Evaluating the Sustainability of Passenger Cars: Interventions and Trade-offs

A final report completed for the Department for Environment, Food and Rural Affairs by TRL Limited.

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TABLE OF CONTENTS

Glossary

CES	Centre for Environmental Strategy
CO	Carbon monoxide
CO_2	Carbon dioxide
Defra	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
EEA	European Environment Agency
EC	European Commission
ELV	End of life vehicles
EU	European Union
GHG	Greenhouse gas
GSI	Gear shift indicator
HEV	Hybrid Electric Vehicle
HOV	High Occupancy Vehicle
ICE	Internal combustion engine
Mt	Million tonnes
NMOG	Non-Methane Organic Gas
NO_x	Nitrogen oxides
PM_{10}	Particulate matter
RTFO	Renewable Transport Fuel Obligation
SO_2	Sulphur dioxide
SV	Stakeholder View
TRL	Transport Research Laboratory
TSU	Transport Studies Unit
TTW	Tank-to-wheel
VED	Vehicle Excise Duty
WTT	Well-to-tank

Executive Summary

Project Background

The UK, along with the rest of the world, faces unprecedented global challenges such as climate change and the depletion of natural resources, particularly fossil fuels which are our primary energy resource. Individuals, communities and governments are assessing their roles and abilities to tackle these issues. The Department for the Environment, Food and Rural Affairs (Defra), through its sustainable consumption and production programme, is assessing the critical high impact products in the UK, where a better understanding of life cycle impacts could significantly improve the sustainability of these products. The passenger car has been identified by Defra as a product for further evaluation. Whilst the evidence suggests that the car is a major contributor to UK carbon dioxide (CO_2) emissions, a sustainability focused assessment of the whole life cycle of the car is required to highlight additional environmental, economic and social impacts. These impacts need to be considered when evaluating future changes to the passenger car to meet the current global challenges.

Transport is associated with a range of environmental impacts; however the emission that is most significant, and with most relevance to climate change strategies, is the greenhouse gas (GHG) CO_2. The transport sector as a whole plays a crucial role in the efforts to reduce GHG emissions as the sector is responsible for a high percentage of the UK's CO_2 emissions and energy use. Within the UK in 2006, the transport sector accounted for 24.6% of the total UK domestic CO_2 emissions, and passenger cars represented 50.4% of the transport sector CO_2 emissions (NAEI, 2008). The CO_2 emissions are generated predominantly from vehicle fuel consumption, and in 2007 the UK transport sector consumed 78% (5.3 million tonnes) of petroleum products used for energy in the UK (BERR, 2008). The signs are that the impacts of transport are increasing; in the latest TERM report 2008 issued by the European Environmental Agency (EEA), it is stressed that the contribution of transport to greenhouse gas emissions is increasing regardless of all the efforts to focus on improving vehicle technologies and fuel quality (EEA, 2008a).

The project's key objectives were to identify interventions that achieve significant reductions in the environmental impacts of the car, from a whole life cycle perspective, and to highlight any trade-off impacts associated with these reductions. The trade-offs are discussed in wider sustainability terms; social and economic as well as environmental.

Project Methodology

A review of the evidence of the environmental impacts of cars and the possible interventions through a life cycle approach was undertaken. The analysis included academic and stakeholder engagement. Recommendations were delivered to Defra for further research and technological, behavioural and policy based interventions. The key objectives of the project were to:

- Produce a comprehensive review of existing evidence on the environmental impacts of cars;
- Identify current interventions aimed at improving the environmental performance of cars, and determine the improvements these interventions can achieve;
- Engage with key stakeholders and technical expertise through a stakeholder workshop, one-to-one sessions and peer reviews; and
- Identify knowledge gaps and trade offs for existing and proposed interventions and make recommendations for future interventions.

Trade-off summary

Twelve interventions were selected for detailed analysis to achieve the aim of including a broad range of interventions. A trade-off summary was created to compare the impact reduction potential of each intervention against the key trade-offs identified through the literature review and stakeholder engagement, Table ES 1. It is important to note that the selected interventions are at different stages in terms of mass market release and/or policy inclusion, and therefore the trade-off summary reflects a qualitative view of the potential impacts associated with these interventions.

Table ES 1 Potential Trade-off impacts summary

Intervention	Impact reduction potential	Associated trade-offs: within Production, Use and Disposal		
Hybrid	Significant fuel economy improvement under urban conditions	Resource use for battery production	Limited benefits outside urban conditions	Battery replacement and recycling
Electric	Significant reductions in life cycle CO_2 emissions	Resource use for battery production	Shorter driving range and long recharging time	Battery life time, replacement and recycling
Hydrogen	Life cycle GHG emissions and energy consumption are less than ICE	Potential for higher impacts in fuel production	Significant investment in infrastructure is required	Requires a long term cohesive strategy inclusive of government and car manufacturers
Biofuel	Biofuels may offer significant carbon savings, depending on biofuel type and production process.	Economic impacts through diversion of government financial support in producer countries	Land use conversion leading to increased food prices and potentially greater environmental damage e.g. through deforestation	High biofuel blends can invalidate vehicle warranties
Material substitution	Fuel consumption reductions resulting in life cycle CO_2 emission savings	Potential for higher impacts in material production	Costs to manufacturers could cause retail price increases	Consumption of new materials may cause quality issues in recycling
ELV directive	The ELV Directive sets targets of 85% reuse/ recycling and 95% reuse/recovery by 2015.	May hinder technology development, and could restrict the development of more efficient vehicles	Weight percentage based regulations may not result in reduced impacts over life cycle	Higher targets may be difficult to achieve
Eco-driving	Reductions in fuel consumption and CO_2 emissions.	Difficult to measure the true long term impact of eco-driving	Social impacts associated with adapting to change in journey times	Economic trade-offs dependant on level of intervention
Speed control	Could provide significant carbon savings.	Continued research needed into optimum speed due to advancements in technology	Static cameras more likely to prevent harsh acceleration/braking compared to average speed cameras	Economic costs associated with manufacturing and maintaining required infrastructure
High occupancy rates	An increase in commuters car sharing estimated to result in significant reductions in mileage driven to work.	Potential negative impact on car industry if there was a decrease in purchase of new vehicles	Economic and environmental impacts associated with creating, and managing HOV lane infrastructure	Impacts on other alternatives such as walking and public transport
Car labelling	Consumer awareness surveys show an increase in the percentage of people aware of the label.	Difficult to put production emissions on label because of diverse production routes	Comparison of electric with standard conventional fuels is required	Needs clear labelling for disposal, and KPI for recyclability
Early scrappage	Schemes aiming to incentivise the disposal of older vehicles have shown some success in terms of disposal rates.	Further research required to establish optimal lifetime of cars	Socially this may impact negatively on financially vulnerable groups who do not purchase new cars	Economic impact in the reduction in value of second hand cars
Road charging	Environmental zones achieve significant emissions reductions after implementation.	Road charging schemes may increase emissions through the transfer of transport demand	Social impacts associated with effects on vulnerable groups	Economic and environmental impacts of manufacturing and disposing of infrastructure and technology

Recommendations

The process of identifying trade-offs over the life cycle of the car has revealed a number of aspects that link different interventions, where resolving a particular issue could result in considerably higher reductions in the impact of the car, Table ES 2.

Table ES 2 Inter-linkages between interventions

Impact Type	Intervention	Impact Link	Potential for further impact reductions
Energy	**Electric, hydrogen, hybrid**	UK energy mix	The decarbonisation of the UK energy mix will significantly reduce the impacts of these technological interventions over the whole life cycle
Waste	**Electric, hydrogen, hybrid**	Recycling of batteries and fuel cells	Current pilot projects on recycling and disposal of car batteries will reveal the potential to close the resource loop for these interventions. The result will be less pressure on raw material demand and reductions in life cycle impacts.
Materials	**ELV directive and regulations, material substitution, early scrappage, electric, hydrogen, hybrid**	The decisions made during the design and production of cars have direct effects on the impacts across the whole life cycle	The research highlighted that some technologies can be launched into the market before there is a full understanding of the whole life cycle impacts. There are a number of interventions that are clearly linked by the decisions made in the design and production phase of cars. It is therefore important that an evaluation of life cycle impacts is undertaken for changes to vehicle composition and technology.
Social Impacts	**All twelve interventions but specifically; car labelling, eco-driving, speed control, high occupancy rates, road charging**	Public understanding of the reasons for intervention implementation and appreciation of the need for changes in the transport sector	Act on CO_2 is an example of the steps being taken to communicate the sustainability issues of the passenger car. Understanding the social acceptance of interventions and the effectiveness of communicating the information on the impacts of cars will provide a stronger basis for implementation of reduction measures in the future.

Conclusions

There is an urgent need to understand the impacts of transport, specifically the passenger car, and the relationships with consumption. Addressing climate change and energy security issues will rely on effective interventions that reduce the consumption of fossil fuel and raw material resources, whilst imposing limited impacts, whether social, economic or environmental, over the life cycle. The recent advancements in the use of biofuels illustrates how important the understanding of impacts is over the whole life cycle, including fuel production, as insufficient information can lead to policies being brought into question and requiring revision. This report has reviewed a broad range of interventions to identify potential trade-off impacts, and a qualitative summary of the associated trade-offs provides an illustration of where impacts occur over the whole life cycle. The recommendations in this report include areas of further research which will fill knowledge gaps in the evidence reviewed during the project, and could provide stronger support for future interventions.

1 Introduction

The UK, along with the rest of the world, faces unprecedented global challenges such as climate change and the depletion of natural resources, particularly fossil fuels which are our primary energy resource. Individuals, communities and governments are assessing their roles and abilities to tackle these issues. The Department for the Environment, Food and Rural Affairs (Defra), through its sustainable consumption and production programme, is assessing the critical high impact products in the UK, where a better understanding of life cycle impacts could significantly improve the sustainability of these products. The passenger car has been identified by Defra as a product for further evaluation. Whilst the evidence suggests that the car is a major contributor to UK carbon dioxide (CO_2) emissions, a sustainability focused assessment of the whole life cycle of the car is required to highlight additional environmental, economic and social impacts. These impacts need to be considered when evaluating future changes to the passenger car to meet the current global challenges.

1.1 Project Background

A key to the development of sustainable living strategies, and reductions in impacts on the environment and society, is the understanding of consumption behaviours, their demands on production, and the associated impacts across a whole supply chain. A life cycle perspective, from production through use to disposal, gives a holistic view of the environmental performance of a product, and can highlight any trade-offs; whether social, economic or environmental. Sustainable development strategies require strong governance, and public acceptance, to achieve a change in direction towards a more equitable future. The UK has lead the way internationally through the Climate Change Act in 2008, which sets legally binding targets to reduce CO_2 emissions by 26% by 2020, and 80% by 2050, against a 1990 baseline (Defra, 2008a).

Defra contracted TRL to map the life cycle environmental impacts, interventions and trade offs for cars based on the current evidence base as part of the Sustainable Consumption and Production research programme. The project involved a review of current research, key transport and sustainability reports, and engagement with key stakeholders to evaluate the potential impacts of interventions and the potential environmental, economic and social trade-offs.

The long lifetimes of vehicles, and the volume of fuel consumed during use, contribute to significant CO_2 emissions which lead to a focus within transport strategies to reduce the environmental impacts during the use phase of the car; this was highlighted by the UK King Review of Low Carbon Cars (2007 & 2008). Fuel consumption and natural resource depletion not only have environmental effects but may also lead to a future social impact that would be detrimental to the UK economy and its current dependence on petrol and diesel fuelled cars. It is important to consider the full range of impacts of the car, including noise, air and water pollution, waste, accidents, health effects, mobility severance and impacts on vulnerable user groups. Many of these impacts may be felt in countries other than the UK, where raw materials are produced and components manufactured, or vehicles disposed of.

The impacts and interventions associated with the production and consumption of the car are being extensively researched, by manufacturers, government departments and academic groups. The research can be used to compile a robust evidence base to support policy interventions aiming to improve the environmental performance of the car. This project aims to look at the potential trade-offs associated with these interventions, an aspect which is often less well documented.

1.2 Project Scope

The focus of this project is passenger cars, therefore evidence and discussions exclude interventions specifically aimed at motorcycles, light and heavy commercial vehicles, and public transport.

The project included a review of research and case studies from inside and outside the UK; predominately Europe and the US, to capture a wider range of evidence that may be transferred to the UK. The evidence regarding interventions aimed at transport in general was reviewed to identify, where possible, specific quantitative data on passenger cars.

The project investigated a range of technology, behavioural and policy based interventions that have the potential to achieve reductions in the environmental impact of the passenger car, through literature reviews, expert advisors and engagement with key stakeholders.

The King Review of Low Carbon Cars (2007) indicated a potential route to sustainability within cars, Figure 1.1, will incorporate a range of interventions working together, however the associated trade-off impacts of these interventions must be understood to ensure effective implementation. The main objective of the project is to identify the trade-offs associated with these interventions and the impacts these trade-offs may have over the car life cycle. The project has been carried out with a specific focus on identifying known and potential trade-offs of a selection of technological, behavioural and policy driven interventions. The issues surrounding mobility and why passenger cars are used was beyond the scope of this project, but are critical to understanding the consumption of transport and modal choices.

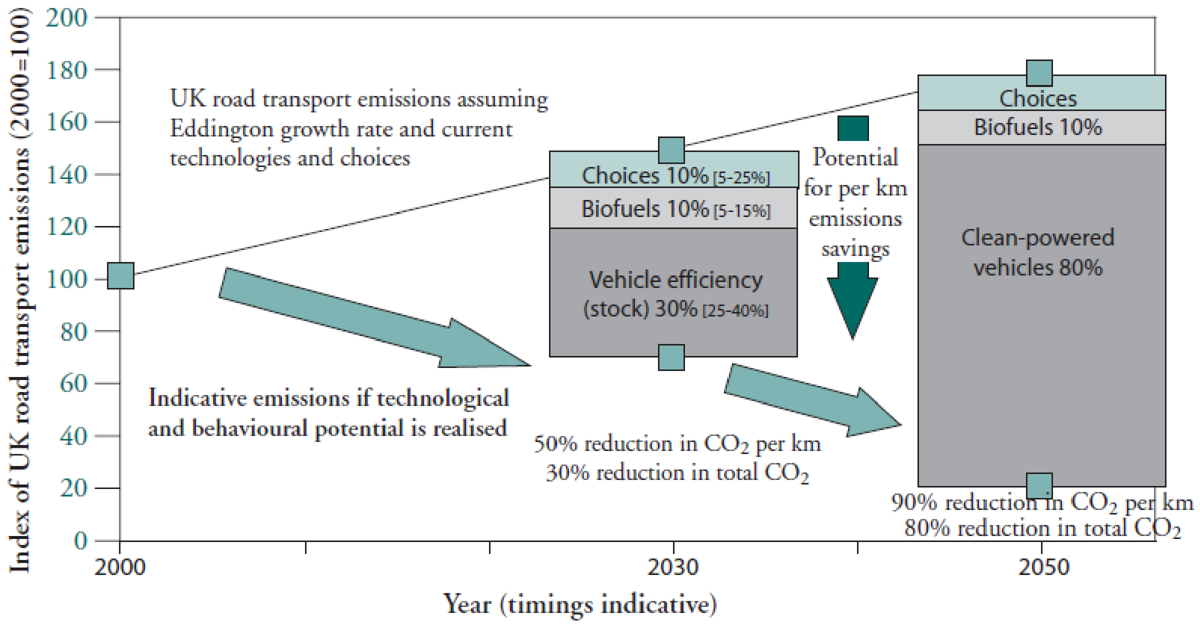

Figure 1.1 A potential combination of interventions to decarbonise road transport (Source: King Review, 2007)

1.3 Environmental impacts of the car

Transport is associated with a range of environmental impacts; however the emission that is most significant, and with most relevance to climate change strategies, is the greenhouse gas (GHG) CO_2. The transport sector as a whole plays a crucial role in the efforts to reduce GHG emissions as the sector is responsible for a high percentage of the UK's CO_2 emissions and energy use. Within the UK in 2006, the transport sector accounted for 24.6% of total UK domestic CO_2 emissions. Passenger cars represented 50.4% of the transport sector CO_2 emissions, Table 1.1 (NAEI, 2008). The CO_2 emissions are generated predominantly from vehicle fuel consumption, and in 2007 the UK transport sector consumed 78% (5.3 million tonnes) of petroleum products used for energy in the UK (BERR, 2008).

Table 1.1 UK CO_2 emissions as carbon and fuel (Adapted from NAEI, 2008)

	2006 (Mtonnes)	% of total emissions
Road transport – passenger cars	18.9	12.4%
Other road transport	13.9	9.1%
Other transport (off road)	4.7	3.1%
Public electricity and heat production	50.3	33.0%
Combustion Industrial/commercial and residential	41.6	27.3%
Other combustion	17.3	11.3%
Production processes	4.7	3.1%
Agriculture/other sources and sinks	0.3	0.2%
Waste and others	0.6	0.4%
Total	152.3	

The signs are that the impacts of transport are increasing; the latest TERM report 2008 issued by the European Environmental Agency (EEA) stressed that the contribution of transport to greenhouse gas emissions is increasing regardless of all the efforts to focus on improving vehicle technologies and fuel quality (EEA, 2008a). Policy driven efforts within the UK to achieve reductions in the impacts of the car include graduated Vehicle Excise Duty (VED), company car tax, the Renewable Transport Fuel Obligation (RTFO) and behavioural campaigns through 'Act on CO_2'. At a European level, the European Council and Parliament has sent a strong message of its intent to reduce the impacts of the car through the recently adopted regulation that requires the average new car CO_2 emissions to decrease to 130g/km by 2015. The target will be phased; 65% of each manufacturer's newly registered cars must comply on average with the target set by the legislation by 2012, 75% by 2013 and 80% by 2014. An extended target of 95g/km by 2020 is proposed by the EC (EC, 2009a).

The UK government, operators within the motor industry and the vehicle consumers need to understand and address the impacts of the car, and make significant changes to outputs and behaviour, to achieve environmental impact reductions within the transport sector.

Impacts over the life cycle of the car

The environmental impacts of the car have been studied over the whole life cycle (Figure 1.2), by vehicle manufacturers and independent collaborations; and key studies including a mass balance of the UK motor industry (Elghali *et al.*, 2004) and the European report, Environmental Improvement of Passenger Cars (IMPRO-car) (EC, 2008a).

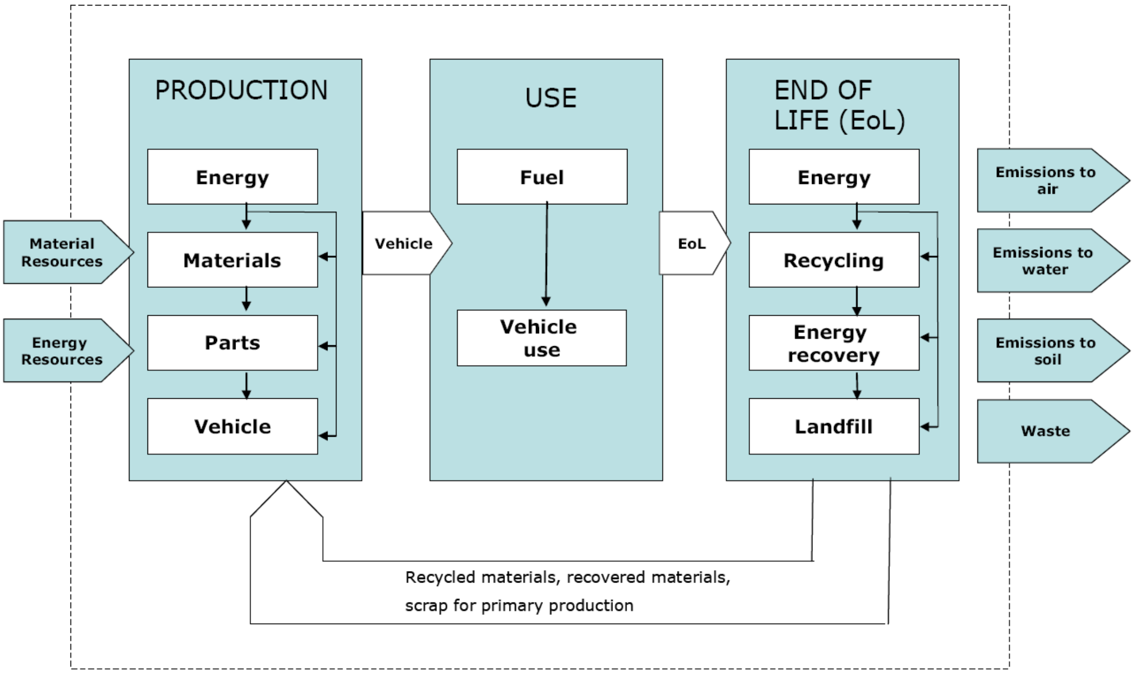

Figure 1.2 Car life cycle and system boundaries (Source: SMMT 2008a)

The IMPRO-car report discusses a broad range of impacts in terms of life cycle mid-point indicators, including global warming potential and acidification, which illustrates the complexity of the environmental impacts of the car. The generic car models included in the life cycle analysis, Table 1.2, are comparable to those in the UK. Impacts were calculated in a functional unit of 100km (62 miles) driven.

Table 1.2 Generic car models used in IMPRO-car analysis (Adapted from EC, 2008a)

	Petrol Car	Diesel Car
Lifespan (years)	12.5	12.5
Emission Standard	EURO4	EURO4
Annual distance (km)	16900 (10500 miles)	19100 (11868 miles)
Cylinder capacity (cm^3)	1585	1905
Power (kW)	78	83
Weight (kg)	1240	1463
Body model	Saloon	Saloon

GHG emissions, resource use and processes associated with the car input into a range of potential impacts on the environment over the life cycle (Figure 1.3).

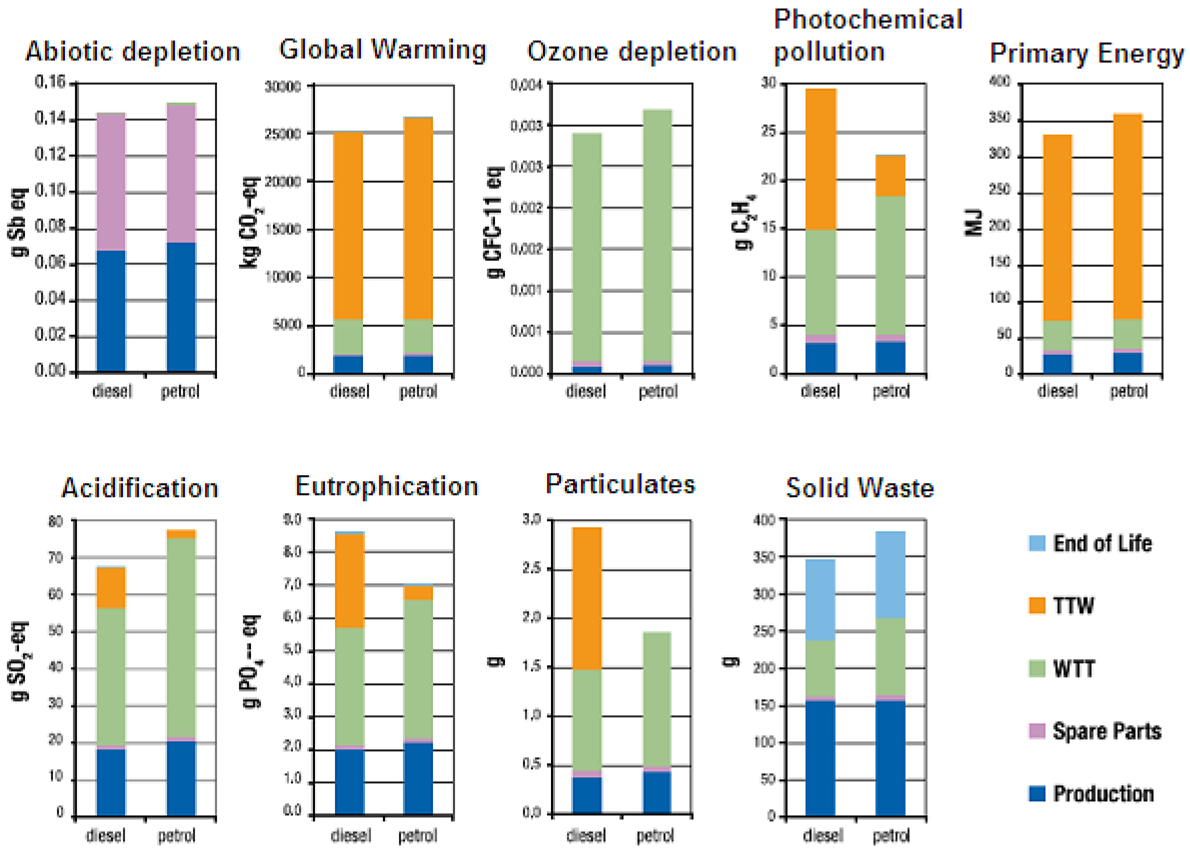

Figure 1.3 Life cycle impacts of a diesel and petrol car per 100km [TTW: tank-to-wheel; WTT: well to tank] (Source: EC, 2008a)

The IMPRO-car results clearly show that certain phases of car life cycle cause significant impacts in different environmental impact categories; production and spare parts dominate the impacts in abiotic depletion caused by the volumes of raw materials used, the tank-to-wheel (TTW) dominance in primary energy reflects the amount of fuel consumption in the use phase of the car. An important result is that production causes higher masses of solid waste than the end-of-life phase, and signifies how efficiency in design process and materials used in production are vital regarding waste generation.

The use phase is the life cycle of the car associated with by far the majority of CO_2 emissions, generated by the levels of fuel consumed over the life time of cars. 85% of CO_2 emissions are from the use phase, 10% from production and 5% from the end-of-life phase, Figure 1.4 (SMMT, 2008a). A life cycle study of the Volkswagen Golf (1.4 petrol and 1.9 diesel engines) generated comparable results; approximately 9% energy used to manufacture the vehicle, 12% to mine the raw materials plus 8% for the required fuel, and 71% consumption of energy in the use phase (Schweimer and Levin, 2000). The Mass Balance of the UK Motor industry also reported a similar percentage of impacts over the life cycle phases (Elghali et al. 2004). It is important to note that reductions in impacts within the use phase of the car will result in the production and end-of-life phase impacts becoming relatively more significant.

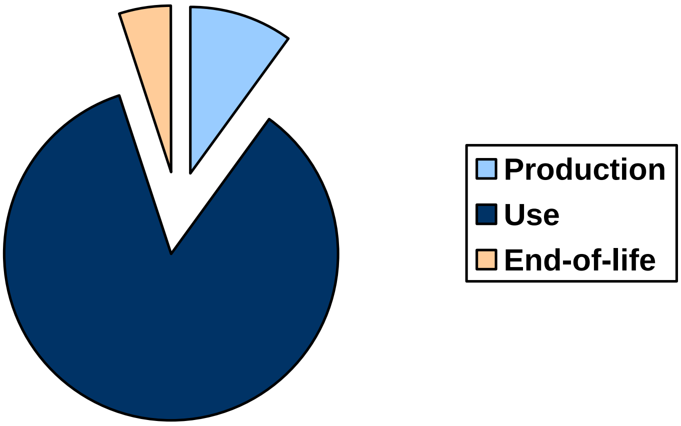

Figure 1.4 CO_2 emissions over the life cycle of the car (Adapted from SMMT, 2008a)

The total tailpipe CO_2 emissions from cars in the UK has decreased by 4.8% from 1997 to 2006, from 72.2 Mt to 68.7 Mt (DfT, 2008a), even though the total distances travelled by cars has increased over this time from 365.8 to 402.4 billion kms. The average CO_2 emission for new cars in the UK in 2007 was 164.9 g/km, which has decreased from 189.8 g/km in 1997, Figure 1.5 (SMMT, 2008a). The EU new car emission target for average new car emissions to reduce to 130 g/km by 2015 will have considerable impact on the average emissions of new cars in the UK.

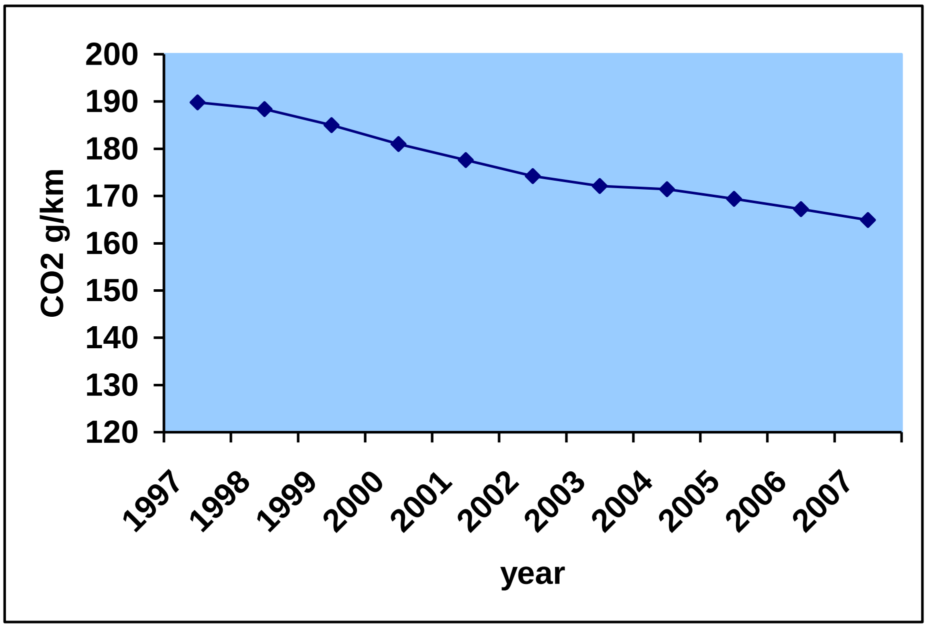

Figure 1.5 New car average CO_2 emissions (g/km) (Source SMMT, 2008a)

Looking beyond CO_2 emissions.

CO_2 emissions based targets and interventions are utilised in many transport and climate change strategies that aim to reduce environmental impacts. However over the whole life cycle of the car it is crucial that other impacts are considered. The impacts of the UK motor industry in 2000, inclusive of vehicles in addition to passenger cars, are shown within a Mass Balance study, Table 1.3 (Elghali et. al. 2004). The SMMT Ninth Sustainability Report (SMMT, 2008a) shows that the industry has made improvements in the reduction of impacts between 2002 and 2007, as energy consumption was down 12%, water use down 9.1%, waste to landfill down 25% and waste for recycling per vehicle produced increased by 21.6%.

Table 1.3 Impacts of the UK motor industry in 2000 (Source: Elghali et. al., 2004).

Lifecycle process	Impact
Production of new vehicles and components	7.23 million tonnes of products
Manufacture of parts and vehicles and the use of vehicles	41.37 million tonnes of oil equivalent
Waste from production, maintenance activities, use and end-of-life vehicles	7.21 million tonnes

Within the mass balance, the total quantity of primary products used by the UK motor industry in 2000 was estimated to be 4 Mt. The distribution of the primary products can be illustrated as percentage by weight to give an idea of the range of materials used, table 1.4 (Elghali et. al. 2004)

Table 1.4 Distribution of primary products used by the UK motor industry in 2000 (Source: Elghali et. al. 2004)

Primary product	Percentage by weight
Ferrous	58
Aluminium	2
Copper	0
Zinc	1
Lead	3
Plastics	10
Polymers	9
Glass	1
Rubber	3
Fluids	4
Textiles	4
Other	5

Data for the emissions from cars is published within editions of the DfT Transport Statistics. The 2008 Edition (DfT, 2008a) includes a range of pollution emission data for 2006, and shows the high volumes of CO_2 emissions compared to other pollutants from cars, Table 1.5. The life cycle analysis of the Volkswagen Golf by Schweimer and Levin (2000) comments that CO_2, CO and NO_x dominate the atmospheric emissions, from energy use, but that other emissions dominated in the production phase; hydrocarbons and SO_2 emissions from production and distribution of fuel and chlorine and metal from the mining of raw materials.

Table 1.5 Pollutant emissions from passenger cars in the UK in 2006 (Source: DfT 2008a)

Pollutant	Emissions (thousand tonnes)
Carbon dioxide (CO_2)	68700
Carbon monoxide (CO)	830
Nitrogen oxides (NO_x)	195
Particulate Matter (PM_{10})	6.0
Benzene	2.2
1,3-butadiene	0.6
Lead	1.3
Sulphur dioxide (SO_2)	2.0

Noise impacts include effects on health, including sleep disturbance, hearing impairment, and psychophysical effects such as stress response and cardiovascular effects. The evidence of road noise on health impacts include studies that have shown “blood pressure to be higher in noise-exposed workers and in populations living in noisy areas around airports and on noisy streets than in control populations.” (Berglund & Lindvall, 1995)

The evidence reviews, intervention and trade-off evaluations within the project consider these wider sustainability impacts, alongside CO_2 emissions, to provide a broad review which includes environmental, social and economic impacts of the passenger car.

2 Methodology

The project has reviewed the quantitative and qualitative evidence of the environmental impacts of cars and the possible interventions through a life cycle approach. The analysis of the evidence reviews, including academic and stakeholder engagement informed the delivery of recommendations to Defra for further research and interventions; technological, behavioural and policy based. The key objectives of the project are outlined in Figure 2.1.

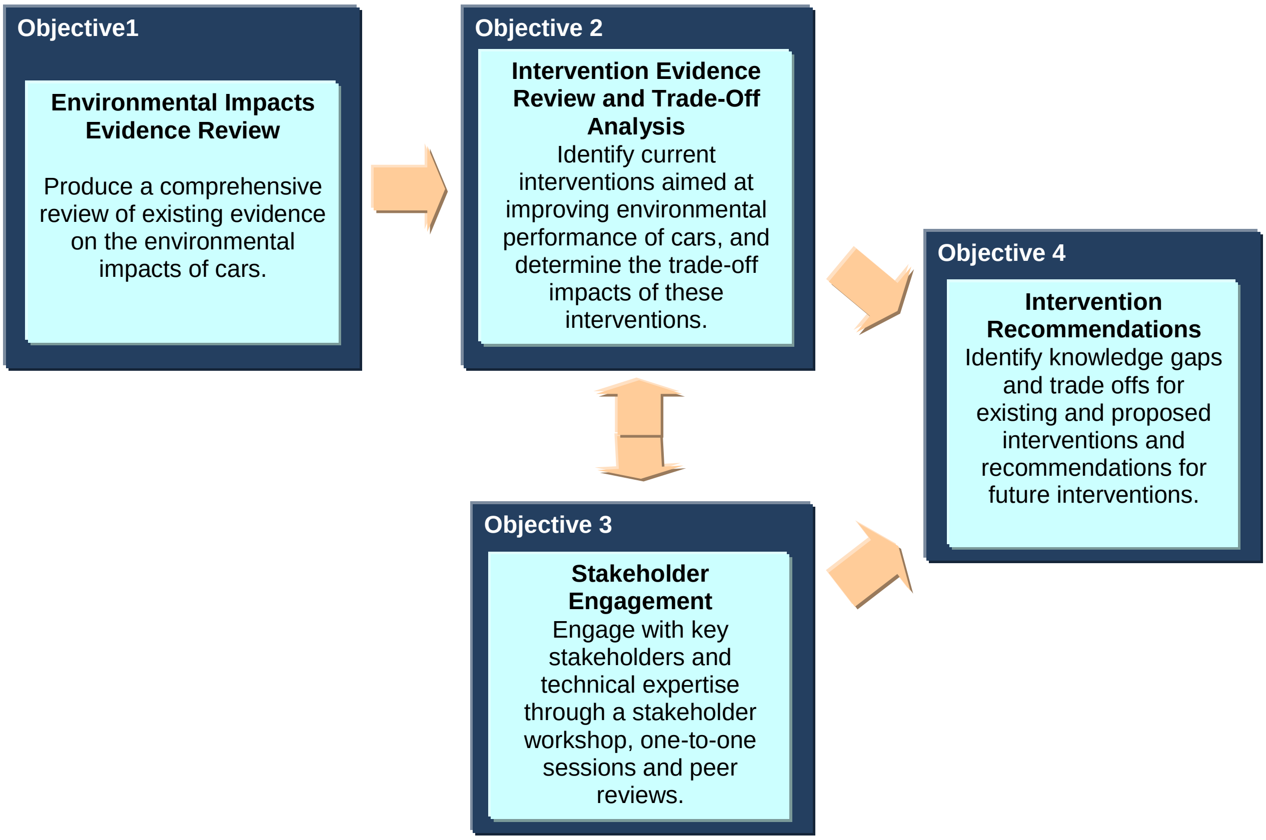

Figure 2.1 Project objectives and engagements

2.1 Environmental Impacts Evidence Review

In order to fully assess the environmental impacts and interventions, an evidence base was required to include information that supported the delivery of the aims of the project, including analysis of;

- Policy and legislation driven improvements
- Technology interventions; fuels, batteries, vehicles, raw materials
- Infrastructure
- Life cycle perspective analysis
- Trade-offs
- Production efficiencies
- Fuel alternatives
- Behaviour changes
- End of life recovery

To ensure that the evidence was as complete as possible, a broad range of sources was assessed to develop an evidence base including current and proposed legislation and recent key reviews of the transport sector (Annex A). In developing the project TRL took steps to seek a comprehensive evidence base with the understanding that the large amount of evidence in this area may mean that not all research has been included. An evidence search strategy was implemented to review the general and transport specific databases, Annex A. Key transport reviews were studied to identify areas of research and technologies currently being discussed and proposed for future interventions.

2.2 Intervention Selection and Trade-off Analysis

The second objective of the project was to take the information from the evidence review and key transport reports, and select a group of interventions that represented a broad range of technology, behavioural and policy based interventions. The process selected interventions based on relevance to key government reports and research papers with a view to provide a broad impact review of existing and proposed interventions. The selected interventions were investigated further for any associated trade-off impacts over the life cycle of the car.

2.3 Intervention Selection Methodology

A group of interventions were identified through the evidence review and steering group recommendations, Figure 2.2. An intervention was required to fit with basic selection criteria; a demonstration of a potential to reduce environmental impacts and reflect the aims of the project.

Figure 2.2 Intervention selection methodology

A key focus of the study was the identification of interventions that are relevant to the UK government's current direction in addressing the environmental impacts of transport. These are clearly presented by the King Review of Low Carbon Cars (2007, 2008); cleaner fuels; more efficient vehicles and smarter choices. The IMPRO-car report (EC, 2008a) is a robust and highly regarded review of the environmental impacts over the car life cycle. The improvement options selected by this report were used as a foundation for the selection of interventions in this project, as the selection criteria within the IMPRO-car life cycle analysis are similar to the aims of this project;

- Relevance in the context of Integrated Product Policy
- Potential to improve processes that generate significant impacts;
- Coverage of the existing technical potential by the existing legislation;
- Reliability of data and information to quantify the environmental impact

The interventions reviewed in both the King Review and IMPRO-car reports along with other key reports; Well-to-wheels analysis (EC, 2007) and the EEA TERM report 2008

(EEA, 2008a) provided support for the selection of interventions for the project. A review of four reports is presented within Annex B to illustrate the range and overlap between interventions discussed within the reports.

An overview of the evidence base and a review of the key reports developed a proposal of 10 interventions, which were submitted to the project internal steering group, Annex C, for consideration. A discussion of the proposed interventions and recommendations from the internal steering group produced a final selection that reflected technology, behavioural and policy based interventions for further analysis. Twelve interventions were selected for detailed analysis to achieve the aim of including a broad range of interventions, Table 2.1. The detailed literature reviews of the 12 interventions including an analysis of credibility and transferability to UK policy are in Annex D, with summaries of the evidence base in Annex E.

Table 2.1. The selected interventions for further review

Technological and alternative fuels	Production and End-of-life	Behavioural	Policy based
Hybrid	Material substitution	Eco-driving	Early scrappage
Electric	ELV Directive and regulations	Speed control	Road charging
Hydrogen		High occupancy rates	
Biofuel		Car labelling	

2.4 Stakeholder Engagement

A key objective of the project was to include broad stakeholder engagement to assist the identification of any trade-off impacts associated with the 12 interventions. A workshop was held on Friday 12th December 2008 in London attended by key stakeholders including car manufacturers, government representatives and technical experts. A list of the attendees is in Annex F, and a detailed summary of the views of the stakeholders on each of the interventions is in Annex G. Additional input by stakeholders was provided through one-to-one meetings, telephone conversations and emails, Annex B.

2.5 Trade-off analysis

An analysis of the trade-off impacts, environmental, social and economic, as well as qualitative and quantitative evidence of the potential impact of interventions was required to assist with identification of evidence gaps. The analysis includes details of the impact reduction potential of each intervention with a comparison of the evidence and stakeholders' views of the associated trade-off impacts. The focus of the report was on the identification of trade-offs, and in many cases the potential trade-offs are discussed qualitatively as time constraints meant the project was not able to research for detailed quantitative data.

2.6 Intervention Recommendations

The final objective of the project was to make recommendations to Defra for further research and potential interventions to reduce the environmental impacts of cars, taking into consideration the evidence reviews and trade-off impacts revealed from the literature reviews and stakeholder engagement. The recommendations will be disseminated to motor industry, government and academic stakeholders to provide support to existing evidence of the environmental performance of cars, and will provide a framework for assessing the impacts and trade-offs for future interventions.

3 Intervention Impact Reduction and Trade-offs Review

In order to provide a clear view of the combined evidence reviews and stakeholder views (SV), a single page summary has been developed for each intervention. These are given on the following pages. Each summary page provides;

- **A brief overview of the intervention**
  A description of the intervention as it has been used in this review.

- **A summary of the impact reduction potential of the intervention**
  Potential impact reductions of the car available through the implementation of the intervention are detailed. Where possible reductions are referenced to evidence, details of quantified data are included in Annex E, along with stakeholders' views; a summary of the stakeholder workshop is in Annex G.

- **A summary of the life cycle based trade-off impacts**
  A description of the trade-offs associated with the interventions highlighted through the evidence review and the stakeholder workshop. Where possible the study has highlighted quantitative data from the evidence review, details in Annex E, and qualitative key stakeholder opinion. In some areas, details on the potential trade-offs are scarce and highlight a need for future research.

- **Potential application of the intervention**
  This section provides suggestions for the future application of the intervention based on a balance of the impact reductions and potential trade off impacts.

The summaries provide a basis for understanding the impact reductions that an intervention can achieve with an awareness of the trade-offs associated with their implementation.

Hybrid

Overview

Hybrid vehicles use an electric motor in combination with a conventional ICE to drive the vehicle. There are a number of different 'strengths' of hybrid, depending on how much the electric motor contributes and if the vehicle can be charged from an external source.

Impact Reduction Potential

Impact reductions depend upon the type of driving the vehicle is used for; greatest benefit is seen in urban driving conditions.
Full hybrids can currently see fuel efficiency increase in urban conditions and associated urban air quality improvements. (Prius II modelled by Fontaras et al; 2008)
It is thought that some of the advantages of diesel ICE over petrol ICE will be carried over into diesel hybrids (Hoyer & Holden; 2007)

Associated Life Cycle Trade-offs

Production

There is uncertainty over the limit of available quantities of materials such as lithium for batteries (SV & Arup and Cenex, 2008).
For plug-in hybrids (and all electric based energy systems), the environmental impacts of the energy source used to produce the energy to charge the batteries needs to be taken into consideration. (Hoyer & Holden; 2007)

Use

Simulations and real-world studies have shown the biggest benefits are currently seen in urban driving conditions with limited benefits on motorway where petrol hybrids are equivalent of conventional diesel ICEs (Prius II & Honda Civic IMA - Fontaras et al; 2008).

Battery/capacitor lifetime is uncertain and batteries are potentially expensive for owners to replace. (SV)

The uptake of plug-in hybrid vehicles is likely to be much greater than that of full electric vehicles in the near future (Lemoine et al; 2006)

Disposal

ELV handlers are still waiting for influx of hybrid vehicles due to limited time on the market (~10 years). Many unknown factors exist, such as amount of recoverable material in components such as batteries. (SV).

The environmental impacts of production of batteries can be compensated for by an efficient and large scale collection and recycling system. (van den Bossche; 2006)

Application

Hybrid technologies do offer a practical compromise between full electric and ICE, and allow further development of common electric vehicle technology. Hybrids are therefore considered to be a bridging technology. The continual improvements in fuel efficiency of ICE engines can be carried through to increase hybrid vehicle efficiency. Hybrid vehicles are most suited to urban driving conditions as most of the technological advantage is lost on motorways.

Electric

Overview

Electric cars utilise energy stored in batteries to drive electric motors rather than petroleum based products and internal combustion engines.

Impact Reduction Potential

Electric vehicles can provide large environment benefits, depending on the energy source for the electricity generation.

Significant reductions in vehicle lifetime CO_2 are realistic, with further improvements to be realised with the reduction of the carbon intensity of the UK electricity supply (Arup & Cenex; 2008). Urban air quality benefits from zero emissions during the use phase and increased Well-to-Wheel efficiency gains over hybrids and hydrogen vehicles if renewable energy is used to generate the electricity supply (Campanari et al; 2009)

Associated Life Cycle Trade-offs

Production

The resource demands of manufacturing electric cars need to be investigated thoroughly, as there may be issues with global lithium supplies and depletion of nickel resources (SV & Arup and Cenex, 2008). There may be impacts on costs of manufacturing batteries for alternative products such as mobile phone and laptops (SV). The energy source for electricity generation for charging the vehicles is a significant factor in the overall impacts of the technology. (Campanari et al; 2009)

Use

The current public perception of electric vehicles may be poor. There are practical issues with the driving range of electric cars, speed limitations and infrastructure, and space taken by the batteries within cars (SV). Various battery types exist with different charge capacities. Lithium based batteries are currently the most promising but require 'further optimisation as to life, safety, stability and production cost' (Van den Bossche; 2006). The same study proposes that Lithium ion batteries have environmental advantages over other common battery varieties. Concerns have been expressed over the likelihood of potential breakthroughs for mainstream application of electric vehicles (Hoyer & Holden; 2007)
Non-traditional refuelling methods required by electric vehicles is also a barrier to widespread uptake (Brey; 2007). The reduction of noise impacts at low speeds could impact on pedestrian safety (SV).

Disposal

There are concerns with how often an electric car battery would need replacing over the lifetime of the car, and the impacts associated with these including economic and environmental (SV). Studies have shown that the environmental impacts of production of batteries can be compensated by an efficient and large scale collection and recycling system (van den Bossche; 2006).

Application

Electric vehicles are suited to urban environments where the recharging time and range limitations are more easily managed. They offer zero emissions at point of use and can produce significant local air quality benefits. Battery technology, resource availability and recycling are areas requiring further development.

Hydrogen

Overview

Hydrogen, produced from a number of processes, can be used within a converted ICE or a fuel cell to generate electricity to drive an electric motor. Hydrogen can be produced from fossil fuels or from water by electrolysis and can be transported in a liquid or gaseous form.

Impact Reduction Potential

The highest savings are realised if hydrogen is produced from renewable sources or natural gas (Brey et al; 2007). For hydrogen fuel cell vehicles, over the complete lifecycle, energy consumption can be significantly less than conventional ICE vehicles (Hussain et al; 2007). If a renewable energy and electrolysis hydrogen production process is utilised, the savings over the lifecycle will be high. Similarly, if there is a high fossil fuel contribution to the energy mix, the benefits will be reduced.

Associated Life Cycle Trade-offs

Production

Studies highlight the importance of energy source for hydrogen production being the determining factor in the overall environmental impacts (Hoyer & Holden; 2007). A number of technical barriers have yet to be satisfactorily overcome. (SV)
Energy consumption and emissions from the well-to-tank phase are 8.5 times greater for hydrogen produced from natural gas than from gasoline (Hussain et al: 2007). Current hydrogen production includes 96% from fossil fuels (Balat; 2008)

Use

Substantial investment in infrastructure for the delivery of hydrogen to the consumer is needed (SV), and hydrogen fuel cell cars are only an option over the long term (Turton & Barreto; 2007). Current prototype fuel cell efficiency is very low (Sorensen; 2007) and the fuel cells have a limited lifetime. The industry goal is to extend this lifetime to ~ 5 years (Sorensen; 2006)

Higher retail prices for vehicles may be prohibitive for mass market penetration of this technology. (SV)

Disposal

The complexities of recycling fuel cells are currently not completely understood (SV) and some studies suggest that the more difficult to recycle materials contained in a fuel cell may best be dealt with via incineration and energy recovery (Handley et al; 2002).
However, fuel cells contain valuable resources and therefore the effort will be made to recycle as much as possible (SV).

Application

Hydrogen offers the use of two potential drive trains, one a modification of an ICE system and the other a move towards electric motor driven vehicles. Given the large task of infrastructure development and technical barriers, the ICE system could serve as a short term technology while fuel cell technology is progressed. Hydrogen production and ELV issues are considered the major trade-offs.

Biofuels

Overview

Biofuels are liquid fuels sourced from agricultural crops and waste material. The most common biofuels are, bioethanol from the fermentation of glucose, and biodiesel from the chemical processing of fats such as palm oil.

Impact Reduction Potential

Due to the variety of biofuel sources and the production processes, it is difficult to identify a precise impact reduction for the full range of biofuels, as illustrated within the Gallagher review (RFA, 2008) in Annex D. Hammond et. al.(2008) suggest that the most efficient biofuels can offer very high CO_2 savings when the fuel is used directly as an alternative to petroleum based fuel. Biofuels, depending upon source and production method, can potentially increase life cycle environmental impacts.

Associated Life Cycle Trade-offs

Production

Stakeholders felt that the production of biofuels requires supply chain verification with audit trails to monitor direct and indirect impacts; biodiversity, deforestation and carbon emissions over life cycles. The second generation of biofuels, including sources from food and forestry waste, will not be commercially viable for 5-10 years (SV). Social impacts within the production of biofuel were identified within the Gallagher Review (RFA, 2008) "biofuels contribute to rising food prices that adversely affect the poorest".

Economic impacts through the need to divert government financial to support biofuel production, as countries that have a biofuel industry, i.e. outside the UK, require subsidies which are difficult to remove entirely (Kojima and Johnson, 2005).

Use

The warranty of a vehicle includes the use of low blend biofuels up to 5%, but higher percentage blends invalidate warranties (SV). There is potential for a significant amount of confusion as drivers become more environmentally conscious and fuel suppliers provide blends higher than 5%. Warnings have been given regarding a biodiesel B30, a 30% blend, available at the end of 2008, as the use of the fuel would invalidate car warranties (Fleet News, 2008). Even if fuel stations label biofuels adequately, are drivers aware of the implications of using certain blends of fuel? Plans exist to increase the warranty threshold in line with the Fuel Quality Directive, and a number of flex fuel vehicles are able to accept E85, an 85% ethanol blend.

Disposal

If different materials are required in some vehicles to develop the use of biofuels, new recycling processes may need to be developed (SV). However, many vehicles on the market are flex-fuel or are biofuel compatible with explicit marketing of the fact and are able to be recycled via current methods.

Application

Biofuels offer a renewable energy source in addition to petroleum based products for vehicle fuel. The concerns for social and environmental impacts from land use conversions in the source countries, and emissions over the life cycle of biofuels indicate that robust controls are needed for this intervention.

Material Substitution

Overview

The use of alternative materials to replace commonly used materials in a car. Material substitution can influence the impacts of the production of the car and its weight, and therefore fuel consumption in the use phase. There are limiting factors on which components can be substituted due to physical properties (e.g. strength). Aluminium and magnesium are focused in this report due to of availability of data, and are used to substitute for steel.

Impact Reduction Potential

A Japanese study compared life cycle impacts of aluminium (Al), magnesium (Mg) and steel for use in a medium size passenger car (Hakamada et al; 2007). The use of 50% recycled Al and 50% recycled Mg can realise small life cycle CO_2 savings (Hakamada et al; 2007, IAI; 2008). However with 75% recycled content and potential strength improvements, Mg material could generate considerably higher life cycle CO_2 savings. In the UK, savings could be potentially higher than the example due to a different usage pattern (e.g. 12 year compared to 10 year lifetime & 180,000 km compared to 100,000km range), however factors such as extra maintenance impacts and energy mixtures need to be considered.

Evidence suggests that materials such as carbon fibre, Kevlar and plastic have potential for significant savings.

Associated Life Cycle Trade-offs

Production

Impacts from production can be increased over conventional materials due to the energy intensity of the refining of the material. However, life cycle analysis can determine if these higher impacts in production are cancelled out by increases in impact reductions in the use and disposal phases.

Use

Potential increase in maintenance and repair costs was suggested by the stakeholders (SV).

Increased costs associated with substitution may fall outside manufacturers accepted premium for light weighting (EAA, 2007) therefore regulatory or financial incentives may be needed to encourage material substitution. It is important to note that safety is a key driving factor in material selection (SV),

Disposal

End of life vehicle infrastructure, methods and energy costs are not affected by increasing quantities of Mg or Al, of which around 95% can be recovered. Al provides a large economic incentive for ELV recycling (EAA; 2007)

Stakeholders raised concerns of potential issues with quality of recovered materials, which may exclude them from reuse in other applications (SV)

Application

Light weighting of vehicles through material substitution can have a large impact on reducing fuel consumption. The use of recycled material may realise a reduction in environmental impacts across the lifecycle, as extra energy demands in the production of virgin material can increase impacts above those of traditional steel manufacture.

ELV Directive and regulations

Overview

The European Commission ELV Directive aims to improve recycling of vehicles through setting environmental standards for dismantling facilities and quantified targets for reuse, recycling and recovery of vehicle materials.

Impact Reduction Potential

The EC ELV Directive sets targets of 85% reuse/recycling and 95% reuse/recovery by 2015 (EC, 2009b), aiming to make vehicles more recyclable in the future. The Directive may increase the use of aluminium as it is easily recycled, and recycling saves 95% of energy used for primary production. The Directive also aims to remove hazardous materials from use and bans mercury, hexavalent chromium, cadmium and lead (Gerrard and Kandlikar, 2007).

Associated Life Cycle Trade-offs

Production

In efforts to increase the percentage recyclability by weight of a vehicle, the use of light weight materials could be used to meet ELV criteria but may not be suitable for recycling. Alternative lighter material may increase the life cycle impacts of a vehicle through higher energy demands within the production phase (SV).

The project stakeholders' view included a difficulty in influencing consumption and purchase decisions through the ELV directive.

Use

For operators in the automotive industry, it may be financially more attractive to develop servicing and a new parts business, rather than develop new cars (SV).

Disposal

The project stakeholders considered that lower targets of 80% reuse/recycling and 85% reuse/recovery within the ELV directive were already achievable due to high metal content, but believed that the 95% target by 2015 may be too high and should be phased in (SV). Reuter et.al (2006) concludes similarly that targets above 85% would be difficult to achieve under the current legislation due to the "light-weight car designs beneficial for less impact during use phase".

Regarding the disposal of materials at end-of-life, there are recycling issues, including plastics due to potential for phthalate leakage and airbags due to explosive charges. Similarly non-metallic material is more difficult to pass on as a waste stream compared to the high metallic content of a car (SV).

Application

ELV regulations are able to create targets for the removal of hazardous material, the increase in 'design for recycling' of cars and increased quality standards for disposal methods and processes. The trade-offs of this intervention lie within the use of materials by manufacturers to achieve ELV targets and the effects on life cycle energy and emissions.

Eco-driving

Overview

Eco-driving involves behavioural changes to achieve fuel efficient driving, reducing fuel consumption and GHG emissions. A key part of eco-driving involves changing gear effectively, an action that can be assisted by in-built gear shift indicators (GSI).

Impact Reduction Potential

The evidence reveals eco-driving has the potential for an average of 10% reduction in fuel consumption and CO_2 emissions in the short term (TNO et al, 2006a; Johansson, Farnlund & Engstrom, 1999). Although in the long term, a year after eco-driving training, reduction potentials may fall. In combination with eco-driving training, GSIs are estimated to achieve a 4.5% reduction in fuel consumption and CO_2 emissions in the long term; while alone GSIs can result in an average 1.5% reduction (TNO et al, 2006b). Increased awareness whilst driving may improve road safety and reduce the number of road accidents (SV).

Associated Life Cycle Trade-offs

Production

The impacts associated with manufacturing GSIs, whether software or hardware based, and retrofitting to existing vehicles would need to be considered. The stakeholder views indicated that legislation would be required to influence the uptake of this technology into standard specifications (SV), and the EU is working towards the mandatory inclusion of GSI technology.

Use

The economic trade-off associated with the potential reductions achieved by eco-driving is dependent on the level of intervention, whether a promotional campaign, new driver or existing driver training (SV & TNO et. al. 2006b). A significant reduction of impacts would need to be achieved over the long term to justify the economic costs of implementation, however the evidence and the project stakeholders views suggests that it may be difficult to measure the true long term impact of eco driving, as there is the potential for people to forget the eco-driving techniques over time (SV).The TNO et. al. (2006a) study reports that only a year after training the reduction potential falls from 10% to 3%. The costs of GSI technology will vary, but appear to be relatively low cost to the manufacturer (TNO 2006b). Social impacts may evolve from increased journey times resulting from greater adherence to speed limits which are a key element of eco-driving (SV).

Disposal

Stakeholders suggested that depending on the nature of the GSI technology, there may be implications in the disposal phase of a vehicle; e.g. rare metals within electronic parts or plastic casings (SV).

Application

Eco driving may offer a relatively cost efficient route to achieving significant reductions in the environmental impacts of cars, particularly with the addition of GSI technology. However the long term impact of eco-driving training is not fully known and further research will be required to examine if this impact would continue into the future.

Speed Control

Overview

Speed control can involve externally enforced speed restrictions, or in-car technologies that influence or restrict the speed at which an individual can drive.

Impact Reduction Potential

It is estimated that fully enforcing the 70mph speed limit on motorways in Britain could lead to significant reductions in tonnes of carbon emitted per year (Anable et al, 2006), while introducing mandatory Intelligent Speed Adaption (ISA) to all cars over a 60 year period could result in total savings of 25 million tonnes of carbon, as well as safety benefits (Carsten et al, 2008). Evidence from an Active Traffic Management scheme aiming to reduce congestion, and keep traffic moving along the M42, which opens up the hard shoulder and reduces the motorway speed to 50mph, resulted in small reductions in CO_2 emissions on the motorway (Highways Agency, 2008).

Associated Life Cycle Trade-offs

Production

Manufacturing, and in the case of older vehicles retrofitting, ISA will have associated impacts, as does the production of infrastructure required to enforce and manage speed control schemes such as cameras, administration networks and penalty notices.

Use

The financial costs associated with maintaining speed control infrastructure as well as sustaining an administration network must be taken into consideration.

The form that speed control takes must be considered carefully, as severe forms such as speed humps designed to reduce vehicle speed to the region of 30 mph to 40 mph can result in increased emissions (Daham et al, 2005). In a similar way to speed humps, standard cameras can result in harsh accelerations and decelerations and so increased emissions, meaning that average speed cameras may be a better choice (SV).

A further consideration is the possible time loss associated with driving within the current, or a reduced, speed limit for some drivers, as well as the public acceptance of stricter controls on speed.

Disposal

The end of a speed control scheme would result in impacts related to the removal and disposal of infrastructure. Additionally, higher technology within the vehicle could increase its residual value (SV) having an effect on disposal.

Application

Speed control requires little in the way of major advancements in technology, and so represents a relatively simple route to reduce emissions. However, the economic costs of infrastructure and management of implementing speed controls could be high. The form of speed control utilised is an important consideration, especially in terms of public acceptance.

High occupancy rates

Overview

High occupancy rates have been encouraged via car sharing schemes as well as high occupancy vehicle (HOV) lanes, the primary aim of which is to reduce the overall number of journeys made by car.

Impact Reduction Potential

If an additional 1 to 10% of car commuters begin to car share over the next ten years, it is estimated this would result in a 0.6% to 11% reduction in vehicle mileage driven to work Cairns et al (2004). HOV lanes have resulted in some success, for example a 5km lane in Leeds resulted in an increase in average vehicle occupancy from 1.35 in 1997 to 1.51 in 2002. Little change in air quality was measured; however a noticeable noise reduction coincided with the HOV lane operating times (Leeds City Council, 2002). Car sharing is an important element of work and school travel plans.

Associated Life Cycle Trade-offs

Production

The ultimate goal of encouraging high occupancy rates is to reduce the number of car journeys made, which may result in a reduction in demand for new vehicles and therefore impact upon car manufacturers (SV). However, in the short term it is thought that high occupancy rates do not have a significant effect upon car production (SV).

The creation, maintenance and management of the infrastructure required for an HOV lane, including cameras and signage, all carry associated environmental impacts and economic costs (SV). Additionally, there are a number of financial costs relating to the complementary measures required for a successful HOV lane including a system of enforcement, police presence, cameras and park and ride schemes (SV).

Use

The economic trade off associated with car sharing schemes should be relatively low, particularly when incorporated into a work place travel plan for example.
A potential long term trade off associated with high occupancy rates is that successfully reducing the number of vehicles on the road, improving the flow of traffic and journey times, may encourage previous non car users to use the roads and take advantage of these improvements.

Disposal

A reduction in vehicle use could impact on operators within the industries involved in maintenance and end of life processes (SV).

Application

Successful encouragement of high occupancy rates can result in significant reductions in car journeys and total vehicle mileage travelled, however the true impact is difficult to accurately measure. This area would benefit from assessments of the effectiveness of existing schemes and the ability to transfer successful schemes to the UK, particularly HOV lanes.

Car labelling

Overview

The fuel economy car label was introduced in the UK in 2005. The car label allows the presentation of new vehicle information to consumers, including VED band, CO_2 g/km emissions, average running costs, make/model/engine details and fuel consumption.

Impact Reduction Potential

There appears to be little evidence of any quantifiable impact reductions of UK vehicle fuel economy label. Consumer awareness surveys by the LowCVP show that the percentage of people (looking to buy, or recently purchased a vehicle) aware of the label are increasing, and a high percentage of these believed the label was important in their purchase decision-making (EAC, 2008).

Associated Life Cycle Trade-offs

Production

The full production impacts of a car would be difficult to include on a simple car label, which is in place to inform consumers, as there are many diverse production routes. The label may already be too complex and could hinder effective comparison between cars (SV).

The vehicle testing cycles that generate the data provide a standard comparator, however these may not be realistic representations of the future performance of a vehicle, for example the average CO_2 emissions of a hybrid vehicle is heavily dependent on the driving style of the consumer (SV). The ability to compare conventional ICE and alternative fuelled vehicles, for example electric, is a critical issue for car labelling and communicating to the consumer.

Use

In 2008, a public consultation into a revision of the EU car labelling directive showed that half of contributors believed that car labels did not adequately inform customers (EC, 2008b). The consultation includes the response to car labelling in general and not the UK fuel economy label specifically. The consultation also indicated that advertising may include misleading ‘green’ claims, and that other pollutants and safety aspects may be overshadowed by CO_2 emissions information. (EC, 2008b)

The project stakeholders discussed the potential for resale information and labelling to inform the second hand car market consumer of vehicle fuel efficiency (SV).

Disposal

The fuel economy label requires clear labelling of disposal and recyclability information, effectively broadening the scope of the label to include a life cycle perspective (SV).

Application

The introduction of a car label to inform consumers of the environmental impact of cars, through fuel efficiency data, is a step towards improving the overall environmental performance of the UK car stock. Future research will be required to study the effectiveness of the label on the production and consumption of cars.

Early Scrappage

Overview

Early scrappage or vehicle retirement programmes aim to remove older, potentially less efficient vehicles, from the vehicle stock. Financial incentives have been used in other countries to encourage drivers to trade-in their vehicles.

Impact Reduction Potential

Optimal lifetime expectancy is a tool in the assessment of scrappage scheme criteria. The results of a US study (Spitzley et. al., 2005) give an indication of the balance required to include all impacts such as carbon monoxide with its own optimal interval between 3-6 years, and CO_2 and energy use with a longer interval calculated to be 18 years. A balanced optimal interval of economic and environmental impacts was reported as approximately 9 years. European scrappage scheme proposals include Germany; €2500 (£2320, £1:€1.077) for a vehicle older than 9 years and buying a new car (Fleet News, 2009).

Associated Life Cycle Trade-offs

Production

Updated evaluations of the optimal lifetime of a vehicle would be needed to reflect advancements and innovation in vehicle technology to create benchmarks for scrappage schemes (SV). Evaluations would achieve higher accuracy with access to detailed life cycle data for vehicles.

The use of cash-for-replacement schemes to influence consumption choices and therefore production of vehicles would reduce public finances (ECMT, 1999)

Use

Scrappage schemes may not incentivise the target groups to trade-in their vehicles, reducing their effectiveness (Dill, 2004), and have potential to impact negatively on financially vulnerable groups; potentially in schemes which dictate younger more fuel efficient vehicles must be purchased to replace a scrapped vehicle to be eligible (SV). Socio-economic impacts may occur for operators within the second hand car market, with effects on residual values and maintenance requirements; used parts manufacturers, dealers and mechanics, and car collectors (Dill, 2004 & SV)

Disposal

The project stakeholders' views include the potential for scrappage schemes to cause reductions in the residual value of cars, and schemes may significantly increase vehicle disposal volumes. Such increases may not be the most sustainable strategy when considering the whole life cycle of a vehicle (SV).

Application

Early scrappage schemes attempt to use optimal lifetimes of vehicles to reduce impacts of their use, and studies have presented an estimation of these intervals. However, UK specific research is needed including the implications on government strategy that aims to reduce consumption.

Road Charging

Overview

Road charging interventions include zone charging, for example congestion charge zones within urban areas or National Parks, and road tolls used predominately on high volume vehicle infrastructures, for example the M6 toll motorway.

Impact Reduction Potential

Reductions in emissions to air have been reported by studies on the London Congestion charge zone area after the first year in operation, including reductions in CO_2, NO_x and PM_{10}. Any reductions after this time can be attributed to other factors such as improvements in vehicle technology (TfL, 2007). A Cambridge congestion charge proposal predicts a similar degree of reduction in CO_2 emissions as well as reductions in travel time (CC, 2008). Additional social benefits of road charging schemes could be reductions in accidents and mobility severance (Steiner and Bristow 2000)

Associated Life Cycle Trade-offs

Production

The design, production and administration of the infrastructure needed to enforce and manage road charging, e.g., cameras, penalty notices and administration networks, will have associated impacts on the environment. Economic impacts could be considerable; for the London congestion charge zone, the initial supply of cameras was reported to cost £8 million, and £280 million for a contracting company to implement and manage the scheme (RTT, 2008).

Use

Road charging schemes may increase emissions through the transfer of transport demand, rather than reduction, to higher emitting vehicles or through changes in travel routes to avoid charging; increases in taxi emissions (LCC, 2008) and potential increases of traffic on peripheral roads (Steiner and Bristow, 2000 & Body, 2006). Economic costs associated with creating appropriate alternatives for car travel inside charging areas (SV); requires good public transport service, cycle lanes and pedestrian paths. Time based road charging, for instance peak hours or daytime, may have social impacts due to people changing working hours to avoid charge (SV). The recent rejection of the road pricing scheme proposed for Manchester illustrates the importance of public acceptance and the fluidity of the acceptance, as a social research study into the scheme in 2007 showed that 56% of Manchester residents were in agreement with the transport proposal including road pricing (Manchester City Council, 2007).

Disposal

The disposal of the infrastructure needed to enforce and manage road charging, e.g., cameras and toll booths, will have their own impacts on the environment and financial costs (SV).

Application

Road charging can take a number of forms, including zone or motorway based. Existing schemes have shown that reductions in emissions can be achieved alongside the main objective to reduce congestion. The impacts of travel changes, social acceptance and costs of charging infrastructure must be fully assessed in evaluations of charging schemes.

4 Trade-off Summary

This report has identified, within the scope of the evidence available, the potential impacts and trade-offs for selected interventions to reduce the environmental impact of the passenger car. A summary of the key sustainability impacts of trade-offs associated with each of the twelve interventions is given below. It is important to note that the selected interventions are at different stages in terms of mass market release and/or policy inclusion, and therefore the trade-off summary reflects a qualitative view of the potential impacts associated with these interventions.

Intervention	Impact reduction potential	Associated trade-offs: within Production, Use and Disposal		
Hybrid	Significant fuel economy improvement under urban conditions	Resource use for battery production	Limited benefits outside urban conditions	Battery replacement and recycling
Electric	Significant reductions in life cycle CO_2 emissions	Resource use for battery production	Shorter driving range and long recharging time	Battery life time, replacement and recycling
Hydrogen	Life cycle GHG emissions and energy consumption are less than ICE	Potential for higher impacts in fuel production	Significant investment in infrastructure is required	Requires a long term cohesive strategy inclusive of government and car manufacturers
Biofuel	Biofuels may offer significant carbon savings, depending on biofuel type and production process.	Economic impacts through diversion of government financial support in producer countries	Land use conversion leading to increased food prices and potentially greater environmental damage e.g. through deforestation	High biofuel blends can invalidate vehicle warranties
Material substitution	Fuel consumption reductions resulting in life cycle CO_2 emission savings	Potential for higher impacts in material production	Costs to manufacturers could cause retail price increases	Consumption of new materials may cause quality issues in recycling
ELV directive	The ELV Directive sets targets of 85% reuse/ recycling and 95% reuse/recovery by 2015.	May hinder technology development, and could restrict the development of more efficient vehicles	Weight percentage based regulations may not result in reduced impacts over life cycle	Higher targets may be difficult to achieve
Eco-driving	Reductions in fuel consumption and CO_2 emissions.	Difficult to measure the true long term impact of eco-driving	Social impacts associated with adapting to change in journey times	Economic trade-offs dependant on level of intervention
Speed control	Could provide significant carbon savings.	Continued research needed into optimum speed due to advancements in technology	Static cameras more likely to prevent harsh acceleration/braking compared to average speed cameras	Economic costs associated with manufacturing and maintaining required infrastructure
High occupancy rates	An increase in commuters car sharing estimated to result in significant reductions in mileage driven to work.	Potential negative impact on car industry if there was a decrease in purchase of new vehicles	Economic and environmental impacts associated with creating, and managing HOV lane infrastructure	Impacts on other alternatives such as walking and public transport
Car labelling	Consumer awareness surveys show an increase in the percentage of people aware of the label.	Difficult to put production emissions on label because of diverse production routes	Comparison of electric with standard conventional fuels is required	Needs clear labelling for disposal, and KPI for recyclability
Early scrappage	Schemes aiming to incentivise the disposal of older vehicles have shown some success in terms of disposal rates.	Further research required to establish optimal lifetime of cars	Socially this may impact negatively on financially vulnerable groups who do not purchase new cars	Economic impact in the reduction in value of second hand cars
Road charging	Environmental zones achieve significant emissions reductions after implementation.	Road charging schemes may increase emissions through the transfer of transport demand	Social impacts associated with effects on vulnerable groups	Economic and environmental impacts of manufacturing and disposing of infrastructure and technology

5 Recommendations and Conclusions

The project has reviewed the interventions to assess the potential for improving environmental impacts against trade-offs with sustainability implications. There appears to be no single current intervention that alone will significantly reduce the impacts of the car, and it is clear combinations of interventions are required to effectively reduce impacts through technical and behavioural changes, supported by a strong policy framework.

Evidence Gaps

The report has reviewed the evidence for reductions in impacts across the lifecycle of the car for the twelve interventions discussed. In some cases, quantitative evidence for impacts is available for specific interventions. However in most cases the full environmental impacts are not known and this report focuses on potential reductions and trade-offs. The stakeholder engagement was a key part of the project and enabled the identification of the trade-offs associated with each intervention from a broad group of experts, and provided a clearer view of each of the twelve selected interventions.

An objective of the report was to highlight areas in research where knowledge gaps may exist and further research may provide evidence foundations to support the future development of these interventions. Table 5.1 illustrates the key pieces of evidence for each intervention which highlight a significant potential impact reduction, and a recommendation for further research which, if carried out, may help to achieve these reductions.

Table 5.1 Evidence gap and research recommendations

Intervention	Evidence	Research recommendation
Hybrid	Evidence suggests greater impact reduction in urban driving conditions.	A review of how hybrids are designated as eco-cars within policy based interventions could determine whether this technology along with driving styles is being promoted effectively.
Electric	Resources for battery production, particularly lithium are limited.	An analysis of the results of current pilot studies into the recycling of electric car batteries could uncover the potential to close resource supply loops, reduce pressure on resource supply and impacts of production and disposal.
	Electric car battery recycling is in the early stages of development and restricts assessment of full life cycle implications.	
Hydrogen	Requires widespread availability of infrastructure and technology to ensure take-up. This is currently prohibitively expensive.	A review of hydrogen implementation would highlight the potential for a number of parties; government, fuel suppliers, car manufacturers and consumers to commit to a long term low impact strategy for this technology.

Intervention	Evidence	Research recommendation
Biofuel	Social and environmental trade-offs, including land use conversions and deforestation are significant for first generation biofuels, but are not fully understood for second and third generations.	The lessons being learnt regarding the impacts of first generation biofuels must be used to ensure the impacts of further developments in biofuel production are understood.
	The use of some biofuel blends may invalidate warranties.	A review of the gaps between vehicle warranty and biofuel availability will highlight the potential for these gaps to cause consumer issues. A review should include the labelling of biofuels and communication of use to consumers.
Material substitution	Material substitutions can significantly change the energy use over the car life cycle. Non-peer reviewed evidence suggests that materials such as carbon fibre, Kevlar and plastic have potential for significant savings	A review of the inclusion of full life cycle impacts within the development of emerging materials could highlight the potential to create a more robust evaluation process. A process would need to include the impacts of the end-of-life directive.
End-of-Life directive and regulations	Concerns that the 95% target will be difficult to achieve.	The weight percentage basis of end-of-life regulation should be reviewed to ensure this is the most appropriate route for reducing impacts over the whole life cycle.
Eco-driving	Currently only short term evidence is available and long term assessment is determined after one year of eco training.	The uncertainty of the effectiveness of eco-driving schemes over the long term suggests that further research is required in this area to create more informed costs and benefits for this intervention.
Speed control	A significant reduction in passenger car CO_2 emissions can be achieved through enforcing the current speed limit of 70 mph.	The level of potential reduction of impacts through speed limit adherence warrants a review of measures beyond high cost infrastructure based enforcement, for example deterrent measures.
High occupancy rates	Insufficient evidence to assess the value of high occupancy lanes. Current assessments are specific to individual schemes.	The small number of case studies of HOL schemes in the UK indicates further research is required to understand the potential for impact reductions and associated trade-offs.
	Potential for large impact savings through car sharing.	A review of the results of the initiatives within the Sustainable Travel demonstration towns, due this year, will provide a route to understanding the impact reductions achievable through car sharing.

Intervention	Evidence	Research recommendation
Car labelling	Evidence suggests that 44% of prospective buyers were aware of the label and 70% said it was important in helping them to decide what car to purchase. However it was not understood whether this encouraged consumers to buy lower emitting vehicles.	Research into the ability of a car label to encourage the purchase of lower emitting vehicles could inform the future development of the design of the label. Studies should look into the links between consumer choices, driving style and car use.
Early scrappage	The optimisation of early scrappage has a complex set of variables but studies from case studies in Europe have shown some success.	UK specific research is needed to assess the costs and potential impact reductions of a UK scheme, and to investigate the complex links between environmental, social and economic impacts of these schemes.
Road charging	Road pricing shows potential to reduce impacts in specific areas and emissions as a whole. However the public is not clear as to the reason for their implementation – revenue raising, decreasing congestion, etc.	Research is needed into how communication of additional benefits, such as health, as well as congestion reduction can influence the social acceptance of charging schemes.

Recommendations

A significant finding of the project was the limited amount of quantitative life cycle evidence for trade-offs associated with the interventions. This may be an indication of the barriers, financial and time based, to carrying out detailed life cycle assessments, or simply the difficulty in identifying the trade-offs themselves. The project found the stakeholders input to be invaluable in identifying and supporting the potential trade-offs highlighted within the report. The process of identifying trade-offs over the life cycle of the car has revealed a number of issues that link different interventions, where resolving a particular issue could result in considerably higher reductions in the impact of the car, Table 5.2.

Table 5.2 Inter-linkages between interventions

Impact Type	Intervention	Impact Link	Potential for further impact reductions
Energy	**Electric**	UK energy mix	The decarbonisation of the UK energy mix will significantly reduce the impacts of these technological interventions over the whole life cycle
	Hydrogen		
	Hybrid		
Waste	**Electric**	Recycling of batteries and fuel cells	Current pilot projects on recycling and disposal of car batteries will reveal the potential to close the resource loop for these interventions. The result will be less pressure on raw material demand and reductions in life cycle impacts.
	Hydrogen		
	Hybrid		

Inter-linkage	Intervention	Impact Link	Potential for further impact reductions
Materials	**ELV directive and regulations**	The decisions made during the design and production of cars have direct effects on the impacts across the whole life cycle	The research highlighted that some technologies can be launched into the market before there is a full understanding of the whole life cycle impacts. There are a number of interventions that are clearly linked by the decisions made in the design and production phase of cars. It is therefore important that an evaluation of life cycle impacts is undertaken for changes to vehicle composition and technology.
	Material substitution		
	Early scrappage		
	Electric		
	Hydrogen		
	Hybrid		
Social Impacts	**All twelve interventions but specifically;**	Understanding of the reasons for the intervention and appreciation of the need for changes in the transport sector	There is a considerable amount of work within research and government policy on the behavioural aspect and consumer awareness of interventions. Act on CO_2 is an example of the steps being taken to communicate the sustainability issues of the passenger car. Understanding the social acceptance of interventions and the effectiveness of communicating information on the impacts of cars will provide a stronger basis for implementation of future reduction measures.
	Car labelling		
	Eco-driving		
	Speed control		
	High occupancy rates		
	Road charging		

Conclusions

There is an urgent need to understand the impacts of transport, specifically the passenger car, and the relationships with consumption. Addressing climate change and energy security issues will rely on effective interventions that reduce the consumption of fossil fuel and raw material resources, whilst imposing limited impacts, whether social, economic or environmental, over the life cycle. The recent advancements in the use of biofuels illustrates how important the understanding of impacts is over the whole life cycle, including fuel production, as insufficient information can lead to policies being brought into question and requiring revision. This report has reviewed a broad range of interventions to identify potential trade-off impacts, and a qualitative summary of the associated trade-offs provides an illustration of where impacts occur over the whole life cycle.

The recommendations in this report include areas of further research which will fill knowledge gaps in the evidence reviewed during the project, and could provide stronger support for future interventions. The trade-off identification research revealed inter-linkages between a number of interventions where development of a particular area of technology, or understanding of consumer behaviour, could significantly increase the impact reductions of a group of interventions, specifically;

- Decarbonisation of the UK energy mix
- Closing resource supply loops
- Full life cycle assessments of changes to vehicle composition and technology
- Understanding social acceptance of interventions

The acceptance of technology and transport initiatives aiming to reduce the impacts of the car is an important factor in the implementation and development of all interventions. There must be a clear understanding of why consumers choose certain modes of transport, who will consume new technologies and the impacts interventions have on individuals and society as a whole. It is clear that future technology uptake and development for cars will be determined by consumer demand and economic factors. Policy may be more effective through the implementation of a 'technology neutral' approach, through tailpipe emissions regulations for example. This does not imply that the life cycle impacts of technology will be minimised through this route, therefore life cycle based regulations will be critical in monitoring the development of vehicle technology.

The UK has recently lead the way with the Climate Change Act 2008, and can follow this with strong evidence-based policies specifically aimed at reducing the impacts of the passenger car and the transport sector.

Annex A: Evidence search strategy

The collation of evidence of the impacts of the car, and the interventions aimed to reduce these impacts, was achieved using a review of key transport reports and a search of general and transport specific databases using a search strategy, Table A1.

Search databases and key transport reviews.
The evidence base was investigated using search criteria (Annex A) in general and transport specific databases;

- International Transportation Research Document Database (ITRD),
- Science Direct,
- Ingenta Connect and,
- Transportation Research Board Information Service (TRIS).

The key transport reviews include;

- the King Review of Low Carbon Cars (King Review, 2007 & 2008),
- the Environmental Improvement of Passenger Cars (IMPRO-car) report (EC, 2008a),
- the Carbon Pathways Analysis – Informing Development of a Carbon Reduction Strategy for the Transport Sector (DfT, 2008b),
- Well-to-wheels analysis (EC, 2007).and,
- SMMT sustainability reports;
- The ninth sustainability report: The UK automotive sector 2007 data (SMMT, 2008a)
- SMMT New car CO_2 report 2008: Driving down emissions. (SMMT, 2008b)

Table A1 Keyword search criteria for database search

Car/Automotive/Motor vehicle/motorcar				
1. Raw Materials	2. Manufacture	3. Distribution	4. Waste Management & 6. Recycling*	5. Use
Environmental impacts	Environmental impacts	Environmental impacts	Environmental impacts	Environmental impacts
Greenhouse gas (GHG) emissions	Greenhouse gas (GHG) emissions	Greenhouse gas (GHG) emissions	Greenhouse gas (GHG) emissions	Greenhouse gas (GHG) emissions
Resource use	Resource use	Life cycle	Resource use	Air quality
Life cycle	Life cycle	Energy consumption	Mass balance	Noise
Mass balance	Regulation	Impact assessment	Regulation	Alternative fuels
Impact assessment	Energy consumption		Energy consumption	Hybrid
Energy consumption	Waste		Waste	Electric vehicle
Fuel consumption	Recycling		End-of-life	Regulation
	Impact assessment		Recycling	Trade-off
			Impact assessment	Eco-driving
				Energy consumption
				Fuel consumption
				Impact assessment
				Congestion charge
				Road pricing/charging

Annex B: Review of key transport reports

A review of interventions within key transport reports

Technological
Behavioural
Policy based

King Review	IMPRO-car	Well-to-wheels analysis, V2c	EEA - TERM 2008 success stories
fuels for the future	car weight reduction	Compressed Natural Gas (CNG)	Ecodrive - Netherlands
biofuels	aerodynamics	Biogas	Speed control - Rotterdam
electricity	tyres	LPG	Congestion Charging – London
hydrogen	mobile air conditioning	Biofuels	Environmental Zone – Prague
	tailpipe abatement systems	Hydrogen	Freight Construction Centre - London
vehicle technologies	powertrain improvements		Teleconferencing - UK
incremental powertrain enhancements	hybrid cars		
Light weighting	biofuels		
low rolling resistance tyres	end of life recovery		
improved aerodynamics	speed control		
hybrid - mild	driving behaviour		
hybrid - full			
hybrid plug-in			
electric			
hydrogen powered			
consumer choices			
choosing - VED			
using - smarter driving			

Annex C: Project steering groups

Internal Steering Group

Dorothy Maxwell	Defra
Carolina Escobar	Defra
Alice Baverstock	Defra
James Hooson	DfT
Dennis Morgan	DfT
Duncan Kay	Sustainable Development Commission
Sue Dibb	Sustainable Development Commission

Wider Steering Group.

The draft report was distributed for comment to a wider steering group for review. The group included the stakeholders who attended the project's stakeholder workshop.

Additional stakeholder input

In addition to the stakeholder workshop a group of stakeholders provided further input into the project

Robert Walker	SMMT
Bernadette McSharry	SMMT/BMW
Peter Stokes	CARE
Geoff Fletcher	Clifford-Thames
Michael Green	D & G Batteries

Annex D: Literature review

Alternative fuels - Electric, Hybrid, Hydrogen, Biofuel											
Source title	**Author(s)**	**Year**	**Source details**	**Region/ country**	**Impacts in Life Cycle Phase**			**Data source robustness (high/medium/low)**			
					Production	**Use**	**End-of-life**	**Credible source**	**Reason**	**Transferable to UK policy**	**Reason**
Well-to-Wheels analysis of future automotive fuels and powertrains in the European context	Well-to-Wheels Report	2007	WELL-to-WHEELS Report	EU	Well to Wheel for Fuels			High	Joint Research Centre EU	Medium	EU wide analysis, slight differences in UK scenario
Assessing total and renewable energy in Brazilian Automotive Fuels: A life cycle inventory (LCI) approach	Almeida D'Agosto, M. & Kahn Ribeiro, S.	2008	Renewable and Sustainable Energy Reviews, In Press	Brazil	Fuel Life Cycle			High	Federal University of Rio De Janeiro - Peer Reviewed Publication	Medium	Implications for Fuel production
The Prospects for Global Green Car Mobility	Moriarty, P. & Honnery, D.	2008	Journal of Cleaner Production, Volume 16, Issue 16, 2008, Pages 1717-1726	Global	Fuel Life Cycle	Comparisons of vehicles and systems efficiency		High	Monash University, Australia - Peer Reviewed Publication	Medium	Global perspective but technologies and specific scenarios discussed.
Evaluation of Automobiles with alternative fuels utilizing multicriteria techniques	Brey, J.J, Conteras, I., Carazo, A.F., Brey, R., Hernandez-Diaz, A.G. & Castro, A.	2006	Journal of Power Sources, Volume 169, Issue 1, June , Pages 143-168		Well to Wheel for Fuels	Emissions and estimate of damage per unit of emissions		High	Pablo de Olavide University, Spain - Peer Reviewed Publication	Medium	In depth consideration and balancing of factors of the alternatives
Vehicle Transport Futures: U.S. and China Scenarios based on Car Carbon?? An Alternative Vehicle & Fuel Choice Model with Energy &	Bryne, J., Waegel, A., Tian, J., Meyer, P. & Veerabhadrappa, V.B.	2008	Center for Energy and Environmental Policy	USA, China		Predictions of Emissions and Energy Consumption		Medium	Center for Energy and Environmental Policy	Medium	Prediction of Effects of policies

Alternative fuels - Electric, Hybrid, Hydrogen, Biofuel											
Source title	**Author(s)**	**Year**	**Source details**	**Region/ country**	**Impacts in Life Cycle Phase**			**Data source robustness (high/medium/low)**			
					Production	**Use**	**End-of-life**	**Credible source**	**Reason**	**Transferable to UK policy**	**Reason**
Emissions Analysis Outputs											
Alternative fuels and Sustainable Mobility: is the future road paved by biofuels, electricity or hydrogen	Hoyer, K.G. & Holden E	2007	International Journal of Alternative Propulsion, Volume 1, No.4		Well to Wheel (WTT & TTW)	Comparison of alternative fuels and engine technology energy consumption & GHG emissions(CO 2, NOx)		High	Oslo University & Western Norway Research Institute - Peer Reviewed Publication	High	Discussion of benefits and issues of various options
Securing a Clean Energy Future - Greener Fuels, Greener Vehicles: A State Resource Guide	National Governors Association	2008	National Governors Association	US	Fuel Production	Comparisons of vehicles and systems efficiency		Medium	Public Policy Organisation	High	Policy Priorities
Lead Demand of Future Vehicle Technologies	Higgins, C.J., Matthews, H.S., Hendrickson, C.T. & Small, M.J.		Transportation Research Part D: Transport and Environment Volume 12, No.2	Global		Comparisons of vehicles		High	Peer Reviewed Publication	Medium	Vehicle Technology
Life cycle modal of alternative fuel vehicles: emissions, energy, and cost trade-offs	Hackney, J & de Neufville, R.	1999	Transportation Research Part A: Volume 35 243-266		Fuel Production	Comparisons of vehicles and systems efficiency		High	Peer Reviewed Publication	High	Vehicle Technology
A comparison of alternative technologies to de-carbonize Canada's passenger transportation sector	Steenhof, P. & McInnis, B.	2008	Technological Forecasting & Social Change Volume 75 1260 - 1278	Canada		Comparisons of vehicles and systems efficiency		High	Peer Reviewed Publication	Medium	Vehicle Technology and Public transport
Fuel cell vehicles: Status 2007	Von Helmolt, R. & Eberle, U.	2006	Journal of Power Sources Volume 165 833-843	Global		Comparisons of vehicles and systems efficiency		High	Peer Reviewed Publication	Medium	Vehicle Technology

Alternative fuels - Electric, Hybrid, Hydrogen, Biofuel

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
A preliminary life cycle assessment of PEM fuel cell powered automobiles	Hussain, M., Dincer, I. & Li, X.	2007	Applied Thermal Engineering Volume 27, Issue 13, Heat Powered Cycles	US	Energy consumption of production and operation			High	Peer Reviewed Publication	High	Vehicle Technology
Fuel Cells power up	Carney, D.	2007	Automotive Engineering International Volume 115 No.9	Global		Systems Efficiency		High	Peer Reviewed Publication	High	Vehicle Technology
A simplified LCA for automotive sector - a comparison of ICE (diesel and petrol), electric and hybrid vehicles	Nicolay, S.	2000	8th LCA Case Studies Symposium, SETAC-Europe	Belgium	Fuel production - electricity based on Belgian production	Comparison of alternative fuels and engine technology GHG emissions(CO_2, CH_4, N_2O, PM_{10}, CO, NO_x, SO_2, HC)		High	Peer Reviewed Publication	High	Switch Belgium electricity production to UK
Does the hybrid Toyota Prius lead to rebound effects? Analysis of size and number of cars previously owned by Swiss Prius buyers	Haan de, P, Mueller, M. G. and Peters, A.	2005-6	Ecological Economics, 58, (2006), 592-605	Switzerland	Vehicle production demand	Emissions of vehicle, CO_2, rebound effects of reduction in monetary cost, vehicle weight, ownership		High	Peer Reviewed Publication	High	European consumption drivers
The Allure of Technology: How France and California promoted electric and hybrid vehicles to reduce urban air pollution	Calef, D. & Goble, R.	2007	Policy Sciences, Volume 40, Issue 1, Pages 1-34	EU / USA	Vehicle production Influence			High	Clark University, USA, Peer Reviewed Publication	High	Technology forcing policies
Reducing energy consumption in road transport through	Haan de, P, Peters, A. & Scholz, R.W.	2007	Journal of Cleaner Production,	Switzerland		Tax Rebates		High	ETH Zurich - Peer Reviewed Publication	Medium	Uptake of Technology Policies

Alternative fuels - Electric, Hybrid, Hydrogen, Biofuel											
Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
hybrid vehicles: Investigation of rebound effects, and possible effects of tax rebates			Volume 15, Issues 11-12,The Automobile Industry and Sustainability 2007, Pages 1076-1083								
Effects of Plug-in Hybrid Electric Vehicles in California Energy Markets	Farrell, A.E., Lemoine, D. & Kammen, D.M.	2007	Transport Research Board 86th Annual Meeting	USA		Energy Demand and emissions		High	Conference Proceedings	Medium	Wider influence of policies
Experimental evaluation of hybrid vehicle fuel economy and pollutant emissions over real-world simulation driving cycles	Fontaras, G., Pistikopoulos, P. & Samaras, Z.	2008	Atmospheric Environment Volume 42, Issue 18, Pages 4023-4035	EU		Efficiency: fuel consumption and air quality		High	Aristole University, Greece - Peer Reviewed Publication	High	Vehicle Technology
Diesel and Hybrids Don't Mix: Perceptions of the Interested Public and Actual Driving Behaviour of New Car Owners	Gerard, D., Fischbeck, P.S. & Mathews,S.	2006	Transportation Research Record: Journal of the Transportation Research Board No.2017	US		Driving Efficiency Comparisons		High	Conference Proceedings	High	Vehicle Technology and Public Perceptions
The History of Alternative Fuels in Transportation: The Case of Electric and Hybrid Cars	Hoyer, K.G.	2008	Utilities Policy, Volume 16, Issue 2, Sustainable Energy and Transportation Systems, Pages 63-71			Energy Efficiency		High	Peer Reviewed Publication	Medium	Policy Implications

Alternative fuels - Electric, Hybrid, Hydrogen, Biofuel

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Assessing current vehicle performance and simulating the performance of hydrogen and hybrid cars	Sorensen, B.	2007	International Journal of Hydrogen Energy, Volume 32, Issues 10-11, Pages 1597-1604	Global		Efficiency modelling of vehicles in km/MJ		High	Roskilde University, Denmark - Peer-Reviewed Publication	High	Vehicle Technology
Comparison between hydrogen fuel cell vehicles and bio-diesel vehicles	Sorensen, B.	2006	Proceeds of the 16th World Hydrogen Energy Conference, 2006. Paper 111	Global		Efficiency modelling of vehicles in km/MJ		Medium	Conference Proceedings	High	Vehicle Technology
Toyota Prius turns 10	Schreffler, R.	2008	Ward's auto world Volume 44, No.1	Global		Vehicle Efficiency		Medium	Scientific Article	Medium	Vehicle Technology
Electric & Hybrid Vehicle Technology International. Annual Review 2008	Slavnich, D.	2008	Electric & Hybrid Vehicle Technology International	Global	Review of Current Concept Vehicles and Emissions			Medium	Review Article	Medium	Vehicle Technology
Hybrid Electric Vehicles: Evaluating Emission Reductions and Cost Benefits for University Motor Vehicle Fleet	Yun, J. & Miller, T.L.	2007	Transport Research Board 86th Annual Meeting	US		Fuel Consumption, emissions reduction		High	Peer Reviewed Publication	High	Vehicle Technology
Investigation into the scope for the transport sector to switch to electric vehicles and plug-in hybrid vehicles	Arup and Cenex	2008	BERR and DfT report accessed from http://www.berr.gov.uk/files/file48653.pdf	UK	Detailed study of the life cycle impacts of electric vehicles; including air quality, air acidification, photochemical oxidation formation, resources and waste, water, and impacts on people, human health and noise			Med	Consultancy report	High	UK based
A comparison of hydrogen, methanol and gasoline as fuels for fuel cell vehicles:	Joan M. Ogden, Margaret M. Steinbugler	1998	Journal of Power Sources, Volume 79,	US	Fuel production, vehicle weight	Fuel consumption, vehicle performance,		High	Peer Reviewed Publication	High	Vehicle Technology

Alternative fuels - Electric, Hybrid, Hydrogen, Biofuel

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
implications for vehicle design and infrastructure development	and Thomas G. Kreutz		Issue 2, June 1999, Pages 143-168			fuel economy, weight					
Energy analysis of electric vehicles using batteries or fuel cells through well-to-wheel driving cycle simulations	Campanari, S., Manzolini, G. & Iglesia, F.G.	2009	Journal of Power Sources Volume 186 464-477	EU	Well to Wheel for Fuels			High	Department of Energy, Italy - Peer Reviewed Publication	High	Vehicle Technology
Commercializing light-duty plug-in/plug-out hydrogen-fuel-cell vehicles: "Mobile Electricity" technologies and opportunities	Williams, B.D. & Kurani, K.S.	2006	Journal of Power Sources Volume 166 549-566	Global		Use of Vehicle as mobile power supply		High	Peer Reviewed Publication	Low	Focus on remote generation
SUBAT: An assessment of sustainable battery technology	Van den Bossche, P., Vergels, F., Van Mierlo, J., Matheys, J. & Van Autenboer, W.	2005	Journal of Power Sources Volume 162 913-919	Global		Battery Technology Impact Review		High	Peer Reviewed Publication	High	Vehicle Technology
Electric Vehicle: A Futuristic Approach to Reduce Pollution (A Case Study of Dehli)	Ahmed, I. & Dewan, KK.	2007	World Review of Intermodal Transportation Research Vol. 1 No.3	India		Emissions Reduction		High	Peer Reviewed Publication	High	Vehicle Technology
Automobile technology, Hydrogen and climate change: A long term modelling analysis	Turton, H. & Berreto, L.	2007	International Journal of Alternative Propulsion, Volume 1, No.4	Global		Emissions analysis		High	Peer Reviewed Publication	Medium	Long-term Modelling
Potential importance of hydrogen as a future solution to environmental and transportation problems	Balat, M.	2008	International Journal of Hydrogen Energy, Volume 33,4013-4029	Turkey		Energy Consumption		High	Peer Reviewed Publication	High	Vehicle Technology

Alternative fuels - Electric, Hybrid, Hydrogen, Biofuel

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Applicability of gasoline containing ethanol as Thailand's alternative fuel to curb toxic VOC pollutants from automobile emission	Shing Tet Leong, S Muttamara and Preecha Laortanakul	2002	Atmospheric Environment , Volume 36, Issue 21, July 2002, Pages 3495-3503	Thailand		Emissions of VOC pollutants, toxic VOC pollutants, benzene, toluene, m-xylene, formaldehyde and acetaldehyde		High	Asian Institute of Technology - peer reviewed publication	High	Fuel mix
Energy and Greenhouse Impacts of Biofuels: A Framework for Analysis	Kammen, D., Farrell, A.E., Pelvin, R.I., Jones, A.D., Nemet, G.F. & Delucchi, M.A.	2007	OECD Research Round Table - Biofuels: Linking Support to Performance	USA	Fuels lifecycle inventory			High	University of California - Peer Reviewed publication	Medium	Includes market development
Impact of the European Union vehicles waste directive on end-of-life options for polymer electrolyte fuel cells	Handley, C., Brandon, N.P. & van der Vost, R.	2002	Journal of Power Sources Volume 106, Pages 344-352	EU			Fuel Cell Recycling	High	Peer Reviewed Publication	High	Associated Technology
Recycling of batteries: a review of current processes and technologies	Bernardes, A.M., Espinosa, D.C.R. & Tenorio, J.A.S	2004	Journal of Power Sources Volume 130, 291–298	Global			Battery Recycling	High	Peer Reviewed Publication	High	Associated Technology

Material Substitution

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Vehicle body-in-white development using alternative materials for limited production as well as mass	Anderseck, R. and Walz, E.	2001	Proceedings of Technical Congress 2001 - Where Cars	Germany	vehicle production, resource use	fuel consumption		Med	supplier/ manufacturer?	High	International production

Material Substitution

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
production. Which circumstances affect the choice of materials?			and Future Technology Meet - Vehicle Safety, Energy and Environment , (p287-304). Frankfurt: Verband der Automobilindustrie (Vda).								
Life Cycle inventory study on magnesium alloy substitution in vehicles	Hakamada, M., Furuta, T., Chino, Y., Chen, Y., Kusuda, H. & Madbuchi, M.	2007	Energy, 32, 1352-1360	Japan	vehicle production, resource use	fuel consumption		High	Peer Reviewed Publication	High	Vehicle Technology

End-of-life Directive and Regulations

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Directive 200/53/EC	EC	2000	EC accessed from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:269:0034:0042:EN:PDF	EU			ELV Directive; quantified targets for reuse, recycling and recovery of vehicles and parts	High	EC	High	Europe based

End-of-life Directive and Regulations

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Report From The Commission To The Council And The European Parliament On The Targets Contained In Article 7(2)(B) Of Directive 2000/53/EC On End-Of-Life Vehicle	EC	2007	European Commission accessed from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2007:0005:FIN:EN:PDF	EU			Assessment of 2015 targets	High	EC	High	Europe based
Is European end-of-life vehicle legislation living up to expectations? Assessing the impact of the ELV Directive on 'green' innovation and vehicle recovery	Gerrard, J. and Kandlikar, M.	2004	Journal of Cleaner Production, Volume 15,17-27	Canada			Review of effects of ELV directive	High	Peer reviewed	High	Europe based
Network management and environmental effectiveness: the management of end-of-life vehicles in the United Kingdom and in Sweden	Manomaiviboo l, P.	2008	Journal of Cleaner Production, Volume 16, 2006-2017	UK and Sweden			Policy implementation and EPR study	High	Peer reviewed	High	UK based
Fundamental limits for the recycling of end-of-life vehicles	Reuter, M.A., van Schaik, A., Ignatenko, O. and deHaan, G.J.	2006	Minerals Engineering, 19, 433-449	Netherlands & Australia			Study of ELV legislation	High	Peer reviewed	High	EU studied

Eco Driving – GSI

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Household demand and willingness to pay for clean vehicles	Potoglou, D. & Kanaroglou, S.	2007	Transportation Research Part D: Transport and Environment Volume 12, Issue 4, pages 264-274	Canada		Factors influencing choice of 'cleaner' vehicle		High	Peer reviewed publication	Medium	Canadian based
A forecast of household ownership and use of alternative fuel vehicles: A multiple discrete-continuous choice approach	Ahn, J., Jeong, G. & Kim, Y.	2008	Energy Economics, Volume 30, Issue 5, pages 2091-2104	Korea		Forecasted levels of AFV ownership		High	Peer reviewed publication	Medium	Korean based
Eco-driving Simulation: Evaluation of eco-driving within a network using traffic simulation	Kobayashi, I., Tsubota, Y. & Kawashima, H.	2007	Urban transport XIII. Urban transport and the Environment in the 21st century	Japan		Impacts of Eco Driving		Medium	Conference paper	Medium	Japanese based
The effect of improved safety on fuel economy of European cars	Zachariadis, T.	2008	Transportation Research Part D: Volume 13, Pages 133-139	Europe		Vehicle Weight and fuel consumption		High	Peer reviewed publication	High	Europe based
Declining sustainability: The case of shopping trip energy consumption	Kitamura, R., Sakamoto, K. & Waygood, O.	2008	International Journal of Sustainable Transportation, Volume 2, 3, Pages 158-176	Japan		Examines changing patterns in car use		High	Peer reviewed publication	Medium	Japanese based

Eco Driving – GSI												
Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
The social cost of motor vehicle use in the US	Delucchi, M.	1997	The ANNALS of the American Academy of Political and Social Science, Vol. 553, No. 1, 130-142	US		Overview of car related impacts		High	Peer reviewed publication	Low	US focussed
Sustainable transport: Assumptions on behaviour change	Steg, L; Tertoolen, G	1997	Policy, planning and sustainability. Proceedings of the 25th PTRC European Transport Forum, Brunel University, England.	Netherlands		behavioural theories and habits relating to transport. Compare structural and cognitive-motivational strategies		Medium	Conference paper	High	Europe based
Fuel taxes and beyond: UK transport and climate change	Potter, S; Enoch, M; Fergusson, M	2001	WWF and Transport 2000	UK	reviews impact of alternative fuels and technological developments	reviews policies, vehicle and fuel tax, driving behaviour and education, incentives and modal choices		Medium	WWF	High	Vehicle technology / UK policy
Effects of economic disincentives on private car use	Jakobsson, C; Fujii, S; Gaerling, T	2002	Transportation, Volume 29, Number 4, Pages 349-370	Sweden		reducing car use through charging - field experiment		High	Peer reviewed publication	Medium	Focussed on Sweden
Eco-driving in the Netherlands	Ministry of Transport, Public Works and water management		Ministry of Transport, Public Works and water mngt	Netherlands		Summary of eco driving aims and achievements		Medium	Departmental publication	High	Case study

Eco Driving – GSI											
					Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
Source title	**Author(s)**	**Year**	**Source details**	**Region/ country**	**Production**	**Use**	**End-of-life**	**Credible source**	**Reason**	**Transfe rable to UK policy**	**Reason**
The effects of a range of measures to reduce the tail pipe emissions and/or fuel consumption of modern passenger cars on petrol and diesel	Vermeulen, R.J. (TNO)	2006	TNO Report	Netherlands		The impact eco driving has on a range of emissions		Medium	Consultancy report	High	Europe based
Review and analysis of the reduction potential and costs of technological and other measures to reduce CO2 emissions from passenger cars	Smokers, R., Vermeulen, R., van Mieghem, R. & Gense, R.	2006	TNO Report	Netherlands		The combined and singular effects of eco driving and gear shift indicators		Medium	Consultancy report	High	Europe based
Environmental Improvement of Passenger Cars (IMPRO-car)	Nemry, F., Leduc, G., Mongelli, I. & Uihlein, A.	2008	European Commission Joint Research Centre	Europe		Overview of eco driving and gear shift indicator impacts		High	European Commission Research	High	Europe based
Impact of eco-driving on emissions and fuel consumption, a pre-study	Johansson, Farnlund & Engstrom	1999	Swedish National Road administration	Sweden		The impact of eco driving on emissions		Medium	Departmental publication	High	Europe based
Impacts of road user charging/workplace parking levy on social inclusion/exclusion: Gender, ethnicity and lifecycle issues - interim report: Focus groups	Rajé, F., Grieco, M., Hine J. and Preston, J.	2002	Transport Studies Unit, University of Oxford	UK		awareness, perceptions and acceptability of road user charging and a workplace parking levy		Medium	Academic department	High	UK based
Sustainability, Energy, and Alternative Fuels 2007	Transportation Research Board	2007	TRB's Transportation Research Record: Journal of the Transportation Research Board, No. 2017	US		attitudes of diesel and hybrid new car buyers, energy use of plug-in hybrid electric vehicles, GHG emissions of the U.S. transportation sector		High	Peer reviewed publication	Medium	US based

Speed Control											
					Impacts in Life Cycle Phase			**Data source robustness (high/medium/low)**			
Source title	**Author(s)**	**Year**	**Source details**	**Region/ country**	**Production**	**Use**	**End-of-life**	**Credible source**	**Reason**	**Transfer able to UK policy**	**Reason**
Getting the genie back in the bottle: Limiting speed to reduce carbon emissions and accelerate the shift to low carbon vehicles.	Anable, J., Mitchell, P. & Layberry, R.	2006	In Low CVP 'Low Carbon Road Transport Challenge' Proposals to reduce road transport C02 emissions in the UK to help mitigate climate change.	UK		Potential CO2 savings from fully enforcing or reducing the speed limit		Medium	Seminar paper	High	Focuses on UK policy direction
Factors influencing drivers' decision to install an electronic speed checker in the car	Garvill, J., Marell, A. & Westin, K.	2003	Transportation Research Part F 6, Pages 37-43	Sweden	Installation of ISA	Attitude towards ISA, and willingness to install		High	Peer reviewed publication	Medium	Swedish based
The Impacts of Traffic Calming Measures on Vehicle Exhaust Emissions.	Boulter, P.G., Hickman, A.J., Latham, S., Layfield, R., Davison, P., & Whiteman, P.	2001	TRL Report 482	UK		The negative impact traffic calming measures can have upon emissions		Medium	Consultancy Report	High	UK based
External Vehicle Speed Control: Executive Summary of Project Results.	Carsten, O. & Fowkes, M.	2000	Institute for Transport Studies, University of Leeds.	UK		The potential to reduce fuel consumption through the use of speed limiters		High	Academic department	High	UK based
ISA – UK: Executive Summary of Project Results.	Carsten, O., Fowkes, M., Lai, F., Chorlton, K., Jamson, S., Tate, F. & Simpkin, B.	2008	Institute for Transport Studies, University of Leeds.	UK		Cost benefit analysis of ISA		High	Academic department	High	Uk based

Speed Control

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Traffic Management and Air Quality Research Programme.	Cloke, J., Boulter, P.G., Davies, G.P., Hickman, A.J., Layfield, R., McCrae, I.S., & Nelson, P.M	1998	TRL Report 327	UK		The negative impact traffic calming measures can have upon emissions		Medium	Consultancy Report	High	UK based
Reducing the environmental impact of driving: A review of training and in-vehicle technologies.	Cloke, J., Harris, G., Latham, S., Quimby, A., Smith, L. & Baughan, C.	1999	TRL Report 384	UK		Reducing speed has a positive impact on emissions		Medium	Consultancy Report	High	UK based
Quantifying the Effects of Traffic Calming on Emissions using On-road Measurements.	Daham, B., Andrews, G.E., Li, H., Partridge, M., Bell, M.C., & Tate, J.	2005	SAE Technical Paper Series, 2005-01-1620.	UK		The negative impact traffic calming measures can have upon emissions		Medium	Consultancy Report	High	UK based
Transport Statistics Great Britain, 2007 Edition.	Department for Transport	2007	Department for Transport	UK		Driving over the speed limit is frequent in the UK		High	Government report	High	UK based
Success stories within the road transport sector on reducing greenhouse gas emission and producing ancillary benefits.	EEA (European Environment Agency)	2008	EEA Technical Report 2/2008.	Europe		Positive environmental impact brought about through reducing and enforcing speed limits		High	EEA report	High	Europe based
ATM Monitoring and Evaluation: 4 Lane Variable Mandatory Speed Limits, 12 Month Report (Primary and Secondary Indicators)	Highways Agency	2008	Highways Agency	UK		Managing speeds on the motorway impacts on emissions levels		Medium	Consultancy report to Highways Agency	High	UK based
M25 Controlled Motorways: Summary Report.	Highways Agency	2004	Highways Agency	UK		Managing speeds on the motorway impacts on emissions levels		Medium	Consultancy report to Highways Agency	High	UK based

Speed Control

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transfer able to UK policy	Reason
Intelligent transport system and traffic safety – drivers perception and acceptance of electronic speed checkers.	Marell, A. & Westin, K.	1999	Transportation Research Part C, 7, 131-147	Sweden		Drivers' willingness to accept ISA		High	Peer reviewed publication	Medium	Focus on Swedish public
Results of the World's Largest ISA Trial.	Swedish National Road Administration	2002	Brochure - Swedish National Road Administration	Sweden		The impact of large scale use of ISA		Medium	Departmental brochure	Medium	Case study evidence
The effects of in-car speed limiters: field studies	Várhelyi, A. & Mäkinen, T.	2001	Transportation Research Part C, 9, 191-211.	Europe		ISAs impact on driving behaviour		High	Peer reviewed publication	High	Europe based
Managing Speed: Towards Safe and Sustainable Road Transport	European Transport Safety Council	2008	European Transport Safety Council	Europe		Overview of the importance of speed reduction		Medium	European Parliament and Commission advisory group	High	Europe based
Intelligent Speed Assistance - Myths and Reality	European Transport Safety Council	2006	European Transport Safety Council	Europe		Overview of the usefulness of ISA		Medium	European Parliament and Commission advisory group	High	Europe based

High Occupancy Rates

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Smarter Choices – Changing the Way We Travel.	Cairns, S., Sloman, L., Anable, J., Kirkbride, A. & Goodwin, P.	2004	The Department for Transport	UK		Potential impact of car sharing		High	Government report	High	UK based
Traffic Advisory Leaflet 3/06: High Occupancy Vehicle Lanes	Department for Transport	2006	The Department for Transport	UK		Outcomes of trial HOV lanes		Medium	Departmental publication	High	UK based

Fuel Saving and ridesharing in the US: Motivations, limitations, and opportunities	Jacobson, S.H. & King, D.M	2009	Transport Research Part D, 14, 14-21.	US		Potential benefits of car sharing		High	Peer reviewed publication	Medium	US based
HOV Lane Info Sheet	Leeds City Council	2002	Leeds City Council	UK		Outcome of trial HOV lane		Medium	Local Authority publication	High	UK based
Effectiveness of California's High Occupancy Vehicle (HOV) System	Kwon, J. & Varaiya, P.	2008	Transport Research Part C, 16, 98-115.	US		Critical evaluation of a specific HOV lane system		High	Peer reviewed publication	Medium	US based

Car labelling

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	**Use**	**End-of-life**	**Credible source**	**Reason**	**Transferable to UK policy**	**Reason**
Energy Efficiency of passenger Cars: Labelling and its Impacts on Fuel Efficiency and CO_2-Reduction	Raimund, W. and Fickl, S.	1999	Energiewertungsagentur (EVA), Austrian Energy Agency accessed from http://www.eceee.org/conference_proceedings/eceee/1999/Panel_5/p5_5/Paper/	EU		Effect of label on energy savings, fuel consumption and CO_2 emissions reductions		Med	Research and policy institution	High	EU based study
The United Kingdom Parliament, Environmental Audit Committee: Environmental Labelling Memoranda	LowCVP	2007	Accessed from http://www.publications.parliament.uk/pa/cm200708/cmselect/cmenvaud/label/ucmemo.htm	UK		Comments on car label; history, deployment, content and recommendations		Med	Government advisory group	High	UK based

Car labelling

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
The United Kingdom Parliament, Environmental Audit Committee: Environmental Labelling Memoranda	SMMT	2007	Accessed from http://www.publications.parliament.uk/pa/cm200708/cmselect/cmenvaud/label/ucmemo.htm	UK		Comments on car label; history, deployment, content and recommendations		Med	UK automotive trade association	High	UK based
Revision of Directive 1999/94/EC relating to the availability of consumer information on fuel economy and CO_2 emissions in respect of the marketing of new passenger cars	EU	2008	European Commission accessed from http://ec.europa.eu/environment/air/transport/co2/co2_cars_labelling.htm	EU		Consultation feedback; awareness of legislation, consumer information on fuel consumption and CO_2 emissions, advertising		High	European Commission report	High	EU based

Early Scrappage

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Life Cycle optimization of ownership costs and emissions reduction in US vehicle retirement decisions	Spitzley, D.V., Grande, D.E., Keoleian, G.A. and Kim, H.C.	2005	Transportation Research Part D, 910, 161-175	US	Energy and emissions of production of new cars	optimal interval estimations for CO, NOx, NMHC, CO2, energy use and private costs		High	Peer reviewed	High	Applies across all countries
Estimating emissions reductions from accelerated vehicle retirement programs	Dill, J.	2004	Transportation Research Part D, 9, 87-106	US		Effects on emissions reductions, CO, NOx and ROG (reactive organic gases)		High	Peer reviewed	High	Applies across all countries

Early Scrappage

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Making an Informed Vehicle Scrappage Decision	Chen, C. and Lin (Jane), J.	2006	Transport Reviews, 26:6, 731-748	US		Model analysis to estimate of survival probability		High	Peer reviewed	High	Applies across all countries
Cleaner Cars: Fleet Renewal and Scrappage Schemes - Guide to Good Practice	European Conference of Ministers of Transport	1999	Paris: OECD Publications Service. ISBN 92-821-1251-9	Worldwide		Various countries schemes. The environmental and economic impacts		High	ECMT renamed International Transport Forum	High	Applies across all countries
Can Vehicle Scrappage Programs be Successful	World Bank	2002	South Asia Urban Air Quality Briefing Note No. 8 accessed from http://www.cleanairnet.org/caiasia/1412/articles-35253_recurso_1.pdf	Worldwide		Impacts on car markets and reductions of emissions		Med	World Bank briefing note	High	Applies across all countries

Road Charging

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Trade-offs in road pricing: Auckland road pricing evaluation study	Body, A.	2006	ITS World Congress, 8-12 Oct. 2006	New Zealand		Social, economic and environmental impacts of pricing, highlight of trade-offs between environmental benefits and social impacts		Med	Consultancy report for the NZ Ministry of Transport	High	Applies across all countries

Road Charging

Source title	Author(s)	Year	Source details	Region/ country	Impacts in Life Cycle Phase			Data source robustness (high/medium/low)			
					Production	Use	End-of-life	Credible source	Reason	Transferable to UK policy	Reason
Environmental effects of a kilometre charge in road transport: an investigation for the Netherlands	Ubbels, B., Rietveld, P. and Peeters, P.	2002	Transportation Research Part D, 7, 255-264	Netherlands		Estimates of decreases in travelled kilometres, energy and emissions reductions.		High	Peer reviewed	High	Applies across all countries
Road pricing in National Parks: a case study in the Yorkshire Dales National Park	Steiner, T. J. and Bristow, A. L.	2000	Transport Policy, 7, 93-103	UK		Survey of visitors, impacts on mode choice, destination and economic and social impacts in the area		High	Peer reviewed	High	UK based
Sustainability impacts of car road pricing: A computable general equilibrium analysis for Austria	Steininger, K. A., Friedl, B. and Gebetsroither, B.	2007	Ecological Economics 63, 59-69	Europe		Model generated - economic impacts on range of household incomes		High	Peer reviewed	High	Europe study
The impact of congestion charging on vehicle emissions in London	Beevers, S. D. and Carslaw, D. C.	2005	Atmospheric Environment 39, 1-5	London		Analysis of CO_2, NO_x and PM_{10} emissions relative to speed in charge zone		High	Peer reviewed	High	UK based
The impact of congestion charging on vehicle speed and its implications for assessing vehicle emissions	Beevers, S. D. and Carslaw, D. C.	2005	Atmospheric Environment 39, 6875-6884	London		Analysis of CO_2, NO_x and PM_{10} emissions relative to speed in charge zone		High	Peer reviewed	High	UK based

Annex E: Intervention evidence review

Hybrid

The term 'hybrid' covers a group of vehicles which use 2 powertrains to propel the vehicle, independently or in combination. Hybrid electric vehicles (HEVs) are predominantly the integration of an electric motor and an internal combustion engine (ICE). Full hybrids are propelled solely by the electric motor at low speeds with the ICE engaging at higher speeds or when the battery is low. Mild hybrid vehicles use an electric motor to provide additional power to an ICE.

The environmental benefit associated with each type of hybrid is complex and currently under study. Fontaras et al. (2008) tested full and mild production hybrids and compared with the Euro 3 standard. This study predicts a 40-60% potential fuel efficiency increase for full hybrid vehicles. Figure AE 1 shows that the advantage of a full HEV (Toyota Prius II) at low speeds over a mild HEV (Honda Civic IMA) and conventional vehicles. The results also illustrate the decline in fuel consumption improvements demonstrated in HEVs as speed increases. The current evidence indicates that the highest impact reductions from HEVs are offered in the urban/sub-urban driving environment. Benefits associated with hybrids should be considered in the same way as improved efficiency in ICE vehicles, the 'style' of driving can either minimise or maximise impact reductions.

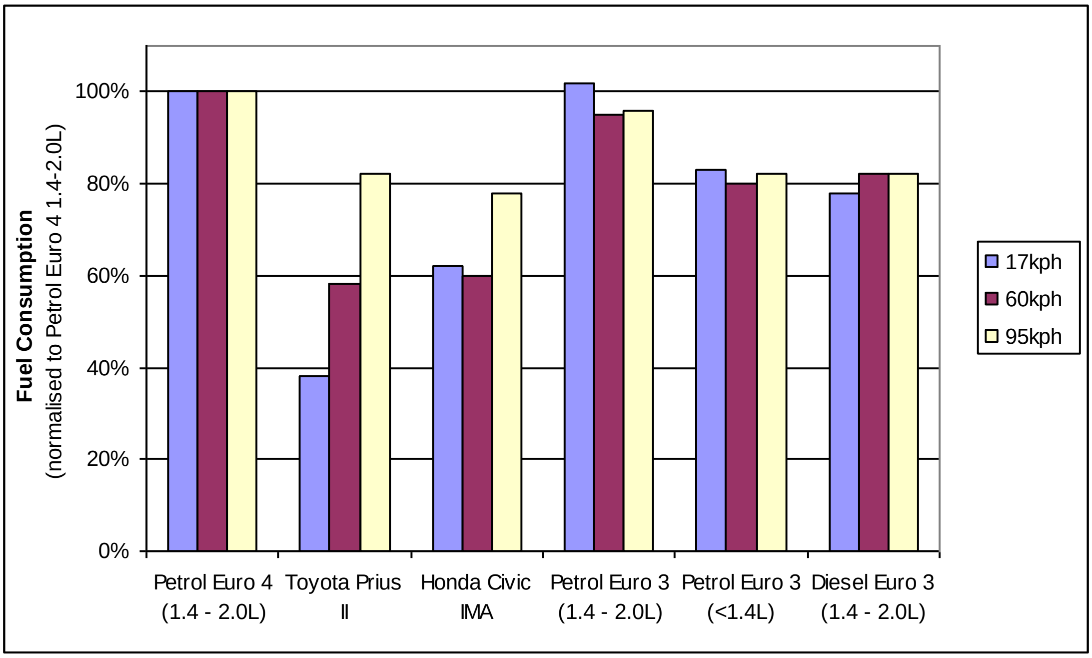

Figure AE 1 Fuel consumption of full and mild HEVs, normalised to Euro 3 standard (Petrol 1.4 - 2.0L)

Fontaras et al. (2008) also highlighted the influence of environmental factors on the performance of hybrid vehicle fuel consumption. In their trials it was shown that an increase in fuel efficiency with an increased ambient temperature and predict a possible 12% increase in efficiency during the warmer seasons. Other combinations of hybrid vehicle are possible such as fuel cell/hydrogen hybrids. These individual technologies are still in early development and small amounts of research exist with regard to their scope for environmental impact reduction and practicality.

The HEV market share in Europe was around 0.5% in 2007 and predicted to increase to 6% by 2010.

Electric

Electric vehicles are in use currently in the UK in a number of capacities, including company owned vehicles for specific site work, such as university campuses, or private vehicles most commonly in cities where short daily mileage is required.

A large proportion of the impacts and environmental benefits associated with electric cars are attributable to the source of the electricity. A study by Steenhof & McInnis (2008) predicted the overall net emission reductions for Canada in 2050 from a 100% electric personal vehicle fleet would be in the region of 14%, when considering transport only. The study highlighted that if Canada decarbonised the electricity production, the reduction of emissions would be more than doubled to 31%.

In the UK, Arup & Cenex (2008) predict reductions of around 40% in vehicle lifetime CO_2 emissions are realistic, with further improvements to be realised with reduction of the carbon intensity of the UK electricity supply.

Campanari et al (2009) suggested that in a scenario of completely renewable electricity supply, the electric vehicle has lower environmental impacts than hybrid and hydrogen fuel cell vehicles. In this scenario, energy conversion from Li-ion batteries was modelled with 92% efficiency and from fuel cells with 55%. However, if the carbon intensity of the electricity supply increases, the hydrogen fuel cell vehicles exceed the battery electric vehicle both in terms of efficiency and CO_2 emissions. Also, the driving range has an effect on the efficiency of the electric vehicle. If the range is to be extended then a larger battery bank is required, this adds to the overall weight of the vehicle and therefore increases the energy required to travel per km.

It has been predicted by the automotive industry and other sources that a limiting factor for electric vehicles will be the availability and expense of material for the on-board batteries. These batteries will also have a limited life span and it is uncertain whether the cost of replacing the banks of batteries, potentially a couple of times over the vehicle's operational life, will be restrictively expensive. There are also environmental impacts to be considered for the production and recycling of these batteries on this scale. Unfortunately there is no conclusive study quantifying these impacts.

Hydrogen

Hydrogen can be used as a transport fuel in two distinct ways. It can be used in a modified internal combustion engine or in a fuel cell to produce electricity and power an electric motor. Hydrogen is currently primarily produced from fossil fuels, however it can also be produced from biomass and from water (electrolysis).

In the case of electrolysis, the environmental impacts of a hydrogen fuelled car during its use phase will be due to the upstream emissions from the electricity generation. If the electricity production is very carbon intensive and environmentally damaging the benefits will be much less than would be realised if the electricity supply is improved and decarbonised. This is similar to the scenario for an electric vehicle in the Steenhof & McInnis (2008) study cited above.

Hussain et al (2007) predicted a hydrogen fuel cell vehicle, over the complete lifecycle, would have an energy consumption 57% less and GHG emissions 62% less than ICE vehicles. This was using natural gas as a source for hydrogen. If renewable energy and electrolysis is used, the savings over the lifecycle will potentially be higher. Likewise, if there is a high fossil fuel contribution to the energy mix, the benefits will be reduced. The study by Hussain et al (2007) predicted that the production of hydrogen for transport from natural gas would be 8.5 times greater in energy and emissions terms than the production of petrol. This however is offset by the savings over the rest of the lifecycle.

The relative levels of development for hydrogen fuel cell and hydrogen ICE vehicles would need to be taken into account when examining the two technologies; there are key differences which will affect the plausibility of either option. It is generally considered that hydrogen ICEs will be a transitional technology, which will be replaced with fuel cell's due to their better efficiency, however technological barriers will have to be overcome.

The hydrogen fuel infrastructure required would be similar to that already used for oil based fuels. There may be scope for conversion of the existing facilities. Further research is necessary to determine the environmental benefits of hydrogen vehicles and the trade-offs required to achieve them.

Suggestions of on-board hydrogen production in vehicles have been made. These would require external electricity and water supplies to convert. Problems with this include the amount of time the vehicle would need to be plugged in to the power supply. Another issue is the extra weight associated with the equipment and possible inefficiencies of a small plant compared to industrial scale production of hydrogen.

Other concepts include a hydrogen/electric hybrid. Essentially the hydrogen vehicle would include a small bank of batteries to store and make use of regenerative braking energy which is captured on most hybrid and electric vehicles. This would extend the range of a hydrogen vehicle.

Biofuel

Bio-diesel, vegetable/plant based oil and ethanol are potential fossil fuel oil replacements, along with newer, 'second and third generation' biofuels derived from waste and algae that are now becoming more viable. Changes to the current oil-based fuel supply infrastructure are minimal and the engine modifications necessary vary from none at all to a secondary delivery fuel system depending on the type of engine and fuel being used. The option of using biofuel is particularly attractive because of the relative ease with which the existing UK vehicle fleet can be converted to use the alternative fuel.

The EU's biofuel target, originally set at 10% by volume, currently stands at 6% by 2020. The disagreements over the potential environmental benefits and costs have lead to intensive sustainability debates. The whole life cycle of biofuels must be considered to assess the positive and negative impacts of different biofuels and production pathways (Figure AE 2).

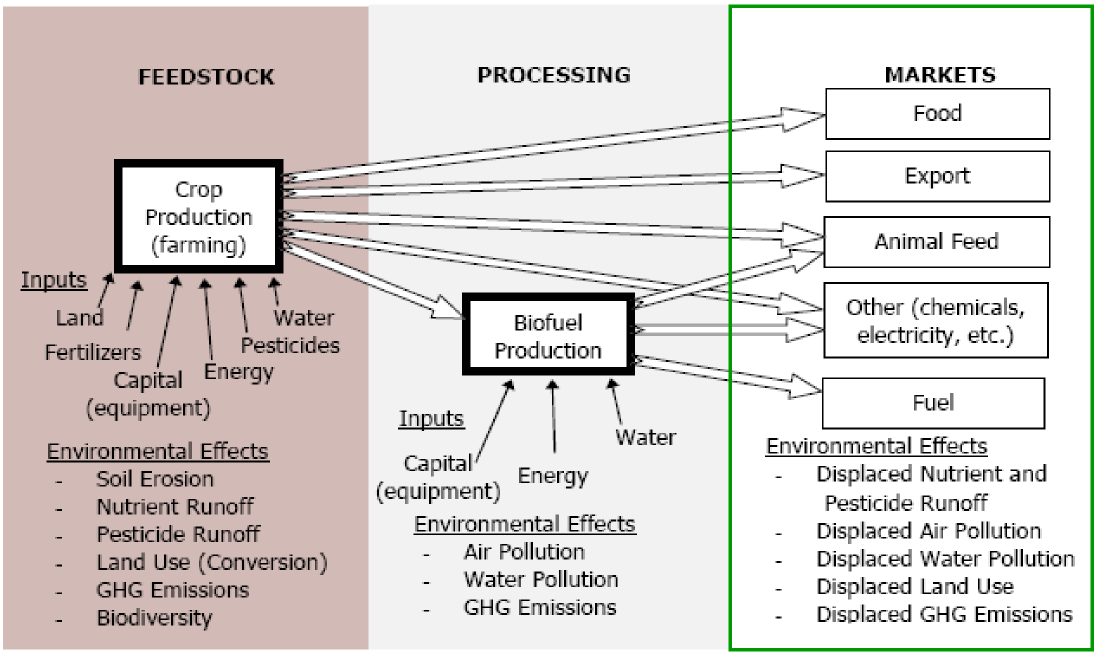

Fig AE 2 Simplified General Biofuel Pathway with Inputs and Environmental Impacts (Source: *Kammen et al, 2007)*

The recent Gallagher Review published by the Renewable Fuels Agency (RFA, 2008), estimated potential GHG emissions savings of around 60 million tonnes CO_2 equivalent for the EU annually by 2020 if the original 10% target was met (Figure AE 3). The review also highlights the importance of avoiding land-use change when growing the crops to achieve the potential savings. Hammond et. al.(2008) suggest that the most efficient biofuels can offer significant CO_2 savings of between 50-70% when the fuel is used directly as an alternative to petroleum based fuel. Biofuels, depending upon source and production method, can potentially increase life cycle environmental impacts.

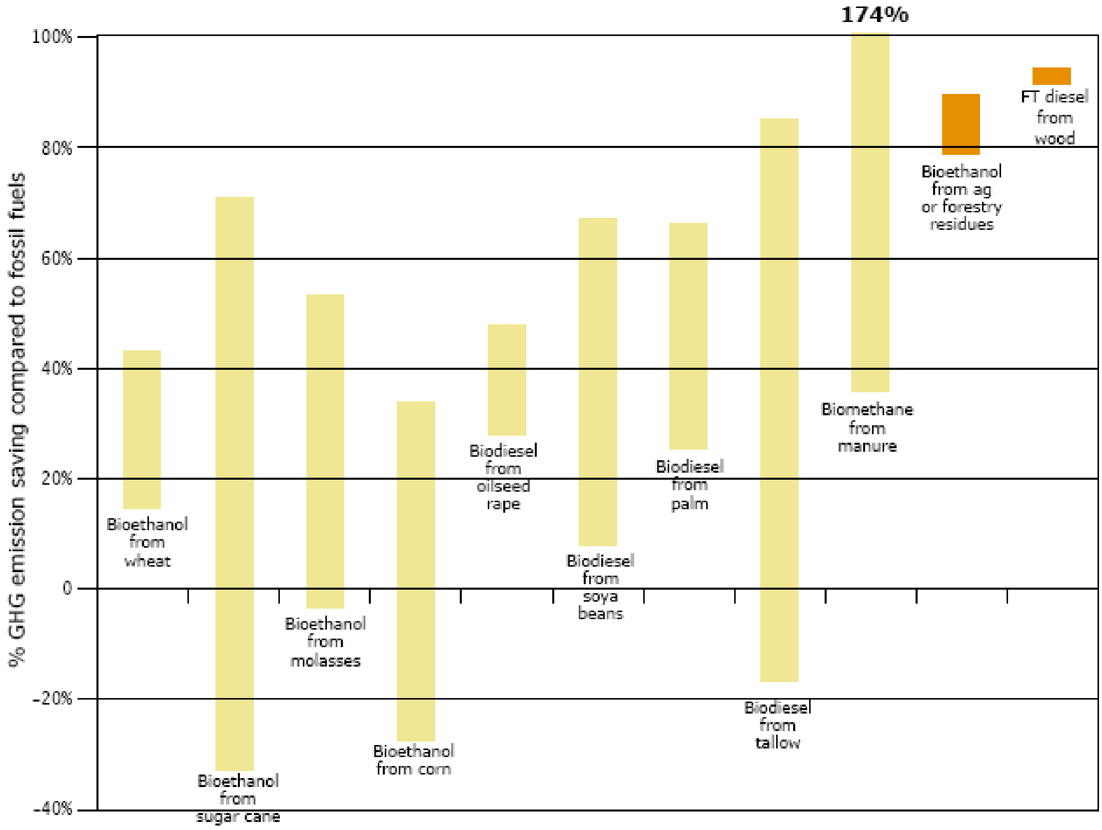

Figure AE 3 From *The Gallagher Review* (*RFA, 2008*); Estimated GHG savings of current biofuels (current technology in yellow, advanced technology in orange)

Material Substitutions

Material substitution can be used for a number of environmental reasons. The substitution might be with the intention of reducing the vehicles weight, for example aluminium and magnesium in place of steel. Alternatively it may be the inclusion of a material with a lower environmental impact associated with the extraction, refining and machining. The key drivers for automotive manufacturers to make material substitutions are mainly safety and fuel efficiency. The ELV directive may influence material substitution, due to the demands for efficient recovery and recycling of materials from vehicles.

Magnesium has been an area of research, with some studies suggesting a life time CO_2 savings for the vehicle of around 6%. The study projects that as the improvements in strength from machining and casting techniques will allow less material to be used, a potential saving of 14% on lifetime CO_2 is possible (Hakamada et al; 2007) In both of these cases the study included a 75% proportion of recycled magnesium as it showed if virgin magnesium is used the lifetime CO_2 is slightly higher than that for steel due to the higher intensity of the refining processes. Aluminium use, with a recycled content of 50%, results in a 5.3% lifetime CO_2 savings compared to (50% recycled) Magnesium which can save 1.5% lifetime CO_2. This is due to the higher processing energy of the virgin magnesium material. Magnesium however potentially has a wider application in vehicles compared to aluminium due to the improved strength and predicted further advances in this area.

Metal substitution does not appear to present any end-of-life recycling issues. A very high percentage of the metal from a vehicle is reclaimed and reprocessed. The exchange of magnesium or aluminium for steel should not cause difficulties as these materials are already included in vehicles and can be successfully recovered and recycled.

Other materials such as carbon fibre, Kevlar, composites and biopolymers are used in high-end sports cars and are being researched for extended use in cars. These are not explored in the report due to the limited data available on their application to mass production vehicles.

End-of-Life Vehicle Processes

The disposal phase of the car includes a number of processes (figure AE 4), and is a significant source of impacts over the life cycle of the car. The end-of-life vehicle (ELV) disposal deals with a range of materials, including ferrous and non-ferrous metals, plastics, fluids, textiles, glass, rubber and hazardous chemicals; such as paint, fuel, oil and inorganic acids (Elghali et. al., 2004). The Mass balance study by Elghali et. al. (2004) also provides an estimate of the mass of hazardous waste (in 2004 termed 'special' waste) arising from ELVs in 2000; a combined vehicle type of cars and taxis is was estimated to produce 9kg fluids and 12 kg battery hazardous waste per ELV. The long lifetime of vehicles produces situations where disposal facilities are attempting to meet the present regulatory controls with vehicles designed and manufactured at a time when such regulations were not in place. In efforts to reduce the impacts in the disposal phase, vehicle manufacturers include 'design for recycling' with their initial production process to minimise the range of materials and make any components easy to disassemble and recover in the end-of-life phase.

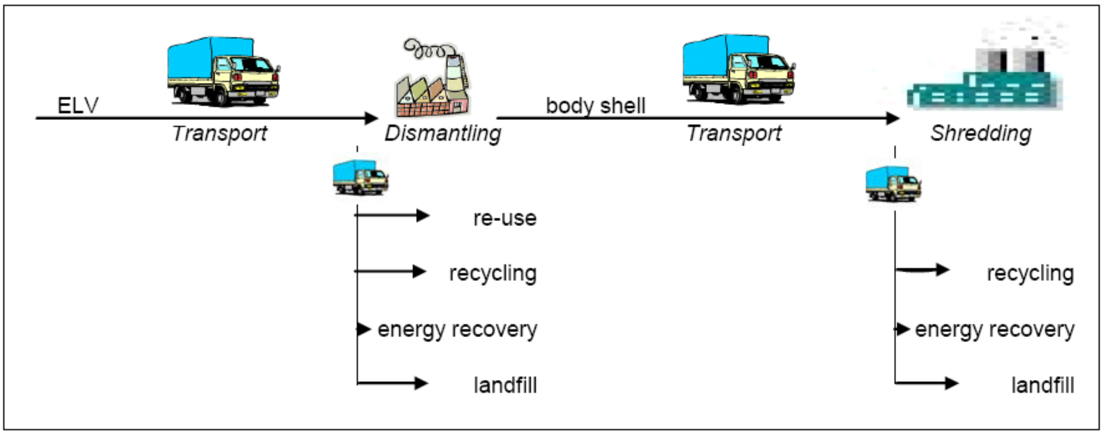

Figure AE 4 ELV Treatment Process (Source: GHK and BIOIS, 2006)

In 2000, the EC adopted the ELV Directive 2000/53/EC. The directive 'aims at making vehicle dismantling and recycling more environmentally friendly, sets clear quantified targets for reuse, recycling and recovery of vehicles and their components and pushes producers to manufacture new vehicles also with a view to their recyclability' (EC, 2009b). The targets within the Directive include 85% reuse/recycling and 95% reuse/recovery by 2015. A group of studies have explored the effectiveness of the ELV Directive. Gerrard and Kandlikar (2007) conclude that the ELV Directive, along with market forces, has been successful at leading to innovation in recycling, increased removal of hazardous substances and improved information dissemination. The paper does comment that the Directive is not successful in generating design for reuse and remanufacturing, which they suggest is key in more sustainable vehicle production. The network management of waste policies in the EU was studied by Manomaivibool (2008), and the paper concluded that the producers perception of extended producer responsibility (EPR) can be influenced by their social interaction with other actors, and the cohesion of policy instruments is an important factor in the effectiveness of waste programmes.

Reuter et. al. (2006) raise a concern that strict targets in ELV legislation are too inflexible, and instead a market driven approach would optimise a recycling system. A conclusion is that recycling above 85% will be difficult to reach and therefore predicts that the 95% by 2015 in the ELV Directive is not attainable.

Eco Driving

While technological improvements and greater fuel efficiency can reduce the environmental impact of the car, such advances alone are unlikely to reduce the emissions produced by the transport sector to a sustainable level. Recent trends have shown larger and less fuel efficient vehicles becoming increasingly popular, while the number of car journeys is likely to continue increasing (Potter, Enoch & Fergusson, 2001). Such patterns cancel out many of the improvements created by enhanced technology. Additionally, to feel the benefits of improved technology or alternative fuels, people must choose to take up these options. Economic modelling estimating demand for passenger cars predicts that even with the introduction of alternative fuel vehicles (AFVs), gasoline-fuelled cars will remain most consumers' first choice (Ahn, Jeong & Kim, 2008). It has been found that a range of factors would influence individuals' willingness to pay for a 'cleaner vehicle', with reduced financial costs, purchase tax reliefs, and low emission rates being particularly influential. However a divide between high and low income households is present, with those from low income households being less willing to pay more for a cleaner car at the time of purchase (Potoglou & Kanaroglou, 2007). So although technological innovation can make a significant difference to the environmental impact of an individual car, the level of take up of such technologies, as well as current trends can have an effect on the overall effectiveness of this approach to emissions reduction. It has been concluded by many that technology alone will not be able to sufficiently reduce car based emissions (Potter, Enoch & Fergusson, 2001; Steg & Tertoolen, 1997), and so it is essential to also focus on travel patterns and driving behaviour.

Behaviour, and individual choice, influence transport related emissions in a number of ways. For example, people can choose to reduce their car use by using alternative modes of travel, or as briefly discussed above, they may choose to purchase a more fuel efficient vehicle. However, the focus here is upon the environmental impacts of car use, and as such on behaviour that can influence this whilst the car is actually in use. Many studies have found that driving a car in a fuel efficient way can lead to significant reductions in fuel consumption and CO_2 emissions. Driving in a fuel efficient manner, often referred to as 'eco-driving' involves;

- Ensuring tyres are inflated to the correct level
- Reducing unnecessary load within the car, including items carried in the boot
- Driving at an appropriate speed
- Avoiding unnecessary stopping and starting by breaking early and gently
- Changing up a gear at the appropriate time, around 2000rpm for diesel and 2500rpm for petrol cars
- Avoiding engine idling, if the car is topped for than three minutes, turn off the engine

(Source: http://campaigns.direct.gov.uk/actonco2/home/on-the-move/driving-your-car.html)

As a policy direction, eco-driving is acceptable to the consumer as it does not involve giving up the car, but rather driving it in a more fuel efficient way. As shall be discussed later, eco-driving is also appealing from a government perspective, as it appears to provide a cost effective way to reduce CO_2 emissions. Due to its all round appeal, this 'no regret' option has received increasing attention from policy makers across Europe and globally.

The benefits of eco-driving have generally been measured in terms of reduction in fuel consumption and CO_2 emissions, with the majority of studies focusing on the effect of training drivers in more fuel efficient techniques. In the short term, drivers may be able to reduce their fuel consumption by between 5% and 25% (Nemry et al, 2008), however this potential reduction is influenced by the individuals existing driving style, as well as how well they follow the eco-driving technique. Reviewing the available literature, it appears that on average a 10% reduction in fuel consumption and CO_2 emissions can be expected in the short term (TNO et al, 2006a; Johansson, Farnlund & Engstrom, 1999). The distinction between short and long term is drawn, as with time individuals may return to some of their old driving techniques, therefore reducing the effectiveness of eco-driving training. TNO et al (2006a) reviewed a number of studies and concluded that in the long term, a year after eco-driving training, a 3% reduction can be expected.

Technology has also been deployed to influence driving behaviour. Gear shifting indicators (GSI) have been examined as a way in which to assist gear changing at the appropriate time, a key element of eco-driving. An extensive study (TNO, 2006a) of the effectiveness of GSIs in reducing fuel consumption and CO_2 emissions estimated that the device alone could bring about a 6% average reduction in the short term, dropping to an average of 1.5% in the long term. GSIs assist in applying and sustaining eco-driving and so combining eco-driving training with a GSI may result in the largest reductions. The TNO (2006a) study estimates that combining the two would result in a 4.5% reduction in fuel consumption and CO_2 emissions in the long term, a 1.5% improvement on eco-driving training alone. However, some caution must be shown as further TNO (2006b) research has found that both eco driving techniques and gear shift indicators can result in an increase in NO_x emissions for diesel cars in an urban environment. It is thought that this increase is brought about by early gear shifting, an issue that can be minimised by increasing the shifting speed, although this results in a smaller reduction in CO_2 emissions and fuel consumption.

There a number of way in which eco-driving can be encouraged, all of which are relatively low cost (TNO et al, 2006a). Teaching new learner drivers eco-driving techniques could cost below 1 Euro per driver, while providing lessons for those who already drive may range between 50 and 100 Euros. The cost of GSI devices is also relatively low, with a retail price estimated at 20 Euros. Eco-driving alone, as well as in combination with devices such as a GSI, clearly presents a cost effective method of reducing fuel consumption and CO_2 emissions.

Speed Control

Recent figures indicate that exceeding the speed limit is common place on British roads, with 54% of cars travelling on motorways at 70mph or higher, and 17% of cars driving at more than 10mph over the 70 mph limit. Speeding is an issue on built up roads too, with 19% of cars exceeding 35mph on 30mph roads (DfT, 2007). Although primarily approached as a safety issue, the speed a car travels at also impacts upon its fuel consumption and GHG emissions. Vehicles have a level of optimum performance at which the least fuel is consumed; low average speeds typically result in inefficient fuel combustion, becoming more efficient as average speeds increase. However, at higher speeds, fuel consumption increases once more as the engine provides additional power needed to overcome aerodynamic drag (Cloke et al, 1999). Based upon a theoretical model, it has been estimated that full enforcement of the 70mph speed limit on motorways and dual carriageways in Britain could lead to a cut in carbon emissions of nearly 1 million tonnes of carbon (MtC) per year. Moreover, if the speed limit on motorways and dual carriageways was reduced and fully enforced at 60mph, this figure increases to a reduction of 1.88 MtC per year (Anable et al, 2006).

It is due to the clear benefits of driving within the speed limit that 'driving at an appropriate speed' is a key aspect of eco-driving. However, as illustrated by the figures for the number of cars exceeding the speed limit, a large percentage of drivers do not appear to follow this advice or, for that matter the law. A variety of methods have been employed to enforce speed restrictions and regulate traffic flow, allowing an examination of the actual impacts such a policy can have on fuel consumption and emissions. Active Traffic Management (ATM) schemes are currently being trialled by the Highways Agency. An ATM scheme in a section of the M42 has meant the introduction of variable speed limits (where electronic signs are used to change the speed limit), as well as directing drivers to use the hard shoulder during times of peak congestion. Monitoring of the scheme has indicated that the ATM has had an impact on the total emissions of the motorway, with CO_2 and fuel consumption reduced by 4% (also CO reduced 4%, HC increased 3%, NO_x reduced 5%, PM reduced by 10%). This decrease is due to the reduction of maximum speeds, smoothing of speed profiles, and a reduction in slow moving congestion. By reducing the speed limit, and effectively opening an extra lane, the motorway traffic is kept moving, avoiding 'stop/start' driving (Highways Agency, 2008), and allowing cars to operate closer to their optimum level. Monitoring of the variable speed limit pilot scheme on the M25 also found that the reduction in stop-start driving, and the improved compliance with the speed limits, decreased emissions overall between 2% and 8% depending on the particular emission measured, while fuel consumption was also improved (Highways Agency, 2004).

An average speed monitoring scheme in Rotterdam, The Netherlands, provides another example of speed control resulting in a reduction in GHG emissions. The speed limit was enforced within a controlled zone via a series of cameras, vehicles caught exceeding the average speed limit would receive an automatic fine. It is estimated that the scheme resulted in a 15% reduction of CO_2 emissions (EEA, 2008b). It is important to note that reducing speeds does not always result in positive environmental outcomes. As described earlier, low average speeds typically result in inefficient fuel combustion, and stop/start driving is particularly disadvantageous in terms of emissions. Traffic calming measures, such as speed humps, designed to reduce speed on roads with 20mph or 30mph limits can have a negative impact on fuel consumption and GHG emissions. Studies focusing on the effect of speed humps and other traffic calming measures have produced a wide range of results; however increases in fuel consumption and CO_2 have been consistently observed (Cloke et al, 1998; Boulter et al, 2001; Daham et al, 2005).

Aside from externally enforced speed restrictions, there has been a growing interest in in-car technologies that influence or restrict the speed an individual can drive. Intelligent Speed Adaption (ISA) refers to a system that 'knows' the speed limit, and ranges from warning the driver they are exceeding the limit (advisory) to restricting the vehicle so that it cannot be driven above the speed limit (mandatory). An override function can also be provided that allows the driver to exceed the limit if they choose (voluntary). Speed limit information can be gathered either through the use of GPS, or via markers at the roadside that send information to the system. As with other schemes designed to reduce speed, the primary focus is safety, however the environmental impacts have also been documented. Using an emissions modelling tool, Carsten et al (2008a) assessed the effect of ISA on carbon emissions. They found that for all levels of ISA the impact on CO_2 per kilometre travelled is variable and small for non-70mph roads, while the changes predicted on 70mph speed limit roads are significant, up to 5.8% (with an uncertainty range of +/- 0.7%) with a mandatory ISA system. Simulation modelling resulted in mixed findings, with ISA having no major impact on overall CO_2 emissions or fuel consumption in the rural network, and a detrimental effect within an urban setting. However, small fuel and emissions savings were predicted for the motorway network. Both methodologies indicate a positive impact on motorways, and although the simulation found a negative impact on urban driving, the authors argue that this can be counterbalanced with real world data which indicates no overall effect (Carsten et al, 2008). Furthermore, a large ISA trial conducted in Sweden over a three year period found that CO_2 emissions decreased by 1%, NO_x by 7%, HC by 8%, and CO by 11% (Swedish National Road Administration, 2002). As with externally enforced speed restrictions, these reductions are brought about by the change in driving style encouraged by ISA, with momentary high speeds being suppressed, resulting in less speed variation (Várhelyi & Mäkinen, 2001).

As a policy, speed control is relatively appealing and cost effective compared to alternative options. In terms of public acceptability, reducing driving speed and staying within the legal limits may prove to be a more attractive and viable option than for example, modal shift to public transport, road user charging, or alternative fuels. Alternative options are often at a financial cost to the public, or involve large behavioural changes. Evidence from a driver opinion survey found that the majority (68%) of drivers liked the variable speed limit system implemented along sections of the M25 and would want to see it introduced to other sections of motorway (Highways Agency, 2004). Also, studies examining users' acceptance of technologies such as ISA generally yield positive results (e.g. Marell & Westin, 1999; Várhelyi & Mäkinen, 2001).

Economically, speed control may prove a comparatively inexpensive option, a cost-benefit analysis examining the introduction of ISA over a 60 year period from 2010 to 2070 found a benefit-to-cost ratio of 10.3 for the implementation of mandatory ISA, 5.0 for a voluntary scenario, and 2.4 for the advisory scenario (Carsten et al 2008). In less than 15 years, under virtually every scenario, ISA recovers its implementation costs. Away from ISA, blanket enforcement of the 70mph speed limit across the road network may not be as economically viable. Analytical work conducted by Defra (2007) concluded that although fully enforcing the speed limit would result in a reduction of carbon emissions, this and other potential benefits are outweighed by the costs of implementing the necessary measures. With the implementation of mandatory ISA over a 60 year period, it is predicted that the total CO_2 savings from 2010 to 2070 would be over 25 MtC. Other benefits include fuel savings, and a reduction in accidents, with 100% usage of mandatory ISA predicted to save nearly 29% of injury accidents (Carsten et al 2008). Such analyses clearly indicate that speed control has the potential to reduce carbon emissions, as well as reduce fuel consumption, reduce accidents, and benefit network reliability. Research has suggested that if this route is to be taken, then implementing ISA throughout the fleet may provide the best solution.

High Occupancy Rates

The principle of reducing the environmental impacts of the car through car sharing is relatively straightforward. If two people use one car for a journey rather than two, then fuel consumption and the resultant emissions will be significantly reduced. Car sharing schemes often focus on the journey to work, or school, where large numbers of people are travelling to the same place at the same time. However it is often difficult to effectively measure the success of such schemes, as factors such as informal sharing are not taken into account. Based upon case study evidence, Cairns et. al. (2004) estimated the potential impacts of car sharing on commuter trips. Making assumptions regarding car occupancy and distance travelled, it was estimated that over a ten year period, if 1% to 10% of car commuters begin car sharing this would achieve a 0.6% to 11% reduction in vehicle mileage to work.

One incentive to encourage car sharing is the introduction of High Occupancy Vehicle (HOV) lanes, particularly on congested routes. HOV lanes typically allow only vehicles with two or more passengers, including buses and coaches, and often operate during peak hours. One of the first HOV lanes to be trialled in the UK was along the A647 in Leeds, introduced in 1998. Vehicle occupancy rates within the trial area increased from 1.35 in 1997 (before the scheme) to 1.43 by June 1999 and to 1.51 in 2002. Journey times improved for all vehicles using the 5 km stretch during the morning peak, with a 1.5 minute reduction for non HOV traffic, and a 4 minute saving for HOVs. Additionally bus patronage increased by 1% during the first year of the scheme. When first introduced, traffic flows reduced on the affected road, while monitoring of other routes within the area revealed a reduction of HOV traffic, suggesting that initially at least there was an exchange of HOV and non HOV traffic. Eighteen months following the introduction of the scheme traffic flows had returned to their original levels. No significant change to air quality was found following the introduction of the lane (DfT, 2006; Leeds City Council, 2002). The Leeds scheme did achieve increased occupancy rates, however with traffic flows returning to pre trial levels it may be that the main impact of HOV lanes lies not in vehicle occupancy levels but by cutting congestion on a particular route and ensuring traffic moves smoothly, thus cutting emissions in a similar way to speed control measures.

Although in principle, increasing occupancy rates per vehicle is a clear way to reduce vehicle journeys and fuel consumption, there are other factors that increase the complexity of the issue. For example, an American study concluded that while there are clear benefits to car sharing, these can be undone if it is necessary to cover additional mileage in order to collect or drop off the passenger (Jacobson & King, 2009). Additionally, the concern that promoting car sharing could negatively impact upon other alternatives such as walking and public transport is also often raised (Cairns et al, 2004). The literature concerning quantitative evidence for high occupancy rates is limited, and although there are appear to be benefits, caution must be shown when considering the potential impacts of this intervention.

Car labelling

The fuel economy label was introduced in the UK in 2005, figure AE 5. The voluntary labelling initiative was put in place to assist consumers to compare new vehicles based on CO_2 emissions and fuel consumption. A banding system, similar to that adopted for electrical appliances, was used to indicate the performance of a vehicle based on g/km of CO_2 emitted and corresponded to the revised Vehicle Excise Duty bands. The extension of the economy label to A-M bands was announced by the Chancellor in the 2008 Budget (LowCVP, 2009).

The evidence does not include quantitative data on the ability of such a label to affect reductions in any environmental impacts. This may indicate the difficulty in assessing the direct influence on consumption. The LowCVP has provided results of surveys on the perception of the label of people who have recently bought a new car or who are considering purchasing a new car. In the 2007 survey results the awareness of the label was 44% and 70% of those regarded it as important in helping decide on what car to purchase. 85% said comparative fuel economy information would be important in influencing their decision. In a memorandum submitted to the Environmental Audit Committee (EAC), an important view of LowCVP was for the next steps to include the potential of extending to nearly new cars. LowCVP also considered that car labelling shows a voluntary approach can be successful; however it could take some time to roll out, and a strong trade body is required to encourage its members to comply with the voluntary agreement (EAC, 2008)

At the European level the success of the car labelling directive was reviewed within a 2008 consultation as it was believed that the Directive was not working and needed revision (EC, 2008b). The consultation included 517 contributions with a majority from individuals (86%).
General conclusions included;

- over 50% stated the labels are not adequate to inform consumers
- 70% disagreed or partly disagreed that the liberty in car advertising is more important than display of the mandatory information
- 65% disagreed or partly disagreed with the voluntary self-regulation of the industry

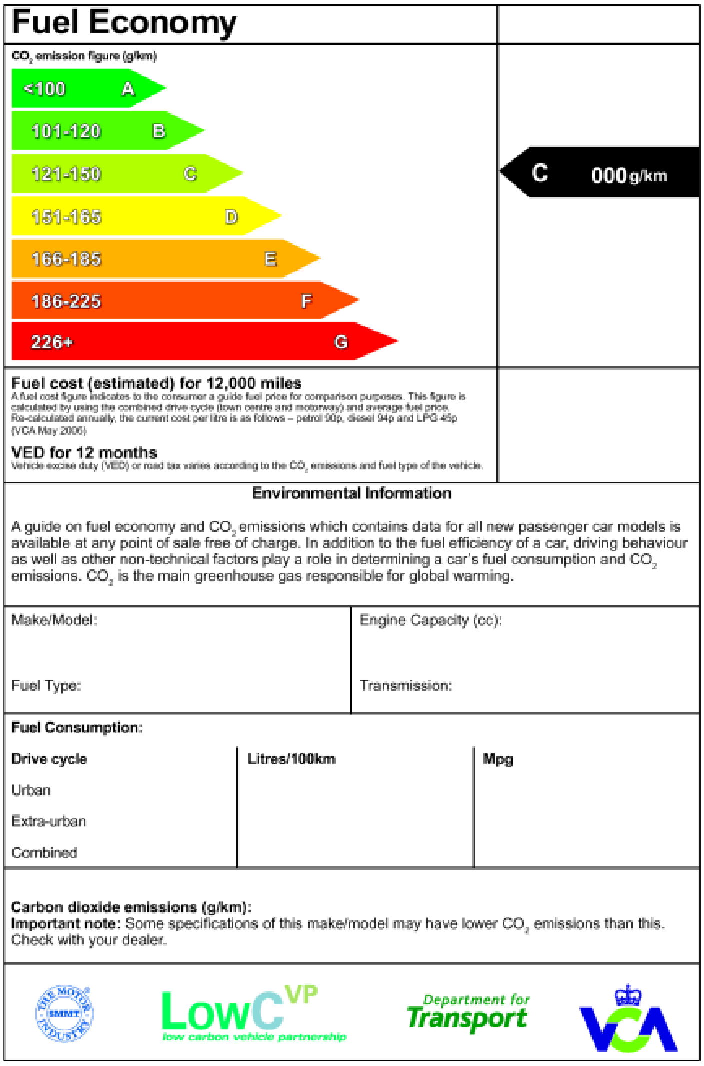

Figure AE 5 UK fuel economy label (Source: www.fuel-economy.co.uk)

Early Scrappage

The renewal of older products for newer more energy efficient models should reduce the environmental impacts of their use. In the case of cars, early scrappage schemes are based on the theory that older more polluted cars could be removed earlier from the vehicle stock, and replaced with younger, less polluting vehicles, or not replaced at all. The innovations and technological improvements in the car industry take many years of research, and potentially high risk cost expenditure, before being made available to the consumer. The embedded energy within a car from the materials and manufacture processes in the production phase, and the resources required at the point of disposal contribute to the need for optimal lifetime research to include the whole life cycle impacts and costs of a car.

Spitzley et.al. (2005) analysed the optimisation of ownership costs and emissions reduction based on US data, incorporating a number of environmental impacts and economic costs. The results of the study gave a range of intervals;

Private costs	17-19 years
CO	3-6 years
NO_x	5-7 years
NMHC	6-9 years
Life cycle CO_2 and energy use	18 years

A balance of the range of economic, energy and emissions objectives results in a replacement interval of 9 years using US data (Figure AE 6), based on a mid-sized saloon vehicle (Ford Taurus, Chevrolet Lumina and Dodge Intrepid, UK equivalents, Ford Mondeo, Vauxhall Vectra). It is important to reflect that UK specific economic and environmental data should be used to create a UK scenario, particularly to evaluate the optimisation of private costs and energy use.

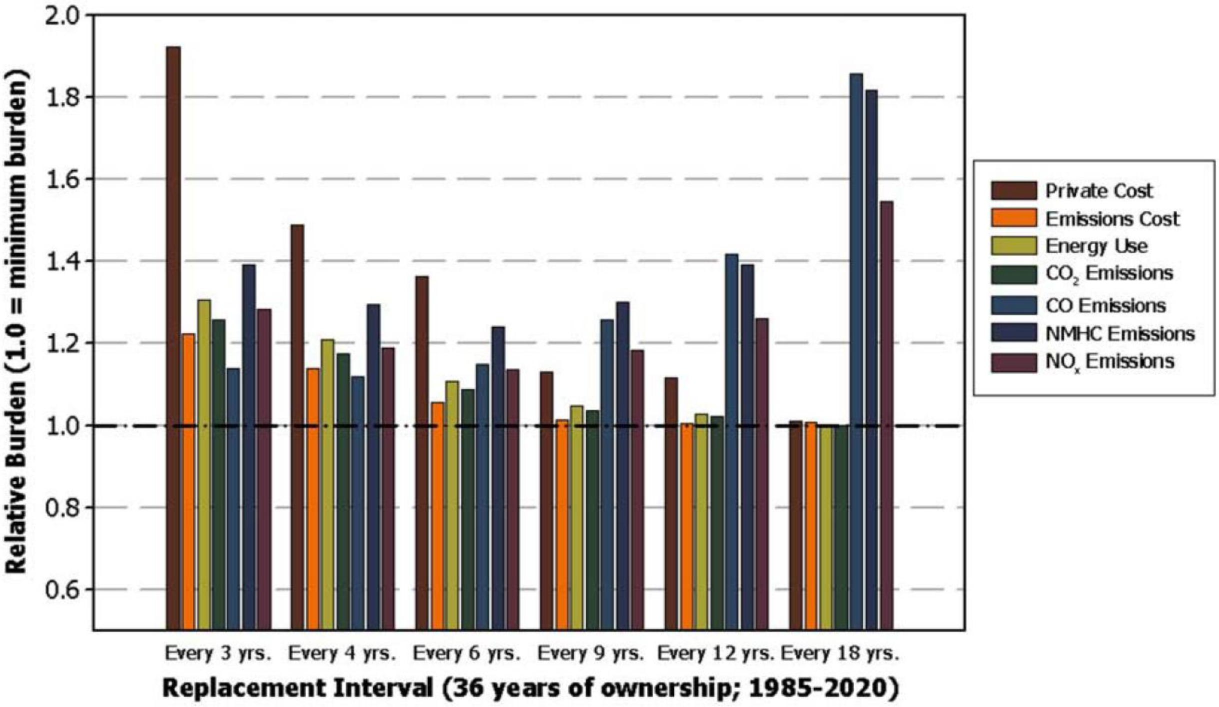

Figure AE 6 Relative economic and environmental burdens associated with regular replacement intervals (Source: Spitzley et. al. 2005)

A number of early scrappage schemes have been implemented in the United States, also known as Voluntary Accelerated Vehicle Retirement (VAVR) programmes. The schemes incentivise drivers to scrap or trade-in their vehicles for financial reward; in early 1990's schemes paid between $500-700 per car which fitted the criteria (ECMT, 1999).

European schemes have included France, who in 1994 offered Fr 5000 for the scrappage of cars older than 10 years and were replaced with new models. A further scheme in 1995-96 offered Fr 7000 for cars older than 8 years. The amount of cars scrapped was above those that would have normally been retired was 700,000. Unfortunately a value in emissions reductions is not provided (OECD, 1999). Recently, the President of France announced that vehicle scrappage incentives would be included within a package to boost the country's economy as a part of a solution to the current global economic crisis (LowCVP, 2008)

In Denmark between 1994 and 1995, US$1000 was given for scrapping a vehicle 10 years or older, regardless of replacement. 6% of the fleet was scrapped in the schemes first six months, 11% of owners bought a new car, 45% bought a second hand car, interestingly 19% of those bought another car older than 10yrs, and 44% did not buy a car. The scheme was estimated to have reduced HC by 0.6% and NO_X by 1% (OECD, 1999).

Dill (2004) comments on the assumptions and limited evidence that support emissions reduction benefits of VAVR programmes, and illustrates the wide range of reductions, and in some cases increases, in emissions when variations in factors such as vehicle miles travelled (VMT) are used in emissions analyses. A basic equation to calculate the emissions avoided by scrapping older vehicles, incorporating emission rate (ER), vehicle miles travelled (VMT) of old and replacement vehicles over the number of years the older vehicle would last (L), clearly shows the elasticity in reduction estimates (OECD, 1999);

Net emissions avoided by scrapping an old vehicle = $(ER_{old} \times VMT_{old} - ER_{repl} \times VMT_{repl}) \times L$

Extrapolating any assumptions of VMT and L would derive questions of the validity of the calculation, particularly if assumptions are based on a drivers own estimation of VMT.

The potential social costs of early scrappage schemes may include impacts on people dependent on the maintenance and servicing of vehicles (Dill, 2004).

Road Charging

TRL Limited and the TSU at Oxford University recently conducted a review for the EEA of successful transport initiatives across Europe that demonstrated GHG emission reduction (EEA, 2008b). One of the studies highlighted the success of the London congestion charge zone which came into force in 2003.

The congestion charge aims to reduce the volume of vehicles within the centre of London through a payment structure which allows discounted entry to the zone for selected groups, including disabled 'Blue Badge' holders, residents who live within the zone, electrically propelled vehicles and drivers of alternative fuel vehicles that meet strict emissions criteria within registers held by the energy Savings Trust, http://www.tfl.gov.uk/roadusers/congestioncharging/6713.aspx.

A reduction in CO_2 emissions was not an initial objective of the congestion charge zone; however the monitoring of GHG emissions has revealed the potential of such initiatives to make sizeable reductions in the environmental impacts of transport.

The TfL fifth annual monitoring report indicated that GHG emissions have been reduced as a result of flow changes and the implementation of the congestion charging zone, (Table AE 1).

Table AE 1 Principal changes to emissions of CO_2, NO_x and PM_{10}. Percentage change between 2002 and 2003. (Adapted from TfL, 2007)

	Charging Zone			Inner ring road		
Flow change Vehicle Type	**CO_2**	**NO_x**	**PM_{10}**	**CO_2**	**NO_x**	**PM_{10}**
Car	-11.2	-4.5	-4.6	-3.9	-1.6	-1.8
Taxi	2.4	2.3	3.8	2.1	2.0	3.6

Any subsequent reductions in GHG emissions since 2003 are reflective of improvements in vehicle technology. For the period 2003-2006, the TfL monitoring report indicates that CO_2 reduced by 3.4%, NO_x by 17.3% and PM_{10} by 24.3% due to fleet turnover.

The emissions reductions seen after the implementation of the London congestion charge zone are specific to this road charging scheme as the degree of emissions reductions will depend on the design and local socio-economic conditions of a charging scheme.

Similar studies by the Environmental Research Group at Kings College London and Institute for Transport Studies (Beevers and Carslaw, 2005a and 2005b) have reported that between 2002 and 2003, the change in vehicle km travelled reduced by 29% for cars, and increased by 13% for taxis. An overall reduction in CO_2 emissions related to transport within the charging zone was estimated to be 19.5%.

Further significant reductions in the GHG emissions in the congestion charge zone may be seen with the introduction of strategies to phase in low carbon vehicle technology in taxis and buses.

Other evidence on road charging includes a UK survey based study into the impacts of a potential road pricing scheme in the Yorkshire Dales National Park (Steiner and Bristow, 2000). The documented impacts of cars included "increase noise, air pollution, visual intrusion, danger to vulnerable road users, erosion of verges and damage to the social fabric of settlements." The paper estimated a road pricing scheme would reduce cars miles by 13500 miles, however due to inclusion of a park-and–ride scheme, bus miles would increase by 2800 miles. The total environmental impact reduction in this scheme would be influenced by the type of high occupancy vehicle used to transport visitors into the park, suggesting that alternative forms of travel are crucial to the success of a charging scheme.

Annex F: Stakeholder Workshop

The project's stakeholder workshop was held on Friday 12th December 2008 at 1 Victoria Street, London. The workshop was attended by;

Flavie Salaun	Defra
Carolina Escobar	Defra
Julia Sussams	Defra
James Hooson	DFT
Dennis Morgan	DfT
Duncan Kay	SDC
Alice Baverstock	Defra
Dr Paul Nieuwenhuis	BRASS
Robert Walker	SMMT
Don Potts	SMMT/Volvo
Bernadette McSharry	SMMT/BMW
Jane Patterson	Ricardo UK Ltd
Adam Gurr	Ricardo UK Ltd
Mike Waters	Arval PHH - Chair Passenger cars Low CVP WG
Malcolm Watson	UKPIA - Chair Fuels Low CVP WG
Peter Stokes	CARE
Duncan Wemyss	Motor vehicle dismantlers association
Dr Shaun Savage	DRIVEnet
Faye Doherty	TfL
Geoff Fletcher	Clifford-Thames
Rupert Russell	Comcar and Carmen Data Ltd
Simon Jackson	Environment Transport Tax Team at Treasury
John Plowman	Consultant to SDC
Dr Jacquie Berry	TRL Ltd
Holger Dalkmann	TRL Ltd
Kevin Turpin	TRL Ltd
Dr Lucia Elghali	Centre of Environmental Strategy, University of Surrey

Annex G: Stakeholder workshop summary

The stakeholder views in italics were received as the feedback for the summary document.

Breakout Session One

During this session attendees were asked to discuss the interventions that affect design, production, retail and distribution of the car.

Hybrid		
Production	**Use**	**Disposal**
• High production costs and therefore high purchasing costs • Battery production impacts, *metals which may be in shorter supply or have higher energy costs in the process of mining and production from raw materials* • The stakeholders held different views on the impacts of including non-ferrous metals in production and recycling - non-ferrous metals in production may hinder recycling - *higher non-ferrous content would have a greater recycling value* • CO_2 test cycle drives production of	• How a hybrid is driven is very important. More effective if used in an urban context as at higher speeds *or heavy engine loads* a hybrid is essentially an internal combustion car. • Less effective in terms of energy efficiency when used on motorways. • Hybrids can be very efficient through optimisation of engine speed and load. • Hybrids could provide an illusion of reducing environmental impacts in 'Green' company car fleets and CSR reporting. More information	• Key is the disposal of batteries. • Electric motors are fairly valuable materials. • Recycling is very much dependent on body shell type. • Potential for inappropriate disposal; *The infrastructure for the correct dismantling of hybrid vehicles has not yet been fully established and the economics of undertaking this process may differ significantly from that of the de-pollution and recycling of existing ELV's.*

Hybrid

Production	Use	Disposal
hybrid rather than use • In addition to Internal Combustion (IC) production hybrids require; - Controllers - Batteries - Regenerative breaking - Electric motors These components are fitted via a restructured production line and would generally result in the energy demand increasing over a standard IC line. • There would also be a higher cost in terms of embodied energy to source materials. This issue should be included in the total energy *and resource* budget for a hybrid.	would be needed of driving styles. • Regulatory controls should be performance based rather than technological, *i.e. congestion charge* • Costs of maintenance higher than standard cars – could be improved, *although feedback included some disagreement with this* • Low noise levels at slow speeds are a potential safety issue • Further research needed to consider the efficiencies of using different fuels.	

Electric fuelled

Production	Use	Disposal
• Regulatory pressures on tailpipe CO_2 emissions may influence the development and production of electric cars. • There is a requirement to extract	• EVs may well encourage and promote more sustainable driving behaviour. • Public perception is poor, 'milk float'	• More research on recycling required, issues regarding the recycling of battery materials (*e.g.* lithium, nickel) and safety of disposal and reprocessing of

Electric fuelled		
Production	**Use**	**Disposal**
materials for the production of batteries and other components in the electric car. It was suggested that there is a low lithium supply that would only replace a fraction of the global car stock. • Nickel, Lithium and Cadmium resource depletion • Batteries are used in a number of appliances and as such costs would increase if the materials were used in cars. The example was given that lithium batteries are used in mobile phone, laptops, etc. • Higher build quality required • Health &Safety issues in production because of a concentration of high voltage in batteries. • Currently it was thought that electric cars may be thought of as a second car use. • Electric cars may take time to implement and replace the current car mix and it was thought that Hybrid was a middle step. • Retrofitting intervention in the short term (*e.g.* battery packs) may increase the embodied energy of cars with conversions applied. • In the longer term it is likely that	• Issues regarding use of batteries, e.g. charging. • Range of current electric vehicles is low • Practical issues where raise such as low capacity for luggage • Refuelling takes a long time and switching battery packs, could be more flexible than 'plugging-in' • Additional impacts of accessories and infrastructure for charging • Higher purchase cost • Overheating in the car • The voltage from batteries will cause problems for emergency services in crashes • At low speeds the noise reduction will have pedestrian safety implications • How would motorway charging be achieved? • Reduced maintenance • EVs have speed limitations. In addition EVs, as standard, require speed management to optimise battery life • EVs may provide reduced running costs for the user but with higher impacts on the environment over the car and electricity life cycle.	batteries • Short battery pack lifecycle • Electric motors are fairly valuable materials. • EVs generally have fewer working parts to disassemble that said, the discussion considered whether in the future parts would indeed be very recyclable and in most cases outliving car bodies. • Recycling is very much dependent on EV body shell type.

Electric fuelled		
Production	**Use**	**Disposal**
retrofits may prove less energy intensive. • The group considered that the most energy efficient cars are most likely to come from new models rather than conversions of existing fleets. • Manufacturers have designed single cars body shells to allow internal combustion (IC) or battery packs to be installed. • An issue was raised concerning the security of supply of battery materials as not from UK. • Reduced insulation materials required for EVs to minimise sound and heat impacts. • Question as to whether EVs require more PVC insulation compared with equivalent IC vehicles. • Discussion about the energy used to cool batteries and power onboard gizmos. *The main problem will come from heating and cooling systems which require large amounts of battery power.* Do the public in general expect EVs to come with the standard IC based equipment?	• Noise impacts would be reduced. Although it was agreed that road/tyre noise would still be the same. • Tailpipe emissions would be zero. • Non-exhaust emissions could reduce. • Not sure whether CO_2 emissions would be significantly affected, *although stakeholder feedback included suggestion that emissions are greatly reduced.* • There needs to be comparative metrics of consumption between different modes – well to tank and tank to wheel • Different battery technologies may require a mixture of battery charging regimes. It would be better for everyone concerned if this was to be narrowed down to a specific standard.	

Car Labelling		
Production	**Use**	**Disposal**
• Testing cycles not realistic regarding performance • Buying habits consumer driven • Not easy to input production emissions on label because of diverse production routes • Could be helpful if the car label included information regarding the standard equipment that helps to improve efficiency of vehicles – dashboard displays, 'green' tyres, CO_2 performance • Too much complexity	• Labelling to reflect electric vehicles CO_2 equivalent – night and daytime charging cost • Need comparison of electric with standard conventional fuels • Registration – change from twice a year – distribution and purchasing would be more even throughout year • Must not be too complex, however label is about to double in information • Resale labelling – with fuel efficiency information	• A KPI regarding recyclability • Clear labelling of disposal

Biofuel		
Production	**Use**	**Disposal**
• Requires supply chain procedures to verify sources with a complete audit trail • Direct and indirect impact issues - Biodiversity effects - Carbon releases over whole life cycle of biofuels • Requires a significant infrastructure • Is there enough land for production in the UK? How much biofuel will need to be imported? • 2nd generation biofuel technology will not be commercially viable for 5-10 years, should not rely on this, however a lot of work being done on biofuel from straw, food and forestry waste. • Production of biofuels could contribute to deforestation and increase in CO_2 emissions	• Food vs. fuel – complex trade-offs • Efficiency of bioethanol is higher • Biofuels release more energy per metre, however some engines are less tolerant to biofuels than others • Swedish government has an ethanol pump on each forecourt and offers car tax reductions, good take up of technology • EU directives will control biofuel use • Thought that this is not a 'silver bullet' alone • Above 5% mix of biofuel use invalidates warranty, however a mix up to 30% may be possible. *Although increase in biofuel %'s for use can only be achieved with further planned engine development and manufacturing changes which take research and time to implement.*	• New material for new fuels and would need ways to recycle them

Hydrogen		
Production	**Use**	**Disposal**
• Potential resource shortages for fuel cell production • Fuel cell costs are high • Number of engineering challenges need to be overcome, e.g. prototypes and global production • Needs strategic vision and support for engineering and infrastructure development	• There are currently barriers with cost and technology and it is thought we are 20 years away • 'Only game' in town as hybrids are a 'stop gap' technology, *however this view was not shared across all stakeholders* • Infrastructure costs for support of technology • Lack of oil industry support • Safety concerns with storage and use of hydrogen fuel • Is it low carbon? Unless the carbon intensity of electricity supply is reduced there will be no benefits in hydrogen • Electrolysis of water is the preferred method of hydrogen production, potential water supply issues • Distribution and storage of fuel	• How are they dismantled? • Precious metals in fuel cells will encourage recovery

Material Substitution		
Production	**Use**	**Disposal**
• There is an economic costs of substituting materials • Strongly driven by policy • Drivers for material change- weight, aerodynamics, engine management, low friction tyres, trims • ELV – design for recycling, plastics labelling • Substitution should be 'Fit for purpose' – e.g. mercury was removed from headlamps, but was put back for good lights • Owing to the number of trade-offs material substitution can only be rationalised across the whole life cycle. • Steel is a cheap material and substitution of materials requires additional costs increasing from magnesium to aluminium to carbon fibre to Kevlar. • Steel has possibly the most demand as a recyclable material to build cars from in terms of being reused in the car manufacturing industry. • Carbon fibre has a high raw material cost but no knowledge as to the recycling implications.	• CO_2 reductions from lighter vehicles and less fuel consumption • Cost of repair may be more expensive • Changes driven less by consumers • Needs agreed methodology and industry standard, e.g. NCAP • To reward 'good behaviour', consider including a change/benefit in purchase cost for consumers of cars with better materials • In essence materials are substituted to reduce a vehicle weight and as a consequence more energy efficient. These reductions are considered within cost constraints.	• Recycling of aluminium may produce weaker material • High cost of recycling plastics, low value of resale • Metals completely recovered, more economic • Recycling of material driven by cost • Clearly vehicles made from a single material would be the best in terms of recycling. • Taking into account the vehicle life cycle the group considered that ultimately vehicles made of aluminium are more expensive in terms of the raw material and production. However, these vehicles may last longer and be more recyclable. *Material substitution for materials that are lighter or that significantly reduce the impact of a car in its use phase (=>80% of its impact) may be less recyclable therefore there is a trade-off that to gain a reduced environmental impact from a vehicle throughout its entire life you may need to reduce the expectation and legislatively required recycling rates at the end*

Material Substitution		
Production	**Use**	**Disposal**
• Plastic appears to be a good intervention although there are issues in terms of *the impacts associated with production and* recycling (labour intensive). Drive to reduce PVC within the plastics. • Possibly much more can be achieved in reducing the size and weight of drive systems.		*of its life.*

Additional Intervention – Environmental Pollution control in production IPPC/EUETS		
Production	**Use**	**Disposal**
• Regulation for outside Europe? • If regulation is too hard in EU, production will be pushed outside EU where it is less regulated (+ ethical sourcing) • Trade off with traditional focus on Volatile Organic Compounds (VOC) in painting process as less VOC means energy cost to incinerate VOC or heat to dry paint if water based. Which is most important? (VOC or CO_2) • Waste from production: more effort to control materials at source leads to more fractions to transport separately for recycling/treatment, which leads to greater transportation CO_2		• Limited pollution control on exported cars at end-of-life for processing and recycling

Breakout Session Two

During this session attendees were asked to discuss the interventions that affect the use, maintenance and end-of-life of the car.

Eco-driving		
Production	**Use**	**Disposal**
• Development in dashboard displays could show better fuel consumption data • Switch off – stop/start system could be fitted within cars • Technology is costly • *Stakeholders views on manufacturers including GSI technology into cars was mixed;* - No incentive for manufacturers to include GSI, legislation is required. • *Manufacturers are commonly including GSI's on many new models with some installing them across their entire ranges*.	• Acceptable to public as does not involve giving up or changing their car • Training – need benchmark before and after improvement • Difficult to measure the true long term impact of eco-driving, potential for people to forget techniques • Cost effectiveness is dependent on the level of intervention, i.e. adverts, lessons. • Should the money be invested elsewhere • Policy doesn't focus on in-life emissions, mileage/fuel/mpg monitoring • Eco-driving is a 'spiritual concept' • Habit vs. technology • Link to safety – defensive driving • Limited on its impacts (10-15%) • Should be taught whilst learning to drive • Marginal negative effects for GSI • Improved road safety through driving more sensibly	• New technology to dispose of • Higher technology would increase a car's residual value

Speed Control

Production	Use	Disposal
• More research required on what is the most efficient speed of a car • Manual vs. automatic vs. cruise control effects on speed and environmental impacts of driving • Lower maximum speed limits are less popular • Include speed governor as an option on cars – • Company car fleet managers could adopt speed policy e.g. no one above 70mph	• Predictability of journey times • Keep traffic moving and provide less frustration for drivers • Higher regulatory controls may also improve speed of car, e.g. stricter points and fines • Speed limiters on commercial vehicles see benefits in lower fuel bills • Download vehicle performance data and use speed profiles as basis for training • USB download of speed data • Average speed cameras are more likely to prevent harsh acceleration and braking compared to static cameras	

Road Charging

Production	Use	Disposal
• *Installation of infrastructure has both production and disposal impacts and energy requirements through its use period*	• Charging schemes need consistency of application and exemptions • Congestion charging needs	• Infrastructure disposal impacts

Road Charging

Production	Use	Disposal
	alternatives to continue travel, e.g. London OK for alternative travel, however National Parks scheme would have no current alternative and would need 'park and ride' option for example • Key to understanding why is road charging in place? Consumers need to understand, does it aim to reduce congestion or raise revenue • May affect working hours, social impacts of this • Reductions maybe achieved by flexible working instead • Social impacts – ensure schemes do not discriminate against more vulnerable user groups • Zone charging in urban areas rather than road tolling for environmental benefit. Road tolling may lead to greater use of other road networks, more congestion • Road charging should only be used for 'goods' roads such as M6 toll • New road capacity may increase car use • Technology costs of road charging	

High Occupancy Rates

Production	Use	Disposal

• Would High Occupancy lanes (HOL) reduce car production?
• In the short term high occupancy rates were thought to have insignificant affects on car production.
• It was agreed that a road infrastructure would need to be added or modified. This cost is often not considered as part of the energy life cycle.
	• Car sharing - less flexibility, set schedule, privacy issues
	• Infrastructure maintenance costs of HOL
	• Need to change people's attitudes to promote the use of HOL
	• Limited space on UK roads to increase widths to accommodate an extra lane
	• In longer term the group considered that HORs would start to reduce private car ownership, increase public car services (car clubs, taxes, and rental) as well as increase the number and frequency of bus services.
	• HORs need the following complimentary measures to be successful;
	  - A system of enforcement, police presence, cameras
	  - Park and ride schemes
	• Speed controls for effective emissions controls
		• Potentially less cars to dispose of
		• Negative effects on employment

ELV Directive

Production	Use	Disposal
• How do you influence purchase decisions through ELV? *All cars have to reach set standards of recyclability therefore this aspect may not present a vast influence on purchasing* • A perception is new parts are better than remanufactured • Remanufacture has no bearing on ELV • In principle ELV directive was a good idea and has focused the minds of the vehicle manufacturers. • Unintended consequences – lighter materials may not be the best in terms of being recyclable and or in terms of reducing energy. On this basis manufacturers are less likely to adopt new production designs.	• More money in servicing and new parts rather than selling a new car	• Economics dictates decisions on remanufacturing • Competition for remanufactured parts with cheap new parts • 75% metallic content easy to recycle, however only 1% sale of the rest of the parts • Restructuring of business models, less independents, more servicing in manufacturer garages • Potential problems with recycled plastics leaking phthalate compounds • The ELV directive is barely working because it has not pushed the boundaries beyond what was already achievable (i.e. only applied to 85% of the vehicle, 10% of which includes energy recovery). *ELV in the UK needs improvement through improved policing of licensed and unlicensed operators. The development of this process is dependent on the viability of end markets for segregated materials.* • The certificate of destruction (CoD) is open to scrutiny as vehicles can be self certified as being disposed of appropriately by the owners of vehicles. *The issue process needs*

ELV Directive

Production	Use	Disposal
		to be improved to ensure the public dispose of their vehicles to legitimate ELV operators that depollute and recycle vehicles via the correct processes. • On the whole it was agreed that the ELV has become more cost effective owing to high land fill charges. • The group considered the 95% recycling target for 2015 to be too high and should be phased in.

Early Scrappage / Optimal Lifetime Expectancy

Production	Use	Disposal
• Socio-economic trade-offs, i.e. employment in maintenance sectors • Interventions such as interrogating a vehicle onboard diagnostics system would help to inform drivers the status of a vehicles performance to help decide whether a vehicle needs, updating, repairing or totally replacing • Benchmarking of optimal lifetime required on a regular basis to	• Reduces the value of second hand cars, needs a way of working through marginal choices • Those that would want to get off the road are not necessarily the ones that would come off the road • Look to pass on incentives through second hand ownership • 18 years is the optimum life cycle for a car (CO_2). There are implications for fleet renewal polices.	• Recycling of cars make increase rates of removal from vehicle stock • An understanding of the differential between vehicle repairs compared to vehicle worth is required to develop fleet renewal strategies. As vehicles become relatively less expensive people are more likely to scrap and replace them. This may not be the most sustainable strategy. • More research required to

Early Scrappage / Optimal Lifetime Expectancy		
Production	**Use**	**Disposal**
evaluate current technology and average car emissions	• The need for a standard LCA to understand the embodied energy cycle of a vehicle. For example, as vehicles become more efficient the energy to produce and dispose of vehicles become more important. However, if vehicles generally last longer the use becomes the main issue in terms of total emissions. Clearly, as well as average fuel consumption over a test driving cycle the issue needs to be resolved by estimating emissions for a complete cycle. • Technology takes a while to enter into market, therefore longer lifetimes in use will match this trend • Negative social impacts on drivers who cannot afford to change cars regularly	establish optimal lifetime

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