14) 1773–1785.