Energy Saving Trust

Passenger Car Market transformation model

Final report

22/10/07

Energy Saving Trust
21 Dartmouth Street
London
SW1H 9BP
Tel: 020 72220101
Fax: 020 76542444
www.est.org.uk

DISCLAIMER

The report contains a description of the Market Transformation model for low carbon vehicles which was developed for the Energy Saving Trust. As with any model, the results presented are market projections only and should be interpreted in the light of the model methodology used (with its associated limitations) and the uncertainties various inputs to the model. The main aim of the model is to provide a framework for the analysis of various policy scenarios rather than to develop detailed market projections to 2020.

The results relate to a baseline, which was completed in 2006, so does not factor in market changes which may have occurred since. However, the model is being updated during 2007/08 to reflect market and technological changes.

Please contact Energy Saving Trust Evaluation for further details of the operation of the model.

Contact details:

Energy Saving Trust

David Kenington (Evaluation Manager)
Energy Saving Trust
21 Dartmouth Street
London
SW1H 9BP

tel: 020 72220101
fax: 020 76542444
email: david.kenington@est.org.uk

Element Energy

Ben Madden (Director)

London:	Cambridge:
60 Newman Street London W1T 3DA	Jupiter House Station Road Cambridge CB1 2JD
tel 0207 462 5299 fax 0207 323 4645	tel: 01223 369220 fax: 01223 356215

email: ben.madden@element–energy.co.uk

Ricardo UK
Angela Johnson

Shoreham Technical Centre
Shoreham-by-Sea
West Sussex
BN43 5FG

tel: +44 (0) 1273 455611
fax: +44 (0) 1273 464124

email: angela.johnson@ricardo.com

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

This report summarises the work undertaken to build and then iterate a Market Transformation model (MTM) for low carbon vehicles in the UK.

The Energy Saving Trust commissioned Element Energy and Ricardo Ltd to develop a model of the UK vehicle market in 2005/06. The work was carried out in 2006/07, and has been supported by the Low Carbon Vehicle Partnership who have provided valuable technical input and peer review.

The objectives of the project were to:

- Create a simple, effective and independent working model of UK vehicle parc including cars, vans, trucks and buses
- Project carbon emissions from UK vehicles to 2020
- Model policy mechanisms which influence carbon emissions
- Tailor Energy Saving Trust transport programmes to maximise market transformation to low carbon vehicles/ fuels

Market models are mathematical representations of real markets, which are used to forecast future market progression and to assess the likely impacts of changes in market conditions, such as the influence of new policy mechanisms.

The Energy Saving Trust market transformation model is a consumer choice model, which predicts the take up of low carbon passenger car technologies (e.g. hybrids, fuel cell vehicles, electric vehicles etc.) in the UK market. As this is a model based on consumer choice, it is set up to analyse the sales performance of low carbon vehicle technologies in competition with petrol and diesel vehicles from a vehicle buyer perspective.

1.1. Brief description of the model

A detailed model of four different markets for vehicles in the UK has been built, based on a Multinomial Logit structure which has been extensively used in vehicle market modelling in other countries (particularly in US policy making tools). The four markets considered are: passenger cars, buses, vans (sub-divided into three sectors) and trucks. This report considers only passenger cars at this stage, the other vehicle markets will be added in due course.

The functions of the model as described in the main body of this report are complex, however their structural components and the principles by which they interact are relatively transparent. The basic modelling process and structure are summarised below.

Modelling process summary

- From a finite number of choices, the buyer makes a purchase based upon a range of vehicle attributes (cost, comfort, acceleration etc.).
- The model assigns a value (coefficients) to the importance which consumers place on vehicle attributes mentioned above

- The attributes and coefficients combine to provide an overall measure of the “utility” of each vehicle. This is a measure of the attractiveness of the vehicle

- The model predicts market share based on the utility, using a probabilistic model. Higher utility leads to a higher market share.

An extensive dataset on the likely performance of a range of vehicle technologies against specific vehicle attributes has been created based on forecasts by Ricardo and extensive peer review by industry through the Low Carbon Vehicle Partnership. This dataset is used as an input to the Market Transformation model, which assigns a value to the consumer’s attitude to the various attributes of each vehicle technology (i.e. capital cost, fuel consumption etc.). The market model then projects a yearly market share for each technology and this allows a projection of the likely components of the UK vehicle parc to 2020.

This model provides a framework for the identification of different policy scenarios. Its relative simplicity allows a wide range of technologies to be considered, coupled with a wide range of different market intervention options to help inform policy making. The model is designed to allow policy and technological mechanisms to be simulated and to project the impact on the market share for different vehicle technologies and estimate overall CO_2 implications.

The model has been calibrated using a number of mechanisms including a fit to historic data and a detailed consumer survey (by GfK) which quantifies consumer attitudes to different vehicle attributes in the UK.

The model itself has been extensively peer reviewed during its development by LowCVP members, and through an academic review carried out by the Institute for Transport Studies (ITS) at Leeds University. Whilst there are a number of limitations to the accuracy of the relatively simple modelling approach, it has been concluded that the model represents a good framework for assessing a broad range of policy scenarios and technology options relevant to low carbon vehicles in the UK. However, any analysis undertaken using MTM results, should consider the model limitations as described in section 4 of this report.

1.2. Example Modelling

There is a wide range of policy mechanisms which can be assessed within the market transformation model including (but not limited to) the following:

- Consumer Valuation of CO2[1]
- Variation in fuel prices, (due to uncertainty in future oil prices)
- Variation in capital costs of low carbon vehicles
- Variation in running costs of low carbon vehicles
- Fiscal support for clean fuel infrastructure
- Low carbon vehicle procurement programmes

The model can also be used to looks at the impact of technology change as well as policy change. For example the model can be used to:

- Model the impact of changes to assumptions about vehicle performance and cost for the identified technologies:

[1] This simulates the effect on vehicle purchase decision making, in a situation where a consumer places a ‘value’ on carbon emissions

- or model the introduction of new technologies

- Identify changes in sales patterns as a result of technology insertion/improvement:

    i. Identify which existing technologies are displaced as a result of the introduction of these technology changes
    ii. Calculate changes in UK CO2 emissions as a result

- Model could also be run iteratively to identify the necessary change in vehicle attributes (which attribute and the magnitude) required to gain significant market penetration of low carbon vehicle technologies

The purpose of this report is not to provide conclusions on the relative effectiveness of different policy or technology scenarios, therefore detailed analysis of different mechanisms is not provided. Analysis of policy scenarios can be carried out by Energy Saving Trust[2] at the request of 3rd party organisations as a chargeable service, and subject to a review process prior to publication of results. However, base case scenarios[3] and a few example scenarios are shown in order to demonstrate what results the model is capable of producing.

1.3. Summary of results – passenger car

Base case

The base case results for passenger cars are based on a continuation of today's policy regime (and planned policies) with respect to low carbon vehicles. Please note, the model is currently awaiting 2007/08 updates (planned to complete January 2008), and there have been some changes to the UK passenger car market since 2006/07 when the technical inputs were developed.

The results suggest a gradual improvement in the average CO_2 of the new fleet which is caused primarily by a progressive improvement in the efficiency of gasoline and diesel vehicles and some market penetration of lower carbon technologies such as hybrid stop-start vehicles (ending at 143g/km by 2020[4]). The contribution of new vehicle technologies to reducing fleet averaged CO_2 is relatively limited.

[2] Contact David Kenington, Energy Saving Trust Evaluation Manager for further details. Tel: 020 76542497 Email: david.kenington@est.org.uk

[3] Base case scenarios assume that current market conditions stay the same in future years, accounting for known planned future regulatory changes (such as Euro levels).

[4] Note these policy measures are provided by way of example only, 2007/08 planned updates (e.g. introduction of the EC 130 g/km target will have an influence on model outputs.

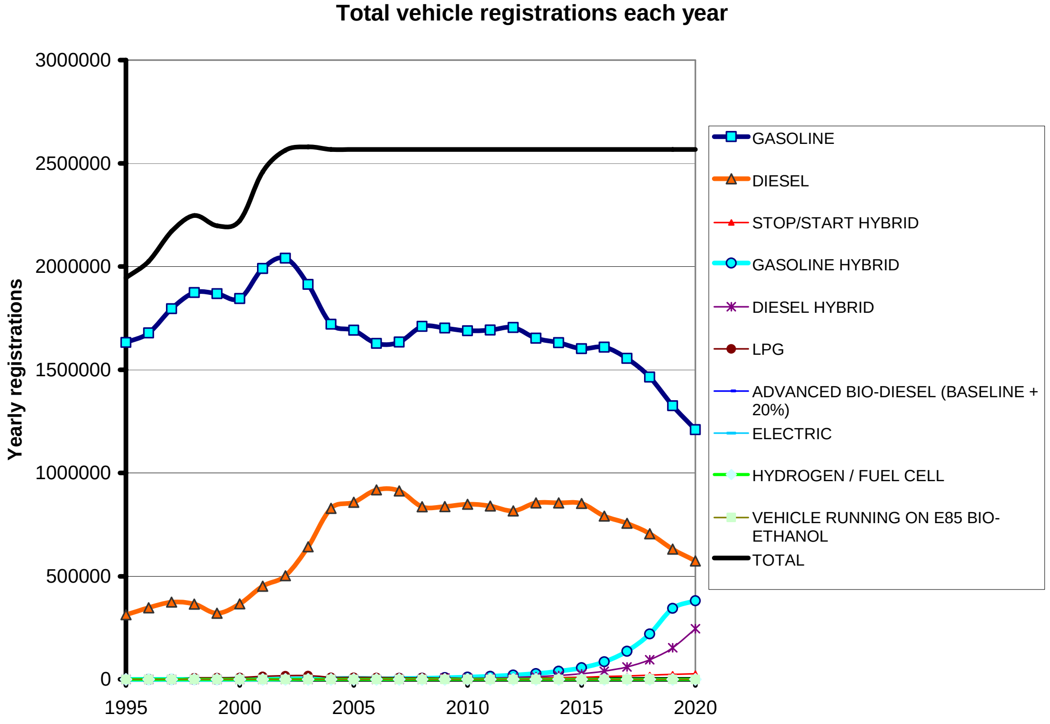


Figure 1, base case results for yearly sales of different passenger car technologies

Considering the UK vehicle parc as a whole, annual CO_2 emission projections show a steady decrease (N.B. this conclusion assumes mileage per vehicle remains constant over time). In addition, the effect of the Renewable Transport Fuels obligation will lead to a reduction in CO_2 emissions when it comes into force in 2008. The base case suggests a reduction of up to $10MTCO_2$/year from the vehicle parc by 2020.

Other than the hybrid and premium gasoline technologies, most low carbon vehicle technologies fail to achieve noticeable mass market penetration. Some appear to be unable to compete with other vehicle offerings over the time-period to 2020; these include electric, hydrogen fuel cells and LPG.

Some technologies such as hybrid vehicles and advanced/premium gasoline have the potential to be a competitive mass market offering but struggle to overcome market inertia in the early years of their introduction to the market. Market inertia is a penalty applied within the model to demonstrate consumer reluctance to take up new technologies through lack of knowledge, familiarity or experience with the new technology.

Stop-start technology does not appear to have significant mass market appeal to drive mass market adoption unless assisted by some policy intervention. [N.B. these technologies and advanced/premium gasoline may be adopted by vehicle manufacturers as part of their own incremental changes to their conventional drive train technologies and as such may not need to overcome such market inertia penalties.]

Bio-fuel technologies outside of the RTFO also do not show significant uptake in the model under base case conditions (high bio-fuel content i.e. B20 and E85). The technologies are held back by high cost of fuel and lack of infrastructure availability. In addition, the market inertial penalties cause problems in encouraging adoption of sufficient bio-fuel compatible vehicles to justify the required fuelling infrastructure investment.

Policy scenarios

Example scenarios for demonstration purposes modelled within the report include:

- Reduction in capital costs low carbon vehicles

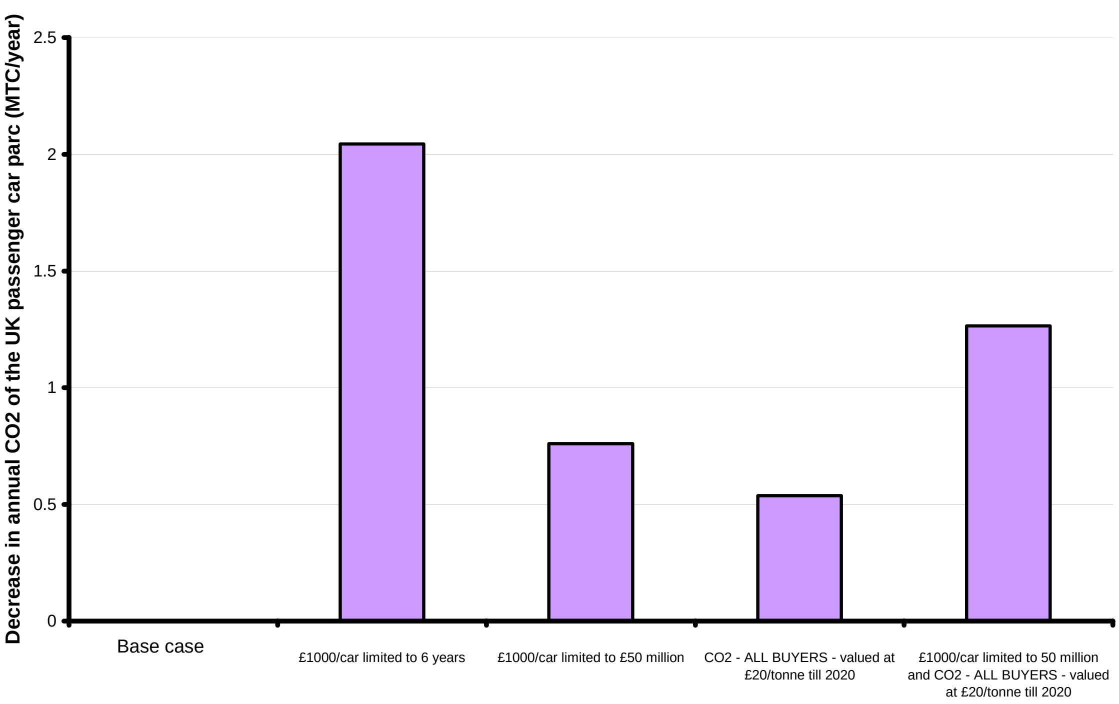
  i. £1000 reduction in purchase price per low carbon vehicle, limited to £25 million
  ii. £1000 reduction in purchase price per low carbon vehicle, limited to £50 million
  iii. £1000 reduction in purchase price per low carbon vehicle for 6 year time period
  iv. £1000 reduction in purchase price per low per low carbon vehicle with no limit to 2020

- Consumer valuation of CO2

  i. All buyers value CO2 at £10 per tonne until 2020
  ii. All buyers value CO2 at £20 per tonne until 2020
  iii. All buyers value CO2 at £70 per tonne until 2020

The graph below shows some examples of the estimated CO2 reduction of passenger cars of various scenarios relative to the base case.

Decrease in annual CO2 emissions of the total vehicle parc relative to the base case - 2020



Further analyses of these scenarios are included in the main body of the report.

2. INTRODUCTION

In recent years, concerns over the rising cost of conventional vehicle fuels and the environmental damage caused by their use has led to an increased interest in developing alternative drive train technologies for lower carbon vehicles. New technologies have included hybridising conventional engines with batteries to improve hydrocarbon fuel efficiency, increasing the portion of bio-derived fuels in the fuel and more exotic solutions such as battery electric and hydrogen fuel cell technologies.

A number of these technologies are now reaching a stage of technological maturity, where they are in a position to begin entry into the new vehicle market. The rate at which the market adopts these new lower carbon vehicles will determine their effectiveness in reducing the overall level of CO_2 emissions from vehicle use in the UK. It is therefore necessary to understand the very complex factors at play in the new vehicle market.

In practice, it is not possible to fully understand all the factors at play in the new vehicle market, as each consumer's decision is influenced by a myriad of different factors. However, looking at the market as a whole, it is possible to make a model of the main factors which are likely to affect the market's response to the new vehicle technologies. Examining the response of the model to different policy scenarios can provide insight to the future market viability of lower carbon vehicle technologies.

In December 2005, Element Energy and Ricardo were contracted by the Energy Saving Trust to develop a model to study the transition of the vehicle market towards low carbon vehicles. The consumers in markets for four distinct vehicle types have been simulated: passenger cars, buses, trucks and vans. This report, looks into the passenger car market in detail[5].

This report describes the modelling methodology used in the project, illustrates the calibration of the consumer models and presents a few example projections of the sales of different vehicle types to 2020 for each consumer segment under different assumptions about the policy environment within which consumers consider new vehicle purchases. All market models have some limitations, given difficulties presented with attempting to mathematically represent real and complex markets. Therefore the report also describes the main limitations of model assumptions, detailed in section 4.

The report is issued alongside two supporting reports. The first is from Ricardo detailing their methodology in vehicle technology modelling. The second is from GfK, explaining a consumer survey commissioned to support the consumer aspects of this work.

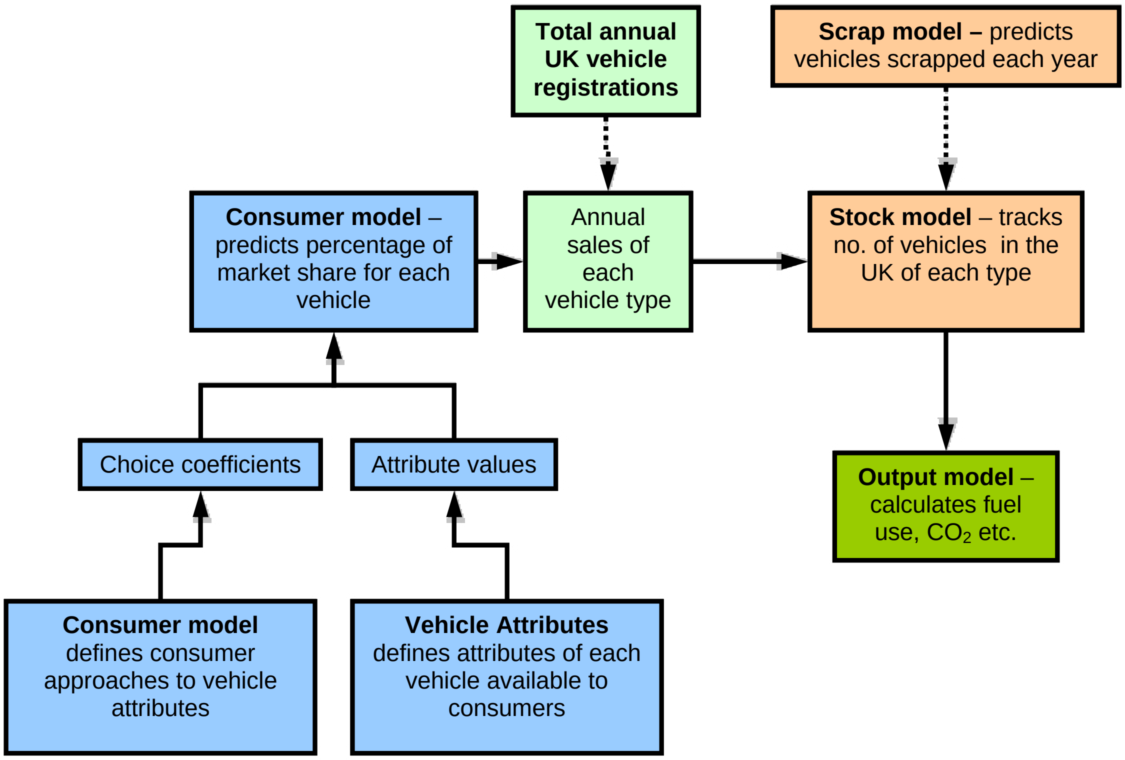
This report supplements the computer models themselves, which have been provided to the Energy Saving Trust for their ongoing work in exploring options for the support of lower carbon vehicles. The models allow the Energy Saving Trust to alter the wide range of assumptions and inputs into the models presented in this study.

[5] Report(s) covering Buses, Trucks and Vans will be published in due course

3. MODELLING METHODOLOGY

3.1. Introduction to the model methodology

The diagram below illustrates the various components of the Market Transformation model and how they relate to each other.



The model begins with an assessment of the likely key vehicle attributes which define consumer response to low carbon vehicle technology (for example, price, fuel efficiency or vehicle range). The past, present and future values of these attributes for each vehicle type are fed into the model from an extensive vehicle attribute dataset produced by Ricardo (values from 1995 to 2020). These attributes are combined with an assumption about how the consumer 'weights' each attribute when considering a new vehicle purchase. The weightings for each attribute are expressed as consumer 'coefficients'.

The combined value of the attributes and their weightings are used in a consumer model to determine the market share for each vehicle technology in any given year. This share is combined with assumptions about the total size of the market to give the total number of vehicles sold per year. The vehicles sold are fed into a model of the vehicle parc in the UK which keeps track of all vehicles on UK roads. The model also requires a model of the scrapping rate of old vehicles to accurately represent the parc. With a model of all vehicles of different ages and technologies in the parc, it is then possible to develop detailed outputs from the parc such as the overall CO_2 emissions and the total fuel consumption each year.

Each component of the model is described in more detail below.

3.2. Vehicle attributes

Numerous studies have considered the main factors which affect consumer attitudes towards new passenger vehicle purchase. In 2004, The Department for Transport commissioned MORI to conduct some market research on new vehicle purchasing decisions, this concluded that the following factors are important, ranked according to responses to the question “What factors were/will be important in deciding what car to buy?”. However, it is important to note that consumer focus has possibly shifted since that time as Government policies have become more focused on addressing environmental impacts, coupled with the increased media coverage environmental concerns now receive.

Most important (10%-30%)	**5%-10%**	**Least important (<5%)**
Price MPG/Fuel consumption Size/Practicality Reliability Comfort Safety Running costs Style/Appearance	Performance/Power Image/Style Brand name Insurance costs Engine size Equipment levels	Depreciation Personal experience Sales Package Dealership Environment Vehicle Emissions Road tax Recommendation Alternative fuel

Figure 2, factors affecting consumer purchase[6]

The list of factors affecting consumer behaviour is varied. Not all of the above factors are directly relevant in distinguishing between low carbon vehicle technologies. For example, it is reasonable to assume that the ‘Style/appearance’ category is to some extent independent of the low carbon vehicle technology option.

Based on the various qualitative consumer studies which have occurred in the UK[7], the various US modelling exercises discussed below, discussions with the Low Carbon Vehicle Partnership and discussions with Ricardo, the attributes which were selected for the passenger car aspects of the study are tabulated below:

[6] Department for Transport, (March 2004) *Assessing the Impact of Graduated Vehicle Excise Duty - Quantitative Report*.
[7] For a good summary, see EcoLane consulting (March 2005) *Consumer attitudes to low carbon and fuel-efficient passenger cars* Low Carbon Vehicle Partnership

Passenger Car

ATTRIBUTE	Comprising:	Scoring type
Capital Cost		Objective numeric (£)
Running cost	Depreciation	Objective numeric
	Insurance	
	Service & maintenance	
	Vehicle Excise Duty	
	Cost of fuel (1 yr, 16,000 km)	
Driveability	Acceleration time	Subjective numeric
	Speed threshold based	
	Smoothness (torque curve/gear shift)	
	Refinement (NVH & Ride/handling)	
	Driver task loading	
Availability	…to purchase	Objective numeric (%)
	…of supporting infrastructure	
Vehicle functionality	Load capacity	Subjective numeric
	Reliability	
	Range (distance on full tank)	
	Perceived safety	
	No. of passengers	
[CO2 emissions] included to enable the Market transformation model to consider policy scenarios including CO_2		Objective numeric based on predicted fuel economy (g/km)

Figure 3, consumer choice attributes used in the passenger car Market Transformation model

The markets for the other three vehicle types (buses, trucks and vans) have historically been less well studied than the passenger car market. However, it is clear that fewer factors are at play from decision makers in these markets as the vehicles are purchased for business reasons. The decision on which vehicle to procure tends to rest on factors affecting business operation – capital cost, running cost etc. As a result it is easier to categorise the attributes affecting vehicle choice. The following criteria are used to define vehicle choices in each of the markets (these choice attributes were defined as most appropriate in consultation with the Low Carbon vehicle Partnership and through individual discussions with a range of suppliers).

3.3. Technologies considered

Discussions with Ricardo, Energy Saving Trust and the Low Carbon Vehicle Partnership sub-groups led to a selection of vehicle technologies to be modelled in each vehicle market. The number of technologies to be modelled was limited by the resources available for the project and because that it is important to keep each choice discrete to avoid presenting the consumer choice model with over-similar choices which will distort the results (see below).

Passenger car – technologies considered
Gasoline
Diesel
Stop-start hybrid
Gasoline hybrid
Diesel hybrid
LPG
Smaller vehicle – representing a half class downsizing
Vehicle using B20 bio-diesel
Battery Electric
Hydrogen fuel cell
Vehicle using E85 bio-ethanol
Advanced gasoline engine

Figure 4, vehicle technologies considered in the model for cars

3.4. Technology Projections

For each of these technologies, Ricardo have developed projections in the likely variations of the key vehicle attributes over time. A detailed explanation of the modelling procedure is provided in the accompanying report from Ricardo. Here a simple overview is provided.

In order to successfully model the trends in each vehicle technology, it is necessary to make various simplifications about the vehicles on offer. It is not practical to attempt to model all sizes and classes of vehicles on the market. Instead Ricardo adopts a methodology which was used to develop the Carbon to Hydrogen roadmap for the Department for Transport. The changes in vehicle technologies over time are modelled in terms of the changes they would make to a baseline vehicle considered typical of the market. In the case of the passenger car market, for example, a baseline vehicle is defined which is an aggregation of the attributes of the five best selling vehicles in the UK. The resulting vehicle is a C/D class vehicle, which provides a median representation of all the vehicle types sold in the UK.

	A	B	C	D	E	F	G	SUV	MPV
Name	Mini / Basic	Supermini / Small	Lower Medium	Upper Medium	Executive	Luxury Saloon	Specialist Sports	SUV / 4x4	MPV
									
Example Models	Chevrolet Matiz Vauxhall Agila	Vauxhall Corsa Ford Fiesta	Ford Focus Renault Megane	Ford Mondeo BMW 3-Series	Mercedes E-Class Volvo V70	Jaguar XJ Mercedes SL	Mazda MX5 Audi TT	Land Rover Freelander Toyota RAV4	Vauxhall Zafira VW Touran
Sales 2004	36,171	839,604	1,188,751		109,667	13,620	73,940	179,439	126,077
Market Share	**1.4%**	**32.7%**	**46.3%**		**4.3%**	**0.5%**	**2.9%**	**7%**	**4.9%**

Figure 5, illustration of the vehicle segments used as the baseline vehicle in the Ricardo modelling methodology

This method of defining a baseline vehicle followed by projecting the impact of technology changes on the various attributes is a very useful simplification, allowing a sensible projection of technical performance across a wide range of different technologies. The technique does suffer from the disadvantage that by aggregating vehicles from all classes (i.e. of different sizes) into a single baseline vehicle, some of the granularity with respect to vehicle size in the vehicle market and accuracy of projected future CO_2 impacts is lost. The result is that the overall Market transformation model provides a very good representation of the effect of different vehicle technologies on the market, but struggles to represent the effect of down-sizing (or up-sizing) of the overall vehicle mix. These limitations are explored in more detail in section 4.

3.5. Modelling consumer behaviour – discrete choice modelling

In order to understand the market for low carbon vehicles out to 2020, a consumer focused approach is required, where the market pull/demand for the technology is quantified. A number of techniques exist to simulate the consumer demand for vehicles, ranging from the very simple (single elasticity models) to the highly complex[8].

The modelling approach used in this study is from a group known as discrete choice models. This is the most widely used approach in the literature (particularly in the US). With these models, the buyer is provided with a finite set of vehicle choices, which differ in their attributes. It is then assumed that each consumer makes an assessment of the various attributes of the vehicles, to define an overall score (or utility) for each vehicle. The consumer chooses the vehicle with the maximum utility.

If we had perfect knowledge of each consumer, we could obtain an accurate model for each consumer's utility score for each vehicle and so be certain of their vehicle choice. Unfortunately in a large population of car buyers, our knowledge of each consumer and how they assign their own utility is subject to a considerable error.

By assuming that the error in our understanding of the utility has a probabilistic distribution, we can begin to assign a probability to a given consumer making one of the discrete choices in front of them. Assuming that the error term is normally distributed gives rise to the 'probit' model for discrete choice models. This model whilst mathematically pure is computationally problematic. Instead, here we make use of the Logit model, which is derived using a simplification to the normal distribution of the error term (Gumbel rather than Normal distributed)[9]. The logit model allows a projection of the probability of a given consumer choosing a particular vehicle given a set of assumptions about the way in which the population considers alternative attributes.

The model is based on assigning consumer behaviour coefficients to each vehicle attribute. Each coefficient relates to the relative importance of each attribute. A large coefficient implies that the consumer is more sensitive to the value of the attribute. A positive coefficient means that an increase in the value of the attribute results in increased utility or perceived level of attractiveness (e.g. acceleration) while a negative coefficient implies the opposite e.g. for capital cost). This is covered in more mathematical detail below.

The use of Logit modelling for projections of the behaviour of new vehicle markets is not new. Numerous researchers have made use of the logit methodology to predict market shares, particularly in the US. There is a significant body of work by David Green at the Oak Ridge National Laboratory, which is used in the US National Transitional Alternative Fuels and Vehicles

---

[8] A useful review of vehicle market models is - de Jong, G., Fox, J., Pieters, M., Daly, A.J., Smith, R. (2004) *A comparison of car ownership models* Transport Reviews 24, pp.379-408 (published by Taylor & Francis Ltd.)

[9] For details of the mathematics of discrete choice modelling refer to http://roso.epfl.ch/mbi/papers/discretechoice/paper.html or M. E. Ben-Akiva and S. R. Lerman (1985) *Discrete Choice Analysis: Theory and Application to Travel Demand*. MIT Press, Cambridge, Ma.,

(TAFV) model operated by the US Department of Energy[10]. These models use multinomial logit structure, with some nesting of coefficients to reflect the (assumed) structure of the decision making process. Greene uses the "Deductive Estimation" process for assigning values to coefficients (see section below on estimating consumer choice coefficients) as well as a limited amount of survey data. Recent work at the Argonne National Laboratory[11] is an attempt to improve upon Greene's work. A Logit structure is still used, but they have implemented market segmentation, with mass market and early adopter consumer groups.

3.6. Mathematics of the Logit model used in the market transformation model

Probability of a discrete choice

The Multinomial Logit model estimates the probability of a given choice, from a finite set of discrete choices.

The model states that the probability of a given choice (i) from a discrete set of choices S is a function of the 'Utility' for that choice Ui and the utilities for all other choices. The function is:

$$\text{Probability of vehicle choice i} = p_i = \frac{e^{U_i}}{\sum_{i=1}^{i=S} e^{U_i}}$$

i.e. the exponent of the utility of i divided by the sum of the exponents for all utilities in the set.

Definition of vehicle Utility

As discussed above, we model the utility of a vehicle choice (i) as a function of each of the vehicles <u>attributes</u>, and the <u>consumer coefficients</u>.

We adopt a linear model for the relationship between attributes and coefficients. The overall utility of a given vehicle choice is therefore a weighted sum of the attributes of a given vehicle, multiplied by the consumer coefficient for that vehicle. In an example where there are a number of vehicle choices, from 1 to i, and a number of attributes from 1 to T, the utility is:

$$\text{Utility of vehicle choice i (from the set S)} = u_i = \sum_{j=1}^{j=T} A_{ij} B_j$$

- Aij is the jth Attribute for the ith vehicle type (e.g. top speed for a hybrid)
- Bj is the consumer coefficient (weighting) for the jth Attribute (e.g. consumer weighting for the top speed). T is the total number of attributes in the model.

This simple functional form for utility is used by numerous vehicle choice models in the US (in particular the National Energy Modelling System – Alternative Fuel Vehicle Choice model). The apparent simplicity can be increased if required by defining each attribute as a function of a 'real'

---

[10] Greene (2001) *TAFV Alternative Fuels and Vehicle Choice model documentation* - Oak Ridge National laboratory ORNL 2001/134

[11] Santini and Vyas (2005) *Suggestions for a New vehicle Choice Model simulating Advanced vehicle Introduction decisions (AVID): Structure and Coefficients* – Argonne National Laboratory

attribute. e.g. the attribute vehicle speed could be expressed as the square root of vehicle speed (in the US this has not been necessary).

Combining the two previous equations, we obtain a projection for the market share of a given vehicle (i).

$$\text{Probability of choosing vehicle i} = p_i = \frac{e^{\sum_{j=1}^{j=T} A_{ij}B_j}}{\sum_{i=1}^{i=S} e^{\sum_{j=1}^{j=T} A_{ij}B_j}}$$

Having established the probability of any consumer choosing a given vehicle technology, it is possible to project the total yearly sales. The yearly sales of a given vehicle type (i) is a multiple of the probability of choosing vehicle (i) and the total sales of all vehicles in a given year.

This is the form of the Multinomial Logit model that is implemented here.

3.7. Nested Multinomial Logit models

In a discrete choice model, it is often the case that some of the choices are more closely related than others. In the low carbon vehicles sector, an example may be that the factors affecting choice between a diesel hybrid and a diesel vehicle are distinct from those between a diesel vehicle and an electric vehicle. In technical terms, the cross elasticities between the different choices are not always identical.

The simple form of the Multinomial Logit model treats each choice with the same weight (i.e. equal cross elasticities) and as a result does not necessarily correctly distinguish the subtleties between the different choices. This is known as the Independence of irrelevant Alternatives problem for simple Multinomial Logit models.

A number of studies using Multinomial Logit modelling to represent new vehicle markets add an extra layer of detail to the Multinomial Logit modelling procedure to overcome this problem. These models use a ‘nesting’ procedure to allow a distinct consideration of the factors affecting choice in particular nests. An example of the nesting structure used by the TAFV model in the US is illustrated below.

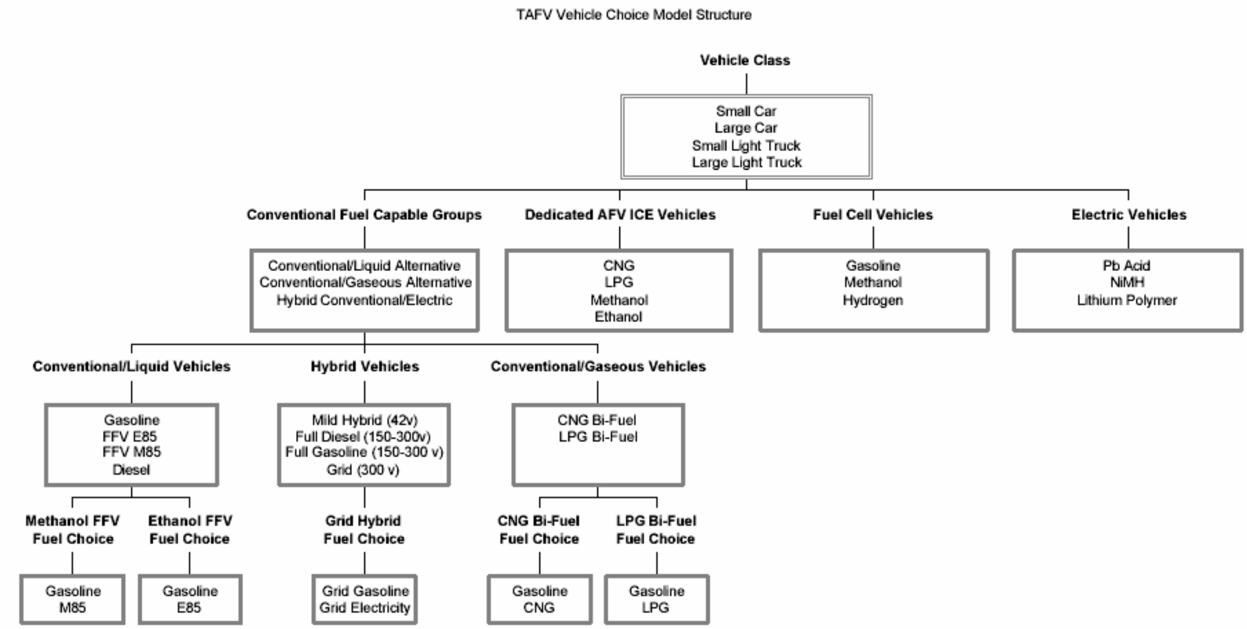


Figure 6, nesting structure in the US TAFV model[12]

Here, similar vehicles are nested together into smaller sets. The choice of vehicles within a given set is evaluated with set specific coefficients, before the overall choice between sets is made. In this way similar choices are treated separately from overall choice.

In order to implement a nested model of the UK vehicle parc, it is necessary to understand the factors affecting the choices within sets and also between sets. In practice, the level of data available characterising the UK market is insufficient to obtain any accuracy with which to estimate the correct coefficients within and between different technology sets. In fact (as discussed below) the lack of quantitative data makes the estimation of coefficients for even a simple Multinomial Logit model very challenging.

As a result, this model does not incorporate a nested structure. The risk of introducing choices which are too similar to each other is mitigated by ensuring that the technology attributes fed into the model represent a 'distinct technology choice' to the new vehicle consumer in the showroom or dealership. However, there are two points of note here:

1. A future development of this study would be to develop a nested model structure. This would require substantial survey work to quantify the various cross elasticities in the market between similar technology sets (e.g. hybrid technologies or gasoline fuelled vehicles).
2. Care is required in interpreting the results and when inputting new vehicle types into the model. The model will tend to over-predict the combined share of two technologies which are very similar.

[12] Greene (2001) *TAFV Alternative Fuels and Vehicle Choice model documentation* - Oak Ridge National laboratory ORNL 2001/134

An academic peer review carried out by Leeds University (see appendix 1 for further details) addresses these limitations of the model in further detail.

3.8. Market structure

The experience of modelling the market in the US with a Multinomial Logit model is that the Logit model provides a reasonable representation of the mass market behaviour but tends to under-predict activity on the fringes, where the market is dominated by consumers with a propensity to experiment with new technology, who obey different rules to the mass market. For example, the TAFV model in the US under-predicted the substantial uptake of hybrid vehicle via the Toyota Prius and other vehicles.

In response to this, the Market Transformation model is divided into a number of groups of consumers, where each group is united by a similar attitude to the market.

3.8.1.Passenger cars market structure

In the passenger car model, we use six different consumer groups. Firstly, the market is divided into PRIVATE (47% of all sales) and FLEET (53% of all sales) markets, to reflect the different nature of the car buying behaviour amongst decision makers authorising purchase for fleet vehicles (typically based on a spreadsheet type analysis, with short discount periods etc.) and for the general public new vehicle purchases.

Each of these markets are then sub divided. The PRIVATE sector is subdivided based on the sub-division noted by EcoLane (2005) in their recent report to the Low Carbon Vehicle Partnership[13]. We consider three groups – the EARLY ADOPTERS, representing 2.5% of the market, who have a propensity for new vehicle technology, a tendency to value environmental issues and a high sensitivity to ongoing costs, particularly the cost of fuel. The EARLY BUYERS representing 12.5% of the market are more conservative, but retain some properties of the early adopters, particularly sensitivity to fuel cost. The remainder of the market (85%) is represented by the MASS market group. It is worth noting that there is some uncertainty in the application of these market splits, although some studies have been done in this area. Further evidence to support these market splits would be beneficial, and as such this is addressed as a model limitation in section 4.

The FLEET market is divided according to discussions with companies providing fleet solutions. The market is split into:

WORKHORSE (61%) – vehicles given to an employee primarily used in fulfilling the needs of their job (company car tax paid) -
PERKS (25%) – vehicles given to employees as a perk from their job – limited use for fulfilling the requirements of the job (company car tax paid)
DEPOT (14%) – vehicles based at a depot, exclusively used for work related activities (no company car tax paid)

Each of these six consumer groups has their own set of consumer coefficients to reflect their different buying habits. In addition, the capital cost attribute for fleet consumers is reduced by 10% to reflect the bulk buying advantages of fleet buyers.

[13] EcoLane consulting (March 2005) *Consumer attitudes to low carbon and fuel-efficient passenger cars* Low Carbon Vehicle Partnership

3.9. Calibrating consumer coefficients

The limited historic uptake of low carbon vehicles means there is a very limited dataset on which to base assumptions about the behaviour of the UK market with respect to low carbon vehicles. Because the level of quantitative data on the behaviour of the UK new low carbon vehicle markets is poor, we adopt a four pronged approach to obtaining coefficients which provide a representation of the market. Four different methodologies are used to eventually arrive at a set of coefficients which are consistent with each of the methodologies. The methodologies are described in turn below, calibration data is presented in section 4.

A) Deductive estimation from basic economic assumptions – an 'engineering' approach

One of the attributes within the model is the vehicle's price P in pounds. Let us represent the coefficient associated with this attribute as Bp.

The advantage of the simple linear form for projecting utility above is that it can be easily differentiated to calculate the elasticity of the market with respect to a given parameter. In this case, we differentiate with respect to price.

$$\frac{(ds_i / s_i)}{(dP_i / P_i)} = \frac{\text{% change in share}}{\text{% change in price}} = \frac{ds_i}{dP_i} \times \frac{P_i}{s_i} = \textbf{Price elasticity of i wrt price} = E_{iP}$$

where **P** is price, **S** is market share, **E** is elasticity, and **B** is the price coefficient in the model.

If we know the price elasticity of the vehicle share for any vehicle type, we can solve the price coefficient Bp, by solving the above equation. This gives:

$$B_p = \frac{E_{iP}}{P_i(1-s_i)}$$

In other words, we can express the price coefficient, if we know the elasticity of the market with respect to price for a given technology choice, at a known price and market share.

The price coefficient is an important number, as it provides a figure for the present value of £1 within the model.

If we can convert the values of other attributes into present value, these can be converted into a utility using the price coefficient. In this way, it is possible to make deductive or 'engineering' estimates of the value of all consumer coefficients. For example, the yearly cost of vehicle maintenance can be converted into Net Present Value (NPV) by using a discount rate and a discount period to define an annuity factor.

NPV of maintenance = Annuity factor x Yearly cost of maintenance

This can be converted into a utility using the price coefficient B_p.

$$\text{Utility for maintenance} = \frac{\text{NPV of maintenance}}{B_p} = \frac{\text{Annuity factor}}{B_p} \times \text{Yearly maintenance}$$

Therefore the coefficient for maintenance is:

$$B_{maintenance} = \frac{\text{Annuity factor for maintenance}}{B_p}$$

This deductive approach for estimation of coefficients is highly useful in an area where there is limited quantitative consumer data. The approach is used extensively in the US logit models, but in all cases, a calibration stage follows to check that the process is providing useful numbers.

B) Comparison with other published data
There is some published data on the assumptions underlying the value of coefficients used in other models. Care needs to be taken with interpretation as the meaning of the assumptions can change depending on the implementation of the model.

There is little quantitative data available on UK consumer choice modelling. Most published data is US based and therefore is likely to have been calibrated to the US market.

The main value of other studies in calibrating the consumer models is as a sense check for the scale of the coefficients and associated assumptions used in the model.

C) Calibration with historical data vs. historical modelling
By comparing model predictions and historic market data, the coefficients can be varied and correlation improved. For the mass market, there is substantial historical data available on historic behaviour. In the passenger car market, for example, the sales of gasoline versus diesel vehicles have been well documented over a long period. By modelling the historic behaviour of the market (in this case from 1995), using observed vehicle attributes from 1995-2005, it is possible to check the performance of the model against historic sales data. If the model accurately predicts the behaviour of the market then this gives reasonable confidence that the coefficient used are providing a good representation of the consumers in each market.

D) Use of Survey data
Many Discrete Choice models infer coefficient estimates by applying statistical techniques to revealed preference surveys. There is very little quantitative consumer survey data available for the UK market. As a result, the Energy Saving Trust commissioned a simultaneous piece of work to support this modelling effort, from automotive survey expert GfK. The work used an on-line survey with conjoint analysis to obtain quantitative values for the consumer valuations of the various metrics.

The survey aimed to identify the consumer coefficients for the various attributes in the 'early adopter' and 'mass market' groups, as defined by a series of pre-screening questions based on the definitions of early Adopter group described by Ben Lane (2005).

The survey results are used to cross check the consumer coefficients defined above against those observed in the UK new car buyer survey, as described in section 5.

3.10. Yearly sales

In order to project the yearly sales of a given vehicle technology, it is necessary to project the total yearly sales of all vehicles in the UK. This is a complicated area, affected by the state of the economy, the average price of new vehicles, taxation and other macro-economic effects. This model does not set out to explore the macro-economic effects which drive overall vehicle sales. Instead, the model includes a capacity to input the total number of vehicle sales into the model exogenously. In this way, the model can in future be linked with other macro-economic models of vehicle purchase etc.

For the purpose of the analysis presented here, the yearly sales to 2020 are defined by simple assumptions about the rate of increase of the overall new vehicle market. For the passenger car market, vehicle sales are assumed to be constant at 2005 levels to 2020. A constant level is assumed as market predictions on future total vehicle sales vary and the importance of the results here is less the real numbers of vehicles sold, but the relative performance of one technology against another. Notwithstanding the above, this assumption is likely to lead to an underestimation of new registrations and new vehicle sales are generally expected to increase with positive GDP growth. This is an easily changeable parameter in the model, so should significant growth or decline become apparent, this can be reflected in future.

3.11. Parc, Scrap and fuel consumption model

The model keeps track of the number of vehicles in circulation in the UK. The vehicles are tracked by:

- Vintage – distinguished for each year from 1995 and including a bin for all vehicles in circulation before 1995
- Vehicle technology – so that the number of vehicles of a given age and a given technology is continuously tracked.

For any given year, the model includes a complete matrix of the number of vehicles of different technologies and vintages.

In order to provide a representation of the vehicle parc, it is necessary to consider both the rate of new vehicle purchase (and hence addition to the parc) and the rate of removal from the parc. The principal mechanism for removal from the parc is vehicle scrappage. A simple scrapping model has been devised which scraps a fraction of the vehicles of any given vintage according to their vintage. The scrapping rate for vehicles with a limited age is negligible, rising to higher rates for the older vehicles. The scrapping rates are tuned to allow the parc to reflect the age profile in 2005 and based on literature profiles for scrapping rates. A simplifying assumption is made that the rate at which vehicles are scrapped is independent of vehicle technology.

The graphs below illustrate the scrapping profile for different vintage vehicles in each of the different markets.

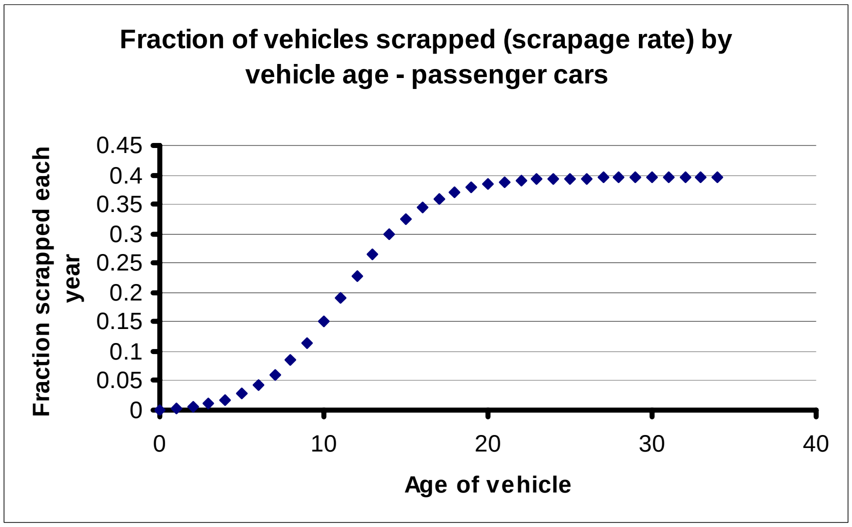


Figure 7, Scrapping profiles for vehicles of different ages. The scrapping rate is the fraction of vehicles of a given age scrapped each year.

A simple model is used to project the reduction in distance travelled per year with the vintage of the vehicle. Previous studies[14] have shown that older passenger cars tend to be driven less. The model assumes a decrease in the miles driven per year for different vehicle ages in the passenger car segment. For the non-car markets, there is less variation in mileage with age, vehicles tend to be bought for a given purpose and used for that purpose until the end of their useful life. Assumptions for the passenger car segment are given below, based on a linear interpretation of a study by Hickman (1999)[15].

Market	Annual km per year (average for first year)	Yearly rate of decrease
Passenger car	21,500	7%

.

Fuel consumption is calculated by multiplying the distance travelled for a given vehicle vintage by the vehicle efficiency for that vintage and technology. This can then be multiplied by the number of vehicles of that vintage and technology to get a fuel consumption. Fuel consumption is converted to parc CO_2 using the CO_2 assumptions discussed below.

3.12. Fuel costs

The table below illustrates the fuel cost assumptions used unless otherwise varied in the analysis of the various policy scenarios. Fuel costs are based on AA figures for fuel price as of January 2006. Due to the significant uncertainties surrounding projections of future oil prices, the base case of the model assumes that the cost of fuels will remain fixed at these levels until 2020. The possibility of fuel price rises is modelled as a policy scenario in subsequent analysis.

		Price (£/unit)	
	Units	**2006**	**2020**
Gasoline	Litres	0.88	0.88
Diesel	Litres	0.92	0.92
Biogas	MJ	0.03	0.03
Electricity	MJ	0.02	0.02
Hydrogen	kg	8.00	3.00
Biodiesel blend B+20	Litres	0.99	0.99
PURE Bio-diesel	Litres	1.27	1.27
CNG	MJ	0.02	0.02
LPG	Litres	0.45	0.45

3.13. CO_2 emissions from each fuel

The CO_2 emissions figures for each fuel are based on Well to Tank figures from a range of sources[16]. The figures vary through time in particular for diesel and gasoline fuels as the effect of the Renewables Transport Fuel Obligation (RTFO) comes into force between 2008 and 2010. The RTFO introduces a 5% bio-fuel component in the diesel and gasoline CO_2 emission figures.

[14] JRC IPTS (2003) "Dynamics of the introduction of new passenger car technologies"
[15] Hickman, A. J., (1999) "Methodology for calculating transport emissions and energy consumption".
[16] Specifically – DEFRA CO_2 calculation methodologies http://www.defra.gov.uk/Environment/business/envrp/gas/index.htm and the CONCAWE report – "Well to Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context" – CONCAWE 2004

Fuel		2006	2020
Gasoline	g/litres gasoline	2750	2687
Diesel	g/litres diesel	2987	2929
Biogas	g/MJ	0	0
Electricity	g/MJ	119	119
Hydrogen	g/kg	8143	8143
Biodiesel ble	g/litre	2678	2632
PURE Bio-di	g/litres bio-diesel	1444	1444
CNG	g/MJ	53	53
LPG	g/litre	1824	1824

Figure 8, CO_2 emission assumptions for various fuels in the model

3.14. Tax

We have taken into account both VED and Company Car tax rates as of October 2006[17] in the model. Company Car tax is applied to the PERKS and WORKHORSE segments of the three fleet groups. The DEPOT group is excluded as vehicles returning to depots don't pay company car tax.

3.15. Feedbacks

In order to accurately represent the behaviour of any market, it is important to consider the dynamics of the market's behaviour. In most markets there are feedbacks between the behaviour of the market in one year and the inputs to the market the next year. Perhaps the most obvious example of this is the relationship between the sales and capital cost of vehicles.

At the peer review session held for the model, three types of feedback were identified:

1. Cost-volume feedbacks – where **increased sales volume causes learning** within the manufacturing sector, reducing unit cost. This 'learning effect' is well documented through manufacturing of almost all consumer products.

2. Market inertia –consumers take time to respond to a new product due to a lack of knowledge about the new product. Learning can only be increased through increased circulation of the product in the market. For cars this refers to the **number of vehicles in the parc**.

3. Manufacturer behaviour – manufacturers (especially in the passenger car sector) will not continue to offer vehicles if they are unable to make sales. This causes a **relationship between sales and the availability of different models (make/model diversity).**

Each of the above feedbacks represent an 'inertial' effect on the market in that they act to slow the penetration of early technologies into the market.

Conversations with Ricardo and the Low Carbon Vehicle Partnership industrial members reveal that there is a **<u>significant uncertainty</u>** about the feedbacks which exist in the UK market. In particular there is uncertainty over the relative strength of each feedback. This might suggest that the feedbacks above should be left out of the modelling and instead various exogenous assumptions made about the likely behaviour of the market with respect to the feedbacks (for example, the price of hybrid vehicles could be assumed to fall at a rate based on an 'assumed' take-up of vehicles). However, if exogenous assumptions are used to define the various effects above, the assumptions define the model output and the dynamics of the market are lost.

[17] These will be updated during 2007/08

It was decided that it is preferable to include the various market feedbacks in the model and to attempt to quantify them rather than leaving the model to exogenous assumptions. The model has been built in such a way that it is possible to switch to using exogenous assumptions about the market behaviour if required.

The table below summarises the feedbacks used in the passenger car market and the following sections describe the justification for the size and importance of each feedback for passenger cars.

Market	
Passenger car	Cost volume relationships, market inertia, manufacturer vehicle availability feedback (i.e. no. of vehicles offered to the market)

3.15.1. Cost volume relationship

Passenger car

The typical learning rate within the automotive sector for new technologies is 95%. The learning effect is applied to the additional cost of each technology above the C/D baseline vehicle. The graph below shows the effect of learning on various technologies, the graph illustrates the model assumptions about the decrease in the on-cost for the new vehicle technologies relative to the baseline C/D vehicle as the number of vehicles in the UK parc increases.

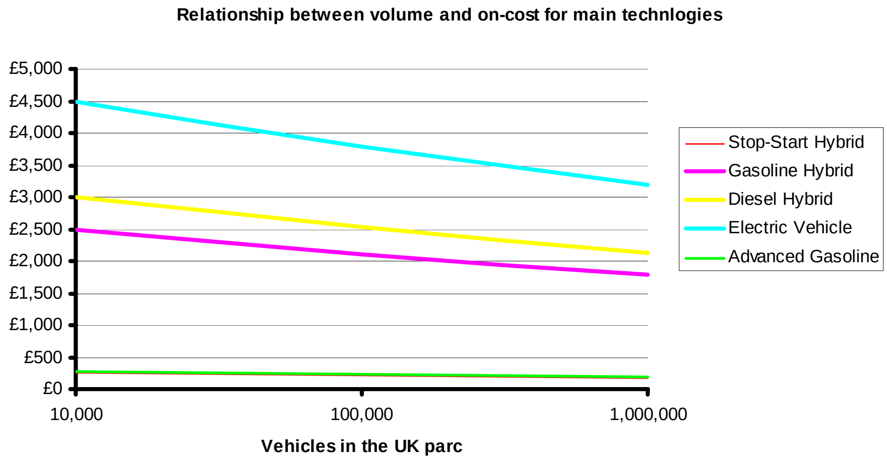


Figure 9, Cost-volume effect for passenger cars, illustrates the additional costs decreasing as the number of units in the UK parc increase

3.15.2. Market inertia

Market inertia is based on a lack of knowledge/experience with the new product in the market. The lack of knowledge prevents take-up as consumers are not in a position to make a vehicle purchase and the lack of experience means that consumers will be concerned over the reliability and maintainability of a new vehicle purchase.

Passenger cars

It is assumed consumers apply a penalty to each new technology until a given penetration into the parc is reached. In this case we use 625,000 vehicles, as this represents 2.5% of the fleet (as per early adopter fraction).

The relative importance of market inertia is then estimated using historical figures for the sale of LPG and hybrid vehicles. The relative importance of market inertia for the different consumer groups is very pronounced. The Early Adopters by their nature are prepared to consider new vehicle technologies and so are only very slightly affected by inertial effects, the Early Buyers and the Mass market place a significantly higher weight on inertial issues. This is one of the key differentiators of the Early Adopters and leads to their behaviour being very important in the adoption of the model.

The Utility penalty for market inertia is represented as a logarithmic function:

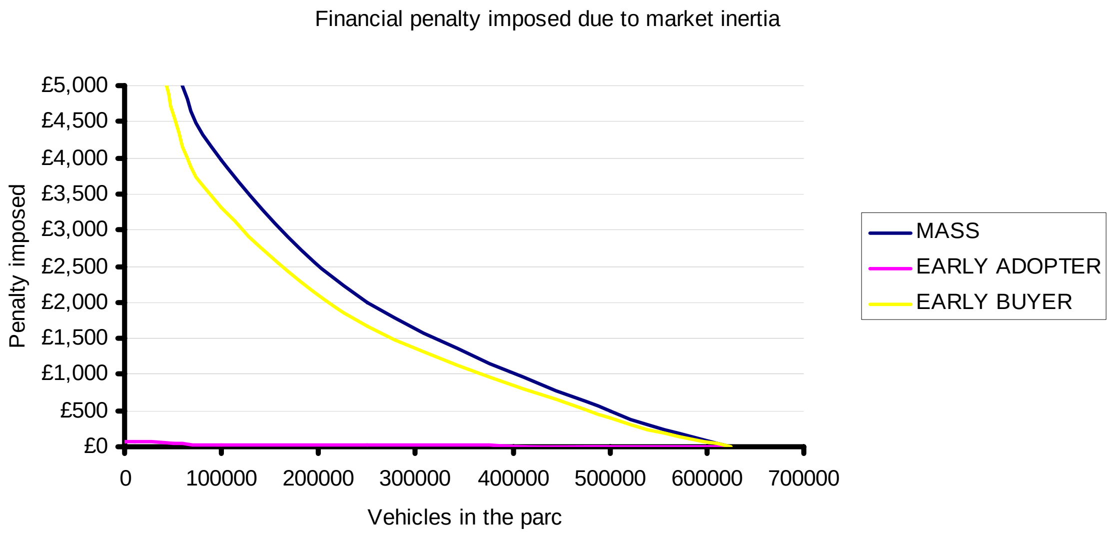
IF $(\text{vehicle in the parc})_{t-1} > 625{,}000$ $(\text{Utility for inertia})_t = 0$

IF $(\text{vehicle in the parc})_{t-1} < 5000$ $(\text{Utility for inertia})_t = \text{Inertia coefficient} \times \ln(5{,}000/625{,}000)$

ELSE

$(\text{Utility for inertia})_t = \text{Inertia coefficient} \times \ln((\text{vehicle in the parc})_{t-1}/625{,}000)$

The graph below illustrates the financial penalty assumed for market inertial effects for the different consumer groups. Note that the function is capped so that below 5000 vehicles in the parc, the market inertia factor is a constant. Note, the graph below is simply illustrative, the actual penalties applied in the model itself are less than that described below, with the maximum penalty placed at approximately £2500.

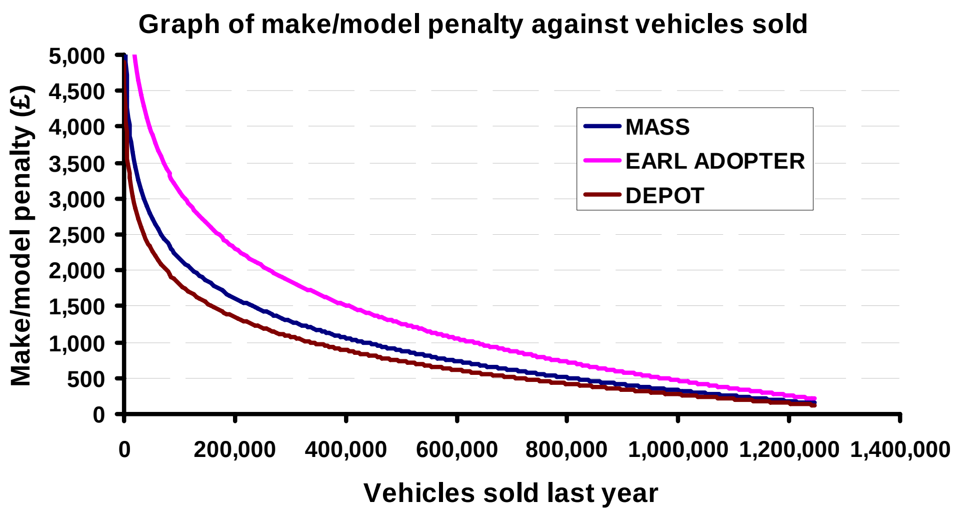


3.15.3. Manufacturer availability feedback

The availability of vehicles is an important parameter in any Multinomial Logit model of new vehicle sales. In Logit theory, the number of vehicle models available with a given drivetrain is a parameter affecting uptake. The reason for this is that it is necessary to include the effect of a given drivetrain only being available for a limited number of brands and models (e.g. the current situation with gasoline hybrids). Because consumers make a selection first of model size then brand before beginning to consider drivetrain (see above), if a vehicle technology is not available in their make/model combination, they will not have access to that technology. As a result, the Logit model needs to be adapted to include a factor to reflect the penalty associated with a mode not being available in all makes and models. The model is adapted using a new attribute called make/model diversity or vehicle availability. The attribute for Make/Model diversity is defined for a given drivetrain as a natural log of the fraction of vehicles available with a given drive train divided by the total number of gasoline vehicles available:

$$\text{Ln} \frac{\text{Number of models available with the drivetrain}}{\text{Total models available supplied with a gasoline ICE drivetrain}}$$

This attribute is included in the logit model with an associated coefficient – the availability coefficient. It is possible to translate the attribute into a financial penalty. The graph below illustrates the effective financial penalty for make/model diversities less than 1.



It is not straightforward to estimate the likely increase in make/model diversity of vehicles over time. The availability of vehicles is subject to the vagaries of decision making on new product offerings within the major auto manufacturers. These vagaries are assumed to be primarily related to the sales success of a given vehicle technology. It is assumed that the number of vehicles offered will increase as the sales increase and this is represented in the model by the following feedback:

It is assumed that manufacturers require 7,500 UK vehicle sales per year to justify each new model (based on peer review discussions). The make model diversity feedback is then calculated as:

$$(\text{Make/model diversity})_t = \frac{(\text{Last years sales})_{t-1}}{7{,}500 \times (\text{number of gasoline models available})}$$

This is then used as the make/model diversity penalty as described above.

4. LIMITATIONS OF THE MODEL

In addition to review through the Low Carbon Vehicle Partnership, the model has been subject to a formal academic peer review undertaken by transport modelling expert Gerard Whelan at the Institute for Transport Studies (ITS), Leeds University. The ITS review has helped inform the limitations section of the report.

The modelling approach described above provides a reasonable basis to approach the simulation of the market for low carbon vehicles to 2020 and to consider various policy scenarios' effect on the market. However, the complexities of the actual vehicle market mean that mathematical representation of it is limited, and therefore market transformation model has a number of significant limitations associated with it.

Prior to exploring these limitations, it is worth noting that the model has been designed to answer specific questions about the relative success or failure of low carbon vehicle technologies in the market. The model is not able to completely describe the whole functioning of the market as capably as other vehicle market models in existence. The 'added value' of the MTM is its ability to examine the performance of low carbon technologies against traditional equivalents in detail as shown in the analyses below.

4.1. Factors incorporated within the model

There are a limited number of factors incorporated within the model in terms of the behaviour of consumers. For example the effect of changes in income and the effect on consumer preference are not directly modelled as a separate attributes in the model.

The model factors this effect by proxy through consumer preferences applied to vehicles with higher or lower purchase and running costs. Different preferences to vehicle price and running costs can be applied across the 6 different consumer types in the model, however long term changes in income and its effect on vehicles chosen within the market cannot be modelled at present. This does limit to some extent the number of scenarios and policies which can be modelled at present.

4.2. Level of Aggregation in the model

At present, the model is based on a C/D segment 'representative' vehicle for each of the vehicle technologies that it includes. The C/D segment represents 46% of the passenger car market in the UK at present. Furthermore, there are 6 consumer segments included within the model across fleet and private purchase, as described in section 3.8.1. This level of aggregation is relatively limited give the level of product differentiation in the UK passenger car market. The effect of this is that the model is able to model large market movements, but less capable of modelling at the extremes. Furthermore it is not able to model consumer up or down sizing from one segment to another.

Variation of consumer preferences across different vehicle segments is important and rapidly evolving. Therefore this limitation needs to be considered within any analysis based on results from the model.

This is one of the most important areas, particularly in terms of the addition of an A/B vehicle segment, and given the importance of this segment in the development of low carbon vehicles, which would benefit from further development.

4.3. Market Classification

For private purchases, the market has been segmented by three consumer groups - 'early adopters', 'early buyers' and 'mass market'[18], with each assigned different consumer choice coefficients. This classification has been applied in order to provide a level of resolution of the purchasing habits of 'innovator' consumers who help to drive market transformation by purchasing new technologies and therefore bringing them into the market in larger numbers. A good example of this has been the group of consumers who have purchased hybrid vehicles in recent years.

This classification is based on a consumer segmentation described by Ben Lane (2005)[19], who based his work on research on the role of consumers in the innovation process by Rogers (1971)[20]. As part of this project a consumer survey was undertaken in order to inform the preferences of these groups, as described in section 3.9. However, there is not a large body of evidence available to support this classification and it is recognised that further work, including sensitivity analysis would be valuable.

4.4. Classification of feedback effects

There is a significant lack of data available on the effect of important feedback effects as described in section 3.15. It is accepted by vehicle manufacturers that these feedbacks do exist, however as a result of the lack of data on consumer preferences, this area is poorly understood at present. More evidence is needed to justify the assumptions made in calibrating the level of feedbacks such as the 'market acceptance' feedback as they can have a large effect on the level of demand generated within the model. This area will be given a high priority within further development work on the model.

4.5. Variation of CO_2 emissions amongst vehicles in the same class

At present, the model does not take account of varying CO2 emissions amongst vehicles within the same class. Empirical evidence shows that these differences can be very significant, for example crossing several graduated VED bands. Using a broad average therefore limits any analysis the model can provide on policies with an objective of reducing carbon emissions.

4.6. Independence of Irrelevant Alternatives

As discussed in Appendix 1, the Logit structure will over-predict the combined market share for two technologies which are over-similar. This problem has been partially mitigated in the model by aggressively only selecting technologies which constitute a clearly 'unique purchase option' for the vehicle consumer. However, it would be preferable to structure the model allowing different choice criteria to apply between similar technology choices to those between very different sets of choices (i.e. to develop a 'nested' model). Unfortunately, the lack of data available on the UK market means any attempt to nest the model would be based on conjecture when estimating the coefficients within nests. A greater level of data about purchasing habits within the UK market and specific survey work on consume behaviour with respect to similar technologies (e.g. gasoline and gasoline hybrid) compared to the behaviour between different technologies (e.g. gasoline and electric vehicles) would be desirable here.

The above described limitations do have a significant effect on model results, and therefore it is important for any analysis based on model results to bear these limitations in mind. However, it is

[18] For fleet purchases, the market has been segmented according the main uses of fleet vehicles

[19] EcoLane consulting, (March 2005). *Consumer attitudes to low carbon and fuel-efficient passenger cars* Low Carbon Vehicle Partnership

[20] Rogers, E. M., (1971). *Communication of innovations. A cross-cultural approach*. London, The Free Press.

also important to note that many of these limitations are prevalent to a greater or lesser degree in all vehicle market models. The main utility of market models is to observe the effects of applied policy mechanisms or scenarios on different market attributes (such as vehicles sales of different vehicle technologies) on a like-for-like basis.

The added value of the MTM is its focus on low carbon technologies and its ability to explore the market in determining their future success or failure compared to traditional equivalents.

5. MODEL CALIBRATION

5.1. Passenger car market calibration

As discussed above, there are four approaches to arriving at a set of consumer coefficients for any given market.

1. A deductive approach, based on estimating a net present value for the coefficient
2. A comparison with other models
3. Running the model with historic data to check against past sales figures
4. A consumer survey

These four approaches are used to produce a set of coefficients for the various consumer groups in the passenger car market model. The values of the assumptions underlying the consumer coefficients are tabulated below.

	MASS market	EARLY ADOPTER	EARLY BUYER	
Overall price elasticity - diesel vs. gasoline	-1	-0.7	-0.9	Reflects the percentage change in the market share of petrol for a 1% change in the price - Higher numbers mean the market is more sensitive to price
Consumer's discount rate	14%	4%	10%	Used for calculating NPV's of yearly costs
Discount periods	5	12	5.5	Used for calculating NPV's of yearly costs
Kilometers driven per year	16000	23000	20000	Varying km per year is a major distinguishing factor between groups
Drivability	£1,250	£1,500	£1,500	The Net Present Value of 1 unit of Drivability, as defined by Ricardo - varies between 3 and 6 for practical vehicles
Functionality	£500	£500	£500	The Net Present Value of 1 unit of Availability, as defined by Ricardo - varies between 3 and 6 for practical vehicles
Importance of availability	0.37	0.37	0.37	A factor reflecting the importance of vehicle availability, varies between 0 (not important) and 1 very important for each consumer group
Fuel availability	£2,222	£1,111	£2,222	Net present cost of only 10% fuel availability
Value of 1 gCO_2/km	0	0	0	Reflects importance of CO_2
Inertia coefficient	1	0.005	0.75	Reflects early adopters capacity to experiment

	WORKHORSE	PERKS	DEPOT	
Overall price elasticity - diesel vs. gasoline	-1.2	-0.7	-1.2	Reflects the percentage change in the market share of petrol for a 1% change in the price - Higher numbers mean the market is more sensitive to price
Consumer's discount rate	5%	5%	5%	Used for calculating NPV's of yearly costs
Discount periods	3.5	3.5	3.5	Used for calculating NPV's of yearly costs
Kilometers driven per year	32000	16000	32000	Varying km per year is a major distinguishing factor between groups
Drivability	£1,250	£2,000	£1,250	The Net Present Value of 1 unit of Drivability, as defined by Ricardo - varies between 3 and 6 for practical vehicles
Functionality	£1,250	£1,000	£1,500	The Net Present Value of 1 unit of Availability, as defined by Ricardo - varies between 3 and 6 for practical vehicles
Importance of availability	0.37	0.37	0.37	A factor reflecting the importance of vehicle availability, varies between 0 (not important) and 1 very important for each consumer group
Fuel availability	£2,222	£2,222	£0	Net resent cost of 10% fuel availability
Value of 1 gCO2/km	0	0	0	Reflects importance of CO2
Inertia coefficient	1	1	0.7	Includes capacity for depot based consumers to innovate

Figure 10, coefficient assumptions for the six consumer groups in the passenger car model

These model inputs can then be compared against historic data and the consumer survey results for calibration purposes. For future proofing, these inputs are variable parameters within the model itself.

5.1.1.Historic data

The graph below shows the historic sales figures for diesel and gasoline registrations in the UK. In addition, the graph also shows the split of diesel vehicles sold to private and fleet markets. The split between private and fleet diesel sales diverges from 2001, when the changes to company car tax are introduced. The changes explicitly value CO_2 emissions in the rate of company car tax paid. This forces more fleet consumers to buy diesel vehicles.

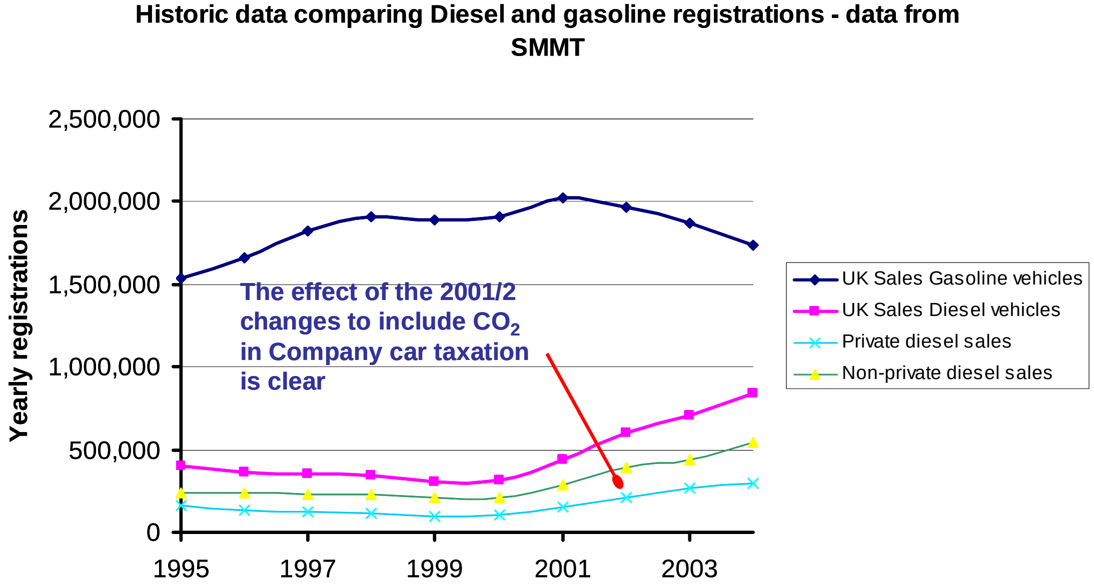


Figure 11, historic data (from SMMT) on the sales of diesel and gasoline markets in the UK, including a sub-division of the sales of diesel vs. gasoline cars.

The graph below illustrates the performance of the model for the period 1995 to 2005. The graph super-imposes model results onto the observed sales figures for gasoline and diesel vehicles. The graph shows that the model is reflecting the changes in the gasoline diesel mix in the new vehicle fleet with reasonable accuracy. Perhaps more importantly, the model is giving a good representation of the behaviour of the FLEET and PRIVATE markets for diesel vehicles. Around 2001, the model shows the number of diesel vehicles purchased by the FLEET sector starting to accelerate at a faster rate than those in the PRIVATE sector. This is caused by the effect of the company car in the model.

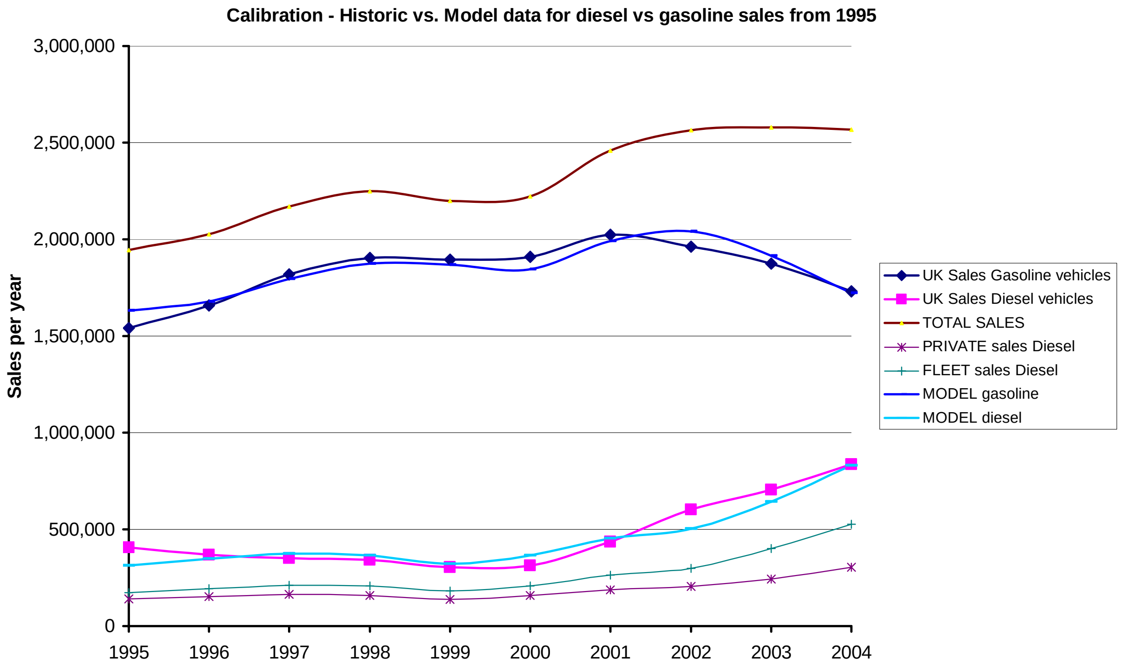


Figure 12, model results for the period 1995 to 2004, super-imposed on the observed results for sales of gasoline and diesel

These data provide a high degree of confidence that the model is correctly predicting the behaviour of the bulk of the new vehicle market for passenger cars.

For the Early Adopter groups, there is considerably less historic data available. Two technologies of interest exist – LPG and gasoline hybrid uptake. The graph below illustrates the model behaviour for LPG and gasoline hybrids between 1995 and 2005.

Total vehicle registrations each year

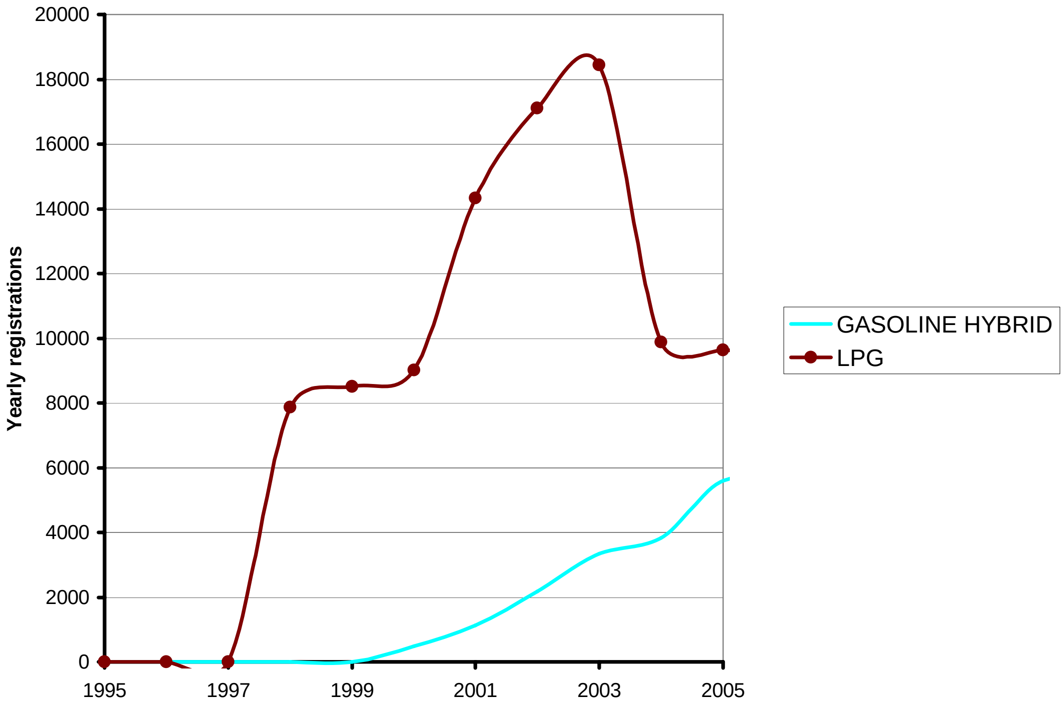


Figure 13, model historical results for gasoline hybrids and LPG vehicles.

The results illustrate the increase in LPG vehicle registrations until 2003, at which point PowerShift grant incentives are removed from the model. This reflects the observed market behaviour, which reached a maximum of approximately 17,000 sales in 2003[21], before falling away with the removal of grant incentives. The gasoline hybrid sales figure grows steadily to approximately 5,000 sales by 2005, reflecting observed sales data from SMMT.

Whilst the above historic results give some security about the values obtained for the early adopter segments in the market, a second method of confirming the coefficients comes from the consumer survey.

5.1.2.Consumer survey

The consumer survey from GfK produced a conjoint analysis based on six key metrics used in the vehicle modeling:

- Vehicle price
- Fuel consumption
- Yearly maintenance cost
- Drivability
- Functionality
- CO_2 emissions

[21] Transtech, Powershift Market Survey (5) for Energy Saving Trust (2004)

The survey is described in more detail in the GfK report which is issued in conjunction with this report[22].

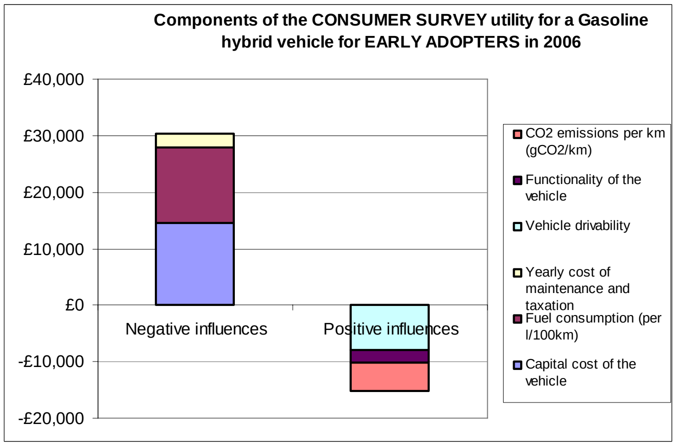
The conjoint analysis produces a series of coefficients for each of the six attributes above. The analysis targeted both the mass market of new car buyers and also separated out a group of early adopters from the larger mass car buying sample.

The data produced by the survey is tabulated below.

	'Very likely' to buy low carbon car	Mass market sample
Capital cost of the vehicle	-0.000134	-0.0003
Fuel consumption (per l/100km)	-0.343733	-0.3188
Yearly cost of maintenance and taxation (£/year)	-0.000989	-0.0047
Vehicle driving experience	0.202934	0.3674
Functionality of the vehicle	0.061310	0.1946
CO_2 emissions per km (gCO2/km)	-0.021908	-0.0118

Figure 14, actual value of coefficients for each metric as obtained from the consumer survey

It is not possible to directly compare coefficients from the conjoint analysis with those used in the model, instead, it is necessary to compare effective utilities. It is possible to express the components of the utility in financial terms. The graph below shows the various components of the consumer's perceived utility for a 2006 gasoline hybrid vehicle according to the coefficients produced by the consumer survey.



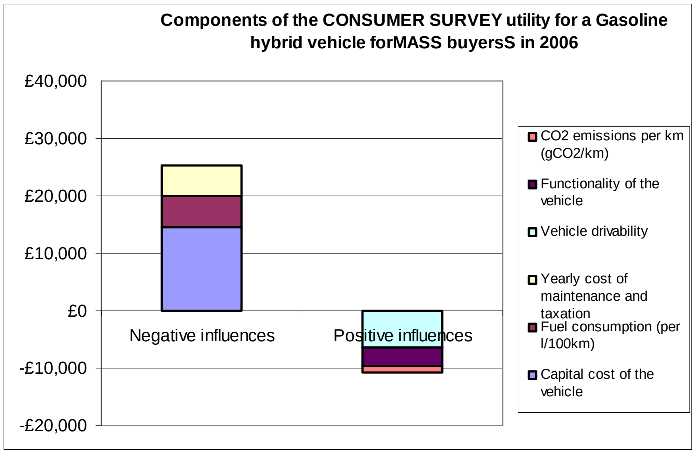


Figure 15, Implications of the consumer survey coefficients for the Early Adopter and Mass market components of the utility for a 2006 Gasoline hybrid vehicle, expressed as an effective cost to consumers

The graphs below illustrate the components of the utilities for the Market Transformation model's coefficients, for the same 2006 gasoline hybrid vehicle for the Early Adopter and Mass market groups.

[22] Available from Energy Saving Trust on request

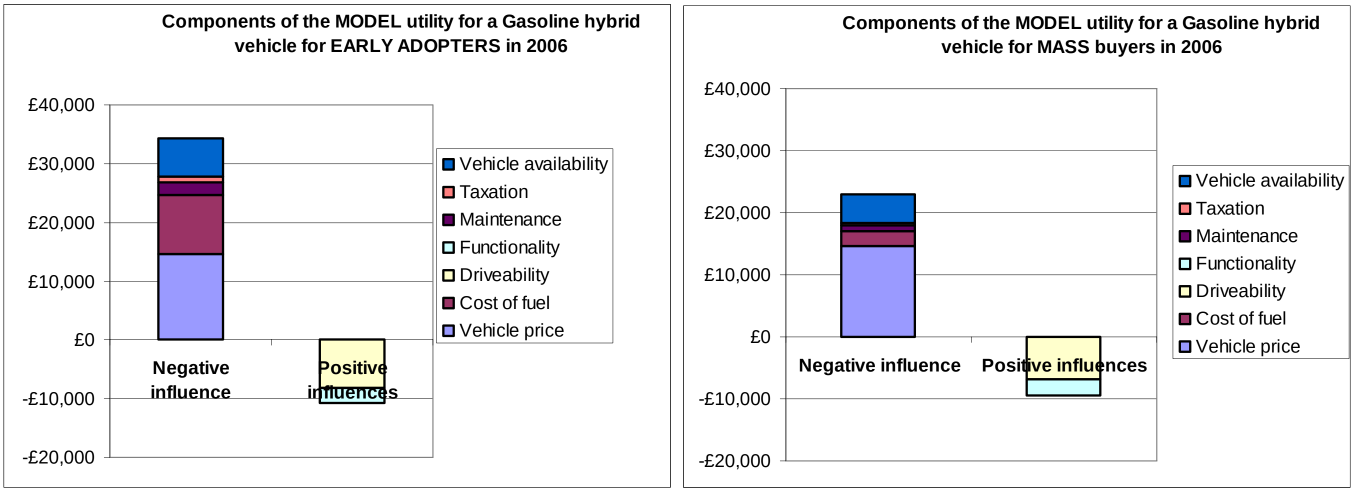


Figure 16, implications of the model coefficients on the components of the utility for Early adopters and Mass market buyers for a 2006 Gasoline hybrid vehicle, expressed as their effective cost to consumers

The data from the consumer survey is similar to the consumer coefficients used in the model for each group. The values of functionality, maintenance and drivability are very similar between the model and the consumer survey for both consumer groups.

The most striking difference between model and consumer survey numbers is the high valuation applied to CO_2 emissions in the consumer survey. It is likely that this is a construct of the surveying methodology. It is well documented that consumer surveys tend to produce an ‘expectation bias’, where survey respondents tend to overestimate the factors the survey is ‘supposed’ to be investigating. This phenomenon has been observed in most of the studies on UK consumer behaviour (notably the recent EcoLane study for the Low Carbon Vehicle Partnership[23]) and leads to a considerable reservation about the size of the CO_2 coefficients observed here.

Due to the uncertainties associated with survey data on CO_2, rather than explicitly including a coefficient for consumers which penalises CO_2 emissions in the model, the possibility of a consumer valuing CO_2 is included as a policy scenario.

The other significant discrepancy is the relatively high valuation the consumer survey suggests for fuel consumption. The current valuations appear unrealistically high, as they imply the average consumer capitalising up to 20 years of fuel costs at the point of purchase (at today’s fuel price). Again this is most likely due to the expectation bias effect. In addition, the discrepancy may reflect consumers’ difficulty in converting from fuel consumption (expressed in l/100km and miles per gallon) into an effective yearly cost. The mechanism of valuing fuel cost using a peer reviewed discounting procedure rather than the survey’s implied consumer coefficient is preferred in the choice of coefficients in the MT model.

Overall, the close correlation between the coefficient values obtained through the consumer survey and the combination of the historic data and the ‘engineering’ approaches provides significant reassurance that the model coefficients are reasonable and fit for the purpose of

[23] EcoLane consulting (March 2005) *Consumer attitudes to low carbon and fuel-efficient passenger cars* Low Carbon Vehicle Partnership

projecting future market behaviour. In particular the relative trends between the early adopter and mass market groups provide considerable reassurance that the approach of dividing up the market to capture early adopter behaviour is reasonably represented in the model.

6. VEHICLE TECHNOLOGY PROJECTIONS

The technical datasets on vehicle performance are provided to the Energy Saving Trust. Here, highlights of each dataset are drawn out for illustration.

6.1. Passenger car attributes for 2009

Technology	Year available	Capital Cost (£)	Fuel consumption (l/100km)		Driveability	Functionality	CO2 - g/km
GASOLINE	1995	11990	6.8	litres/100km	5	4.8	160.1
DIESEL	1995	13638	5.3	litres/100km	5.1	5.5	140.0
STOP/START HYBRID	2000	12308	5.8	litres/100km	4.5	5.1	142.4
GASOLINE HYBRID	2000	14558	5.1	litres/100km	5.5	5.2	119.8
DIESEL HYBRID	2009	15258	3.7	litres/100km	5.5	5.5	92.0
LPG	1998	13866	8.7	litres/100km	4	2.6	142.4
SMALLER VEHICLE	2000	11990	5.3	litres/100km	4.5	2.5	127.7
ADVANCED BIO-DIESEL (BASELINE + 20%)	2006	13738	5.1	litres/100km	5.1	5.5	137.3
ELECTRIC	2000	16558	25.0	kWh/100km	2.5	1.4	107.0
HYDROGEN / FUEL CELL	2012	0	0.0	kg/100km	0	0.0	0.0
VEHICLE RUNNING ON E85 BIO-ETHANOL	2006	12290	9.2	litres/100km	5	4.8	143.3
PREMIUM GASOLINE	2006	12331	5.5	litres/100km	4.5	5.1	130.0

Figure 17, highlights of the passenger car attributes in 2009. N.B. CO_2 figures here are based on the NEDC combined g/km and fuel consumption is based on a combined urban and extra-urban cycle.

7. ANALYSIS – PASSENGER CAR

7.1. Base case results

The model described above has been used to establish a set of results for the likely penetration of new vehicle technologies without any government intervention over that applied today (i.e. a base case). The graph below illustrates the yearly sales volumes for the various low carbon passenger car technologies.

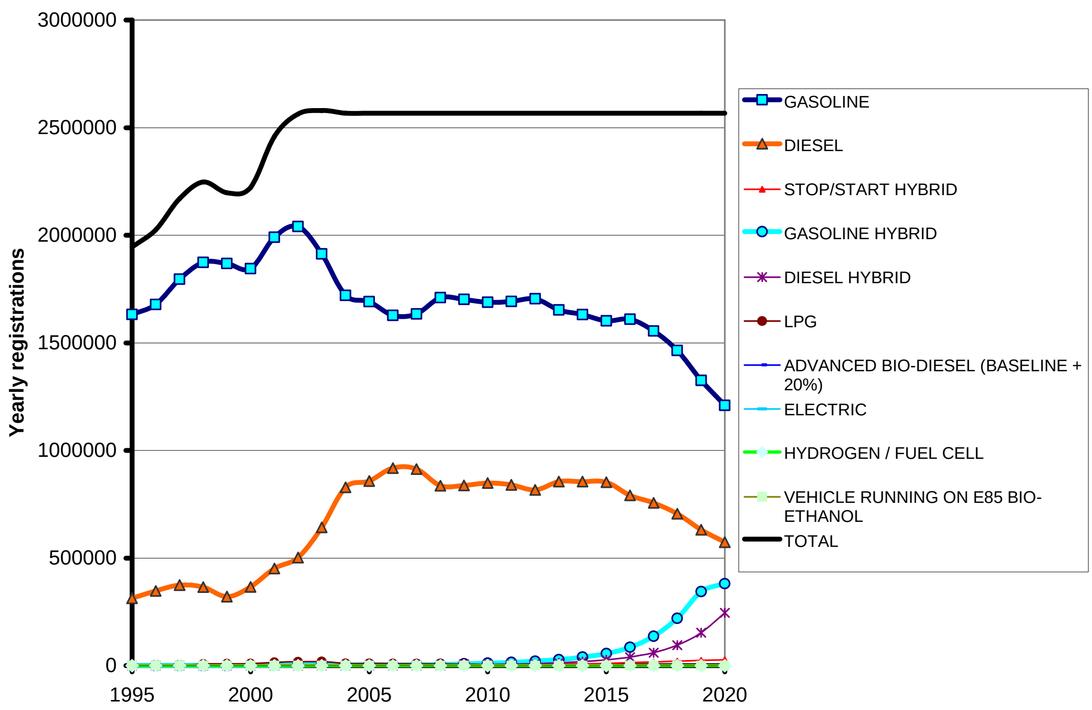


Figure 18, base case projections for the yearly sales of each low carbon vehicle technology

The results reveal a limited penetration for alternative fuel vehicles. Only the two hybrid technologies – gasoline and diesel hybrids - achieve any noticeable penetration set against the total vehicle market. This penetration is not projected to occur until beyond 2015, once the technologies have overcome the market's inertial barriers. Decreasing the scale of the y axis, it is possible to examine the behaviour of the other vehicle technologies in the market.

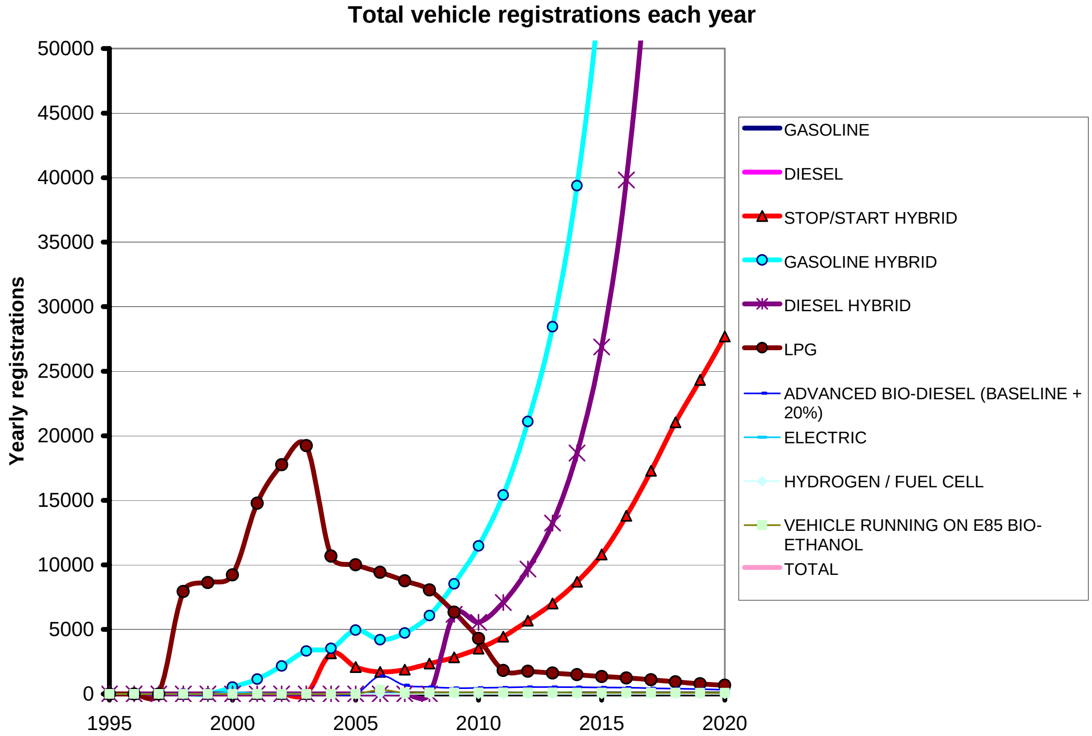


Figure 19, close up of the base case sales of new low carbon vehicle technologies

The graph shows that three technologies gasoline hybrid, diesel hybrid and premium gasoline are attractive enough to begin to penetrate the market in significant numbers by 2020. However, there is a notable lag time present before uptake starts to increase significantly due to inertial feedback effects of the market. Stop start hybrid technology also shows some penetration of the market in this time frame, but to a lesser degree. Other technologies including the bio-fuels, electric vehicles, and hydrogen fuel cells show very little penetration in this base case scenario without intervention.

It is also possible to consider the effect of these yearly sales on the total vehicle parc. The graph below illustrates the effect of the base case vehicle projections on the total vehicle parc in the UK. The graph reveals that even the reasonable penetration of hybrid vehicles observed from the base case has only a small impact set against the scale of the total number of vehicles operating in the UK. Even by 2020, the penetration of the most significant technology (gasoline hybrid) is limited to under 5% of the total parc and the total low carbon vehicle penetration is below 9%.

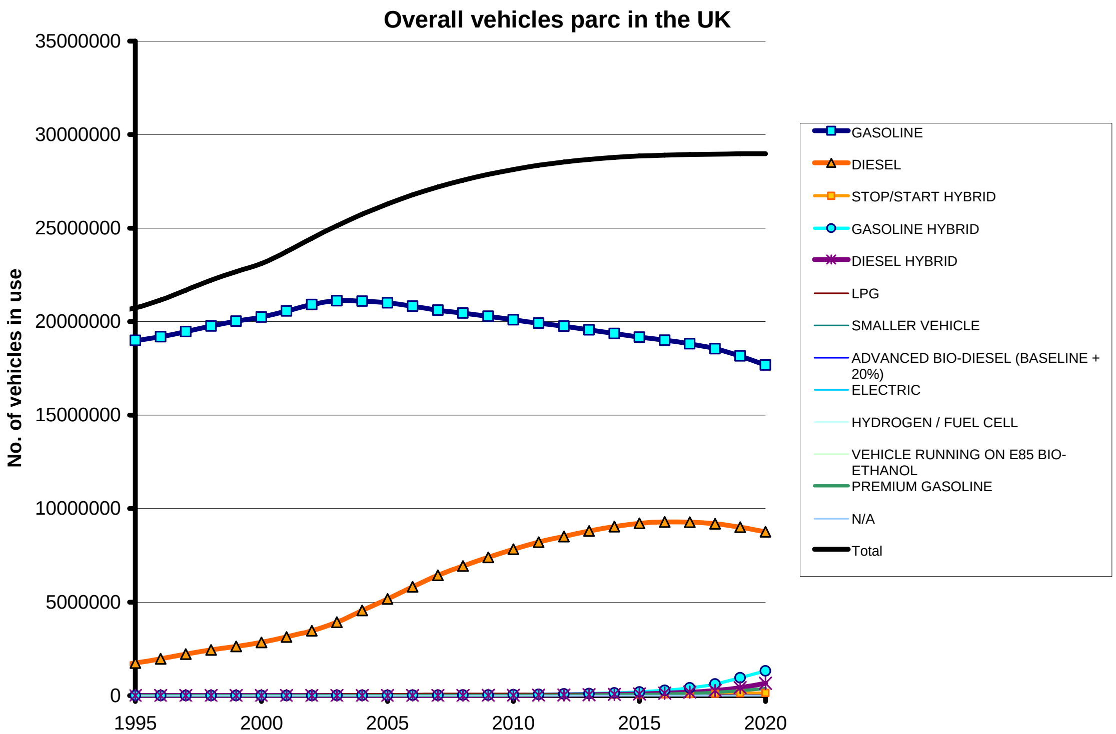


Figure 20, breakdown of the total number of vehicles of different types in the UK parc.

The limited penetration of low carbon vehicles in the parc inevitably feeds through into the overall parc CO_2 numbers. The graph below illustrates the overall parc CO_2 emission projections to 2020. The figures reveal a significant dip in overall CO_2 between 2008 and 2010 due to the impact of the Renewable Transport Fuels Obligation, which reduces the CO_2 content of the fuels. In addition, there is a general downward trend in CO_2 due to the progressive trend for improved efficiency of the vehicle fleet. However, the effect of the lower carbon vehicles on reducing overall parc CO_2 is small.

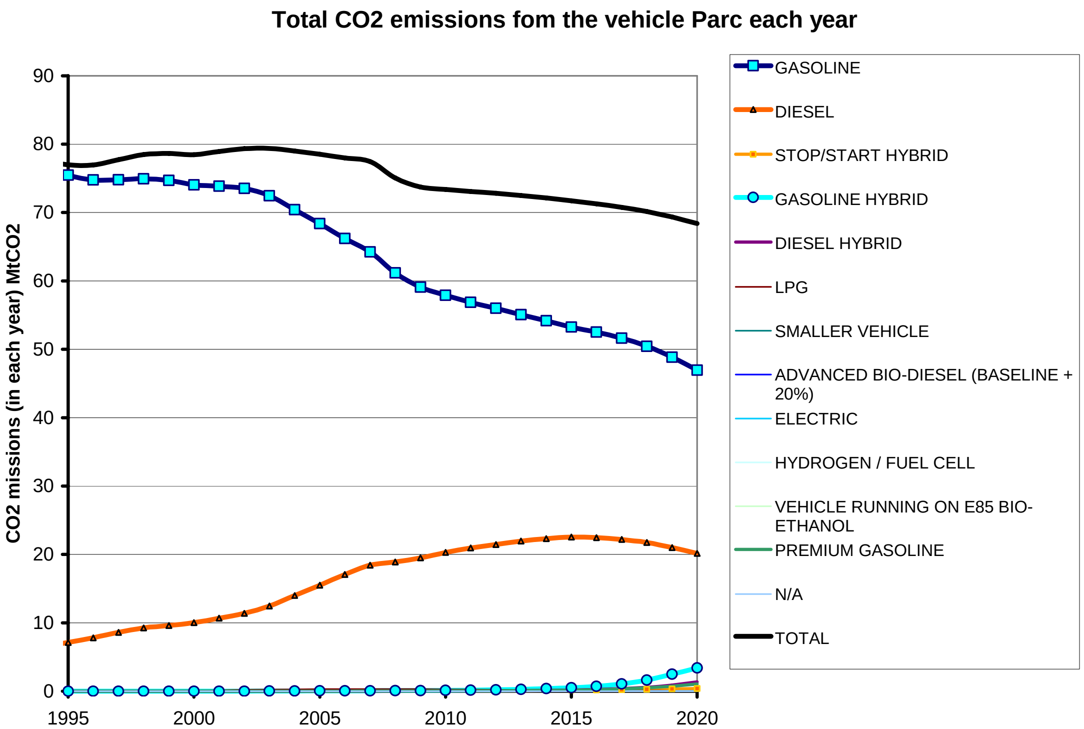


Figure 21, overall CO_2 emissions of the vehicle parc, broken down by vehicle technology

It is also possible to consider the overall CO_2 emissions of the new vehicle fleet, although the level of aggregation in the model means results are subject to degree of uncertainty. The graph below shows a projection for the new vehicle fleet average CO_2 emissions. Again, the limited penetration of the lower carbon vehicles has a limited effect on the overall CO_2 emission of the new vehicle fleet in the base case. The major effect is a general downward trend caused by an assumed progressive increase in conventional vehicle efficiency from the main Ricardo vehicle technology dataset.

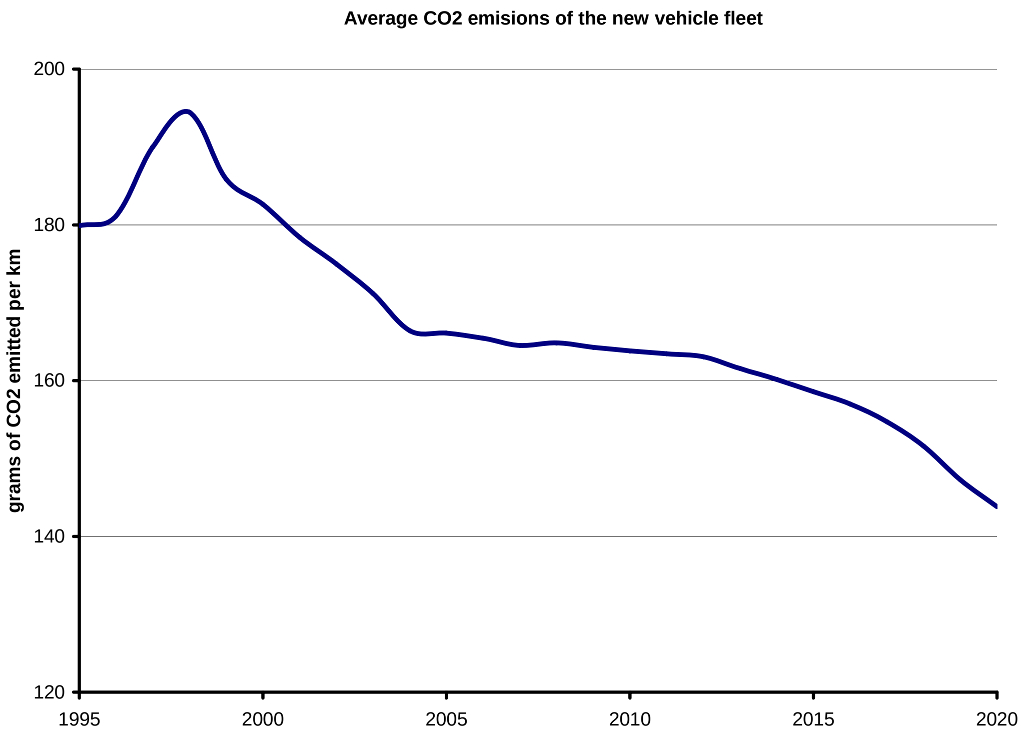


Figure 22, model results for average new fleet CO_2 figures each year to 2020

7.1.1.Summary of points regarding the base case results

The base case reveals that without intervention, the market is likely to continue to be dominated by gasoline and diesel vehicle to 2020. The overall penetration of diesel vehicles in the parc is likely to rise until 2020 at the expense of gasoline vehicles.

The progressive improvements in vehicle efficiency and the RTFO act to bring down the overall CO_2 emissions of the UK parc (by up to 10%). However, the new vehicle technologies do not have any noticeable effect on reducing parc level CO_2 by 2020. Low carbon vehicle technologies represent an opportunity to save CO_2 emissions from the UK vehicle fleet. However, the benefit from new vehicle technologies will not be realised by 2020 under current conditions.

The technologies which do begin penetration under the base case are hybrid based (gasoline and diesel) and premium/advanced gasoline. These appear able to overcome the inertial barriers to entry due to their specific performance advantages for consumer, but without support their entry at a significant level is delayed to beyond 2015.

Stop start hybrid technology struggles to overcome inertial barriers, but does make some penetration into the market.

A number of technologies do not have a significant effect on the overall market: Electric, H_2 fuel cells, and the bio-fuels (which are held back by fuel costs and resource availability). This is mainly because the technologies are assumed to suffer from specific technological difficulties which reduce attractiveness to consumers and which are not predicted to be overcome in this timescale (e.g. range and recharging issues for electric vehicles).

7.2. Policy scenarios

The model is designed to be able to simulate a wide range of policy scenarios, which will affect the market for passenger cars including:

- Variation in capital costs of low carbon vehicles (e.g. due to incentive schemes, or the effect of additional research and development effort on low carbon technologies).
- Variation in running costs of low carbon vehicles
- Cost of fossil fuel – changing the cost of fossil fuels, for example due to global oil price fluctuations
- Low carbon vehicle procurement programmes
- Consumer Valuation of CO_2 – altering consumer perceptions of CO_2 at the point of purchase. Effectively this implies creating a consumer 'value' for the CO_2 emissions of a new car.
- Refuelling infrastructure support – fiscal support for refuelling infrastructure deployment for alternative fuels

This list is not exhaustive, and the model is flexible enough to allow further scenarios to be modelled at a later date should they be suggested by policy makers.

Example Policy Scenarios

Some examples of the effects of simulating policy scenarios are detailed below. Note, these scenarios are shown only for the purposes of demonstrating the capabilities of the market transformation model to simulate the effects on uptake of low carbon vehicles in the market to 2020 under different market conditions.

Policy analysts and/or makers should not draw specific conclusions from these figures. As mentioned, policy makers and analysts are welcome to approach the Energy Saving Trust to have modelling work carried out on their behalf[24]. Results produced will be subject to a review process by the Energy Saving Trust before agreement for publication.

7.2.1. Reductions in capital costs of Low Carbon Vehicles

The model can simulate the effect reductions in capital costs low carbon cars. For the purpose of this model, Low Carbon cars are defined as achieving a carbon emission saving of at least15% relative to their class.

The technologies with a CO_2 emissions reduction of at least 15%, to which cost reductions are applied are gasoline hybrid, diesel hybrid, electric, hydrogen fuel cell and E85 bio-ethanol.

The policy scenario's outlined below are for illustrative purposes only. The various scenarios considered include:

[24] This is available as a chargeable service (to cover costs and staff time), please contact Energy Saving Trust Evaluation Department on 020 72220101 (ask for the Transport Evaluation Manager) for further details.

- **Unlimited** – where a cost reduction is applied until 2020
- **Time limited** – where a time limit is imposed on the cost reduction
- **Cash limited** – where a maximum financial contribution is assigned to the cost reduction

The level of cost reductions per vehicle can be varied. Furthermore running cost reductions can be varied in a similar manner, in combination with capital cost reductions, or independently as a separate scenario.

The graph below summarises the effect of various scenarios on the number of low carbon car sold in the UK.

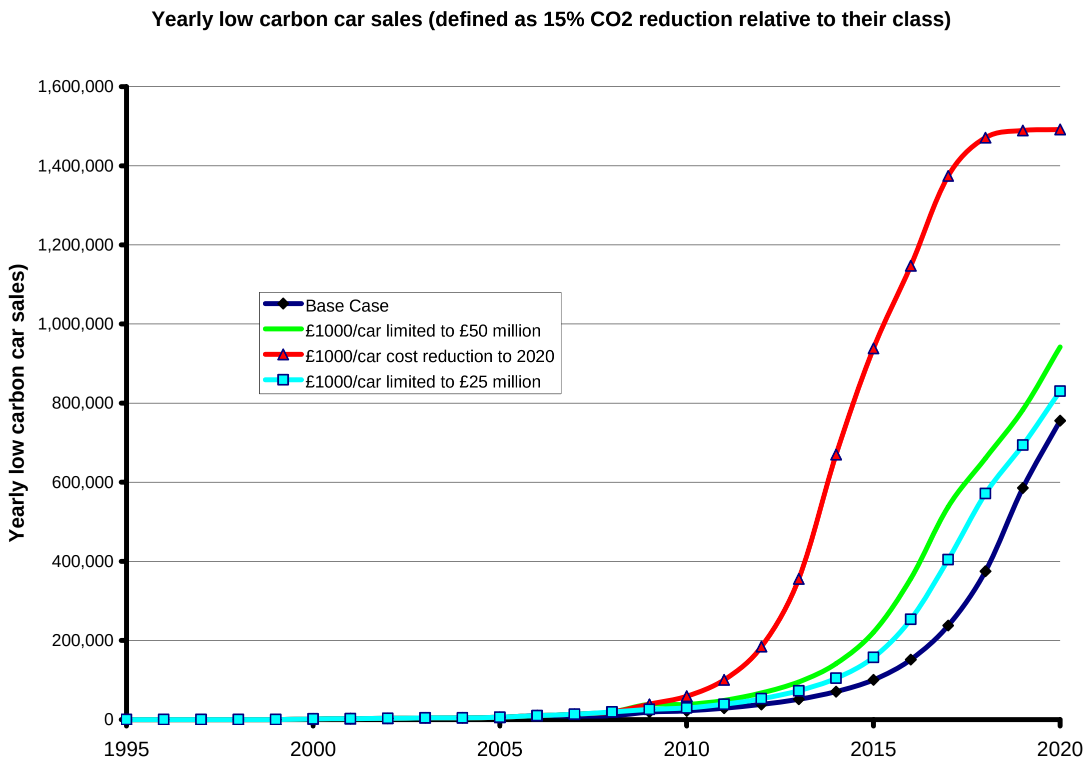


Figure 23, results for various cost reduction scenarios, illustrating the take-up of low carbon cars

The graphs clearly illustrate that cost reduction scenarios lead to an increase in the number of low carbon cars sold. In all cases of these scenarios, the main increases are realised in the sales of hybrid vehicles.

The below graph shows the effects of a cost reduction scenario of £1000, limited to £50 million on registrations of vehicles each year by technology type.

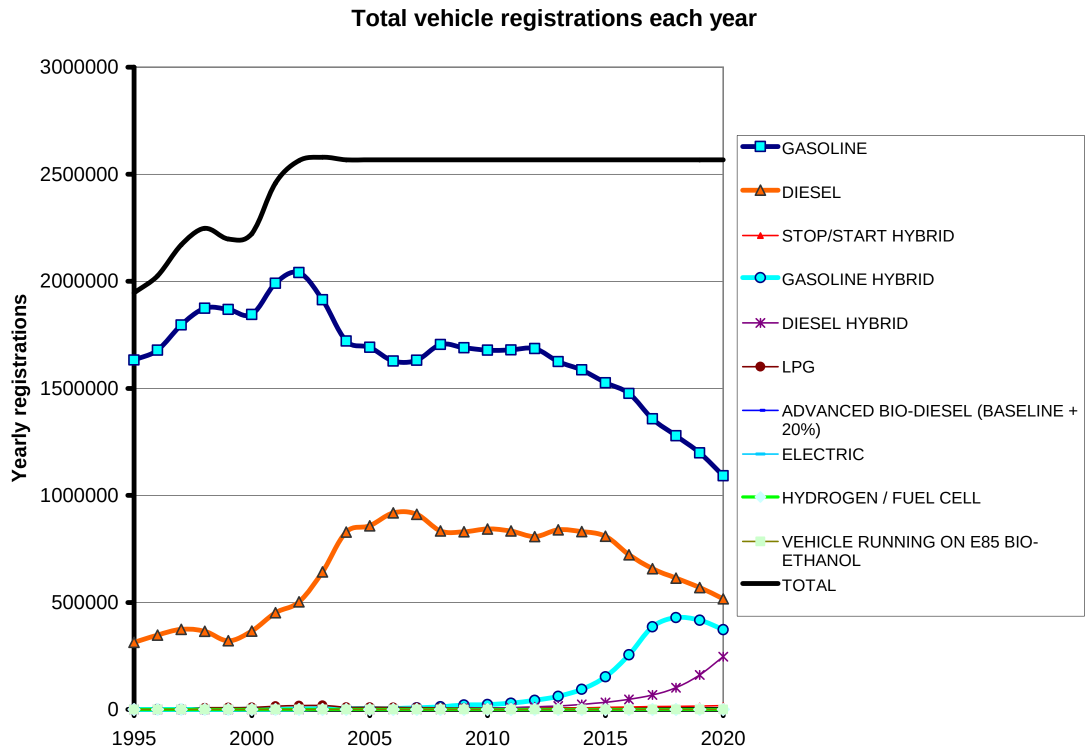


Figure 24, results for total vehicle registrations per year under a scenario of a £1000 capital cost reduction per low carbon car

One point of interest to note is that after 2017-18, market share of gasoline hybrids starts to decrease, and the likely reason for this is that some of this market share is taken up by diesel hybrid vehicles, which become a more attractive option in the longer term due to their higher potential fuel efficiency.

It is interesting to note that although the short term effects of a cost reduction with either time or budgetary limits is limited in the shorter term, the long term effect (e.g. by 2020) is pronounced.

The effect of the different rates of Low Carbon car uptake on the overall CO_2 emissions of the UK vehicle parc can be broadly estimated. The graph below illustrates the effect on the parc CO_2 emissions for the cost reduction scenarios considered above. The graph shows that there are potentially significant benefits in CO_2 terms for the UK parc from the adoption of lower carbon vehicles.

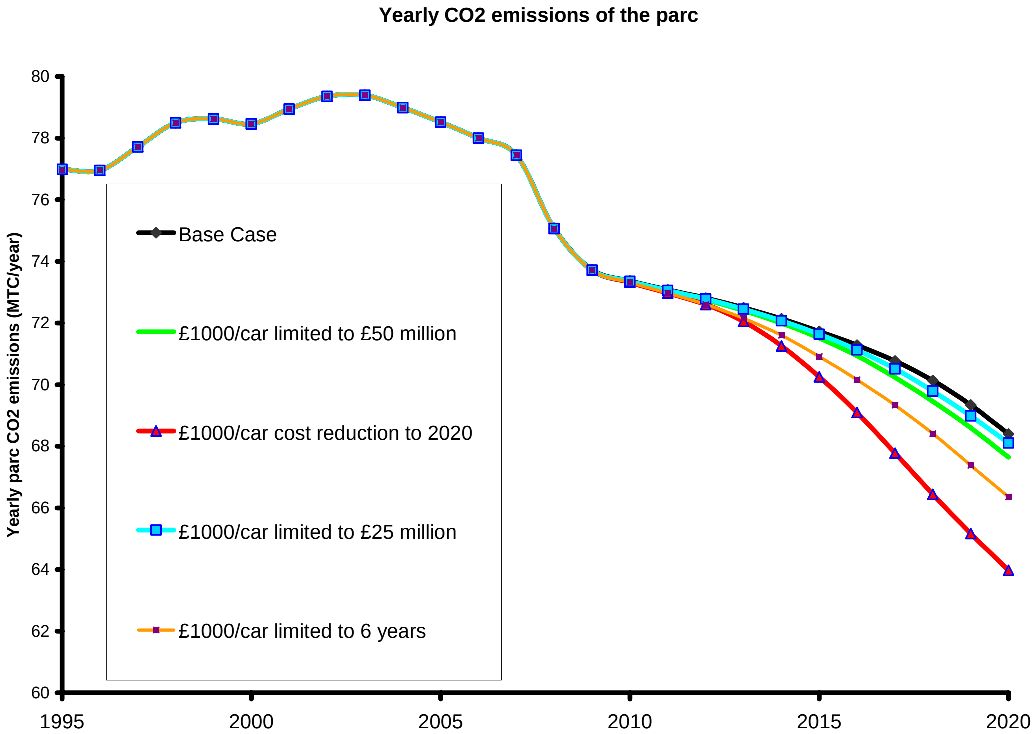


Figure 25, results for the yearly CO_2 emissions of the UK vehicle parc under different low carbon vehicle cost reduction scenarios

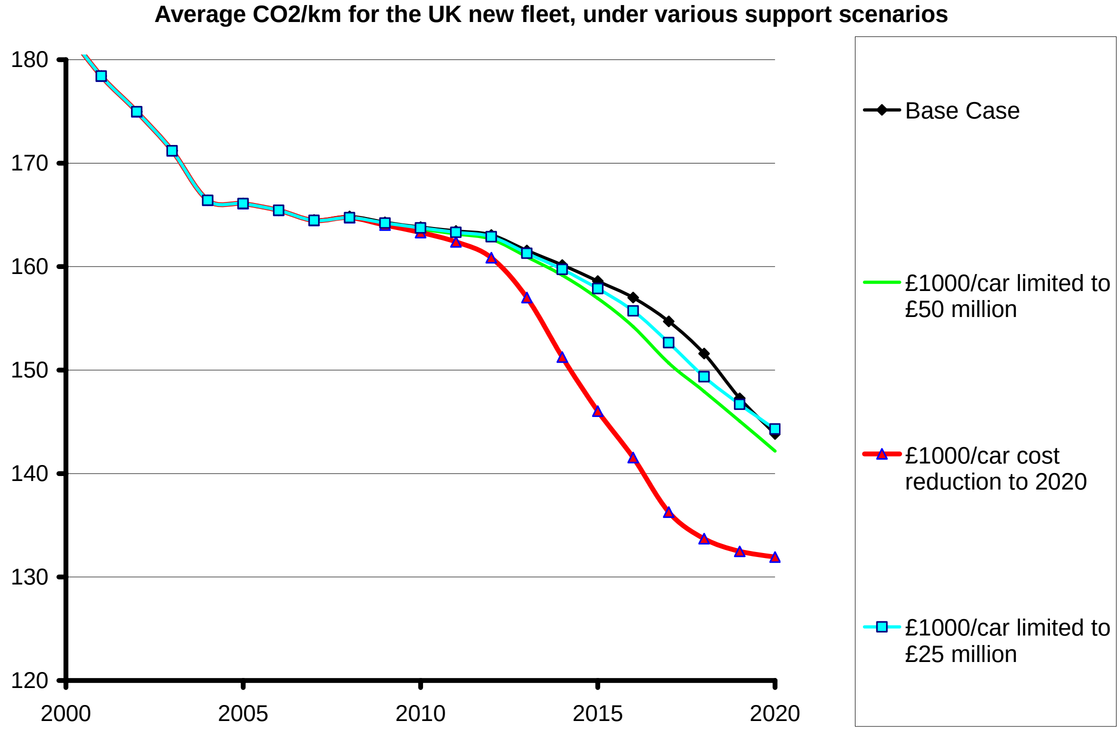


Figure 26, results for average CO2/km of the UK new vehicle fleet under various cost reduction scenarios.

At this point it should be noted that the aggregation issues relating to the mechanism for projecting vehicle performance mean that the effects of vehicle downsizing are not easily represented in the model. Therefore the model may under-predict the effect of consumers switching to smaller vehicles with lower CO_2 emissions. This highlights an opportunity for further development of the model to include one or more other size classes of vehicles.

7.2.2.Consumer awareness of CO_2

Currently evidence from the actual behaviour of the UK vehicle market suggests that few consumers place a significant value on CO_2.The consumer survey results suggest that some consumers (notably the early adopter groups) are prepared to value CO_2 savings at the point of purchase when asked at the *survey* stage. However, based on actual behaviour, it appears that this is rarely turned into practice in the market.

These policy scenarios explore the effect of encouraging consumers to value CO_2. A number of mechanisms are available to encourage consumers to place a value on CO_2. These might include an awareness program for fleet operators, or a CO_2 levy applied through for example the European Emissions Trading System (the ETS), a personalised CO_2 credit scheme or a consumer campaign on CO_2.

It is important to clarify that it is not the intention of this study to explore the mechanisms for creating an awareness of CO_2 rather to attempt to quantify the effect if a consumer valuation could be induced.

The model has been run for various level of consumer value for CO_2, assuming that each year's emissions are valued over the consumer's own discount period and for each consumer group's yearly mileage.

CO_2 is valued at £10, £20 and £70 – per tonne of CO_2, for various intervals. The range between £10 and £20 represents the range of costs in the European Emissions Trading system for carbon emission credits, £20/tonne of CO_2 also approximately represents the government's current valuation for CO_2 (the government values the social cost of carbon at £70/tonne of Carbon in 2000 prices[25], which translates to £19/tonne of CO_2). In contrast, £70 per tonne of CO_2 represents an extreme CO_2 valuation, which could only arise through significantly increased sensitivity to CO_2 through concern over the effects of climate change etc.

The graph below illustrates the effect of creating a CO_2 sensitivity for consumers in the model. The graph illustrates the effect of a sensitivity affecting both private and fleet buyers (although this can be examined individually).

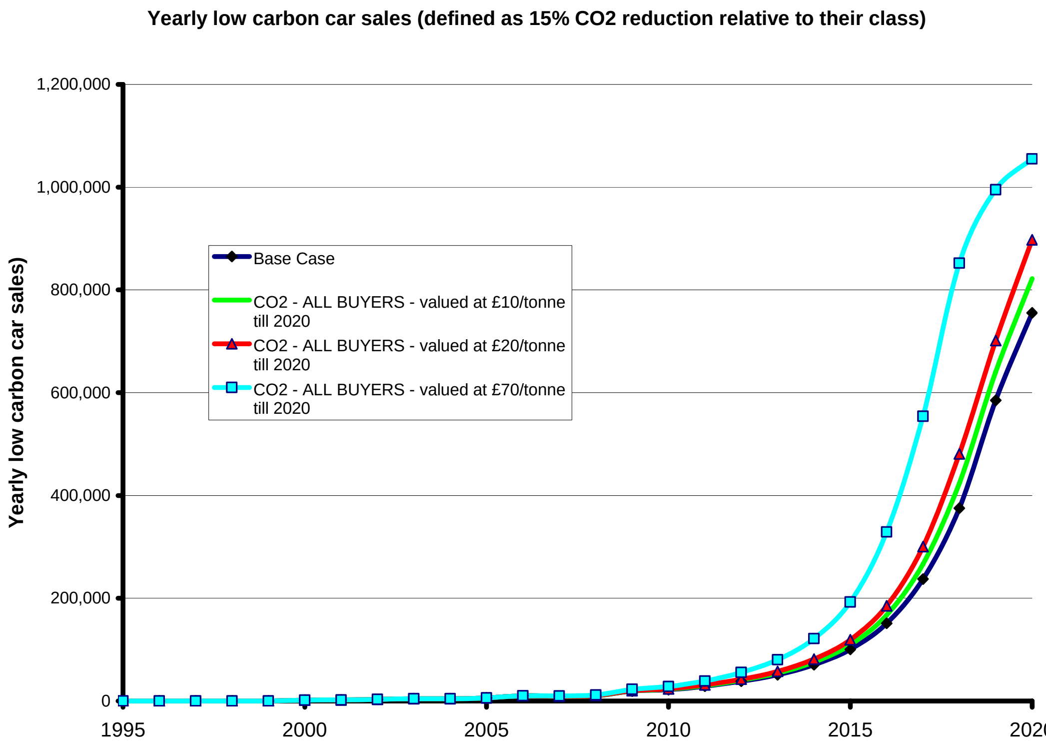


Figure 27, illustration of the effect of different consumer valuations of vehicle CO_2 emissions on low carbon vehicle sales

For limited levels of CO_2 sensitivity (in the £10 to £20/tonne CO_2 range), the effect on new vehicle procurement is limited. Once the CO_2 sensitivity reaches levels of £70/tonne CO_2, a marked effect on low carbon vehicle sales is observed. Up to 300,000 additional low carbon vehicles could be sold each year assuming the consumer awareness is spread over the entire population of new car buyers.

[25] www.defra.gov.uk

The below graph shows the estimated effects of the same scenarios on CO2 emissions of the vehicle parc to 2020 and also the average CO2 (g/km) of the new UK vehicle passenger car fleet.

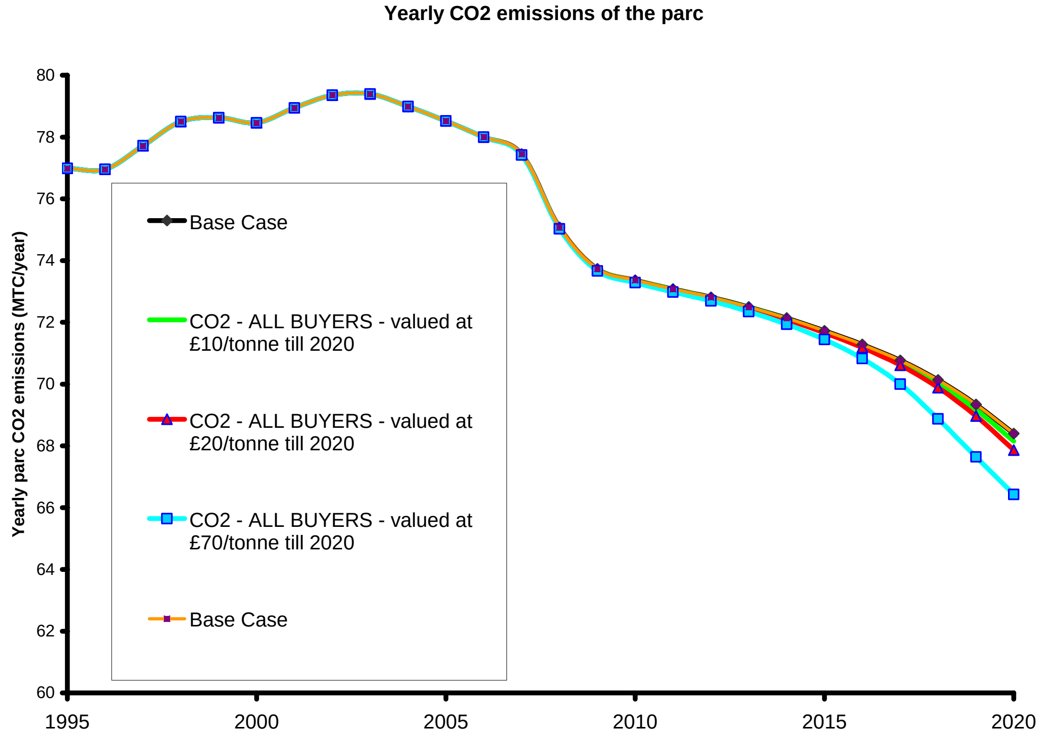


Figure 28, results for yearly CO2 emissions of the vehicle parc to 2020 with various consumer valuation of CO2 scenarios

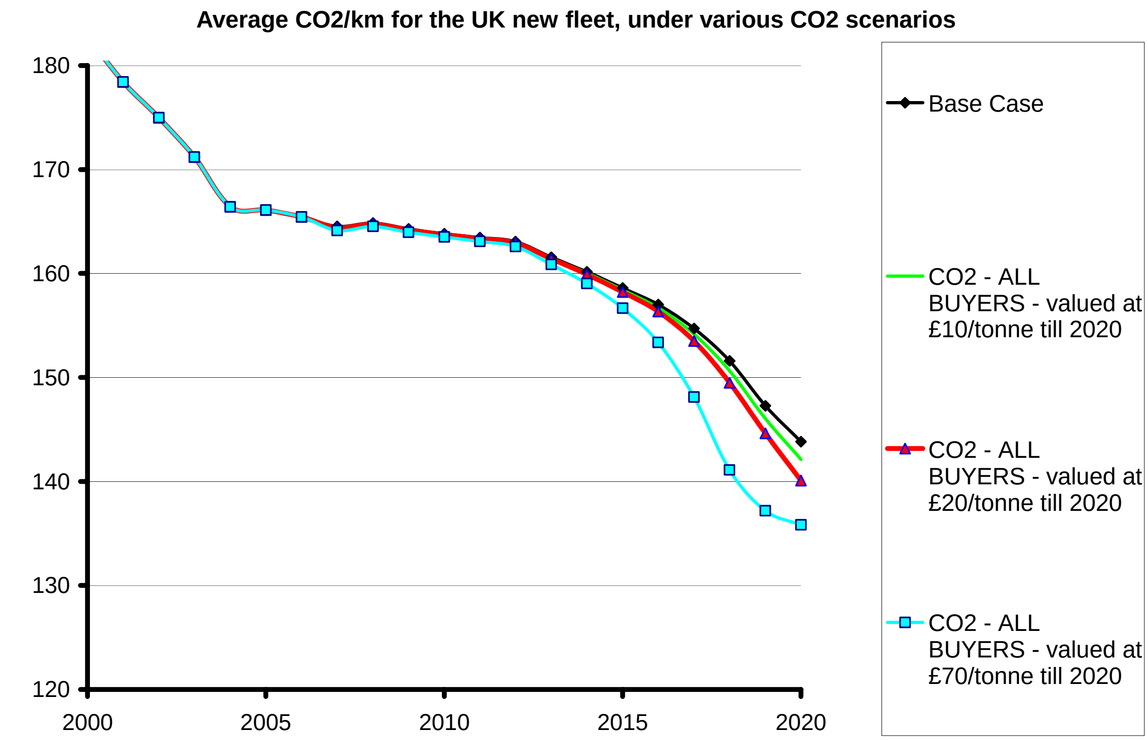


Figure 29, results for average CO2 g/km of UK new fleet under various consumer valuation of CO2 scenarios.

7.3. Passenger car conclusions

7.3.1.Base case

The base case results are based on a continuation of today's policy regime (and planned policies) with respect to low carbon vehicles.

The results suggest a gradual improvement in the average CO_2 of the new fleet which is caused primarily by a progressive improvement in the efficiency of gasoline and diesel vehicles. The contribution of new vehicle technologies to reducing fleet averaged CO_2 is limited. Only gasoline and diesel hybrids achieve any substantial penetration and that penetration only occurs after 2015.

Considering the UK vehicle parc as a whole, annual CO_2 emission projections show a steady decrease due to greater efficiency of gasoline and diesel vehicles (N.B. this conclusion assumes mileage per vehicle remains constant over time). In addition, the effect of the Renewable Transport Fuels obligation is to cause a dip in CO_2 emissions starting in 2008. The base case suggests a reduction of up to 10MTCO_2/year from the vehicle parc by 2020.

Other than the hybrid technologies and premium/advanced gasoline, most Low Carbon vehicle technologies fail to achieve noticeable mass market penetration. Some appear to be unable to compete with other vehicle offerings over the time-period to 2020, these include electric, hydrogen fuel cells and LPG.

Stop start technologies have the potential to be a competitive mass market offering but struggle to overcome market inertial penalties. These technologies do not appear to have significant mass market appeal to drive mass market adoption without intervention. [N.B. these two technologies may be adopted by vehicle manufacturers as part of their own incremental changes to their conventional drive train technologies and as such may not need to overcome the market inertia penalties.]

8. SUMMARY AND CONCLUDING REMARKS

A useful model of the UK market with respect to low carbon cars has been developed.

The range of policies that can be modelled, either individually or in combination with each other is wide and therefore, the model presents an opportunity to help further the policy debate through analysis of the likely effects of new policies on the UK vehicle market. The example scenarios shown above demonstrate some of the capabilities of the model, however there are many other scenarios, which can be modelled. Some examples of the types of policy and technology scenarios which have been tested by the Energy Saving Trust include:

Policy Scenarios

- Consumer Valuation of CO_2 – altering consumer perceptions of CO_2 at the point of purchase. Effectively this implies creating a consumer 'value' for the CO_2 emissions of a new car.
- Cost of fossil fuel – changing the cost of fossil fuels due to global oil price fluctuations.
- Refuelling infrastructure support – support for refuelling infrastructure deployment for alternative fuels
- Variation in capital costs of low carbon vehicles (e.g. due to incentive schemes, or the effect of additional research and development effort on low carbon technologies).
- Variation in running costs of low carbon vehicles
- Low carbon vehicle procurement programmes

Technology Scenarios

- Model the impact of changes to assumptions about vehicle performance and cost for the identified technologies:
- Model the introduction of new technologies
- Identify changes in sales patterns as a result of technology insertion/improvement:
    iii. Identify which existing technologies are displaced as a result of the introduction of these technology changes
    iv. Calculate changes in UK CO2 emissions as a result
- The model can also be run iteratively to identify the necessary change in vehicle attributes (which attribute and the magnitude) required to gain significant market penetration of low carbon vehicle technologies

The model has some limitations (see appendix 1 and section 4), which have been noted within this report, however it is widely accepted through the extensive consultation process, which has been undertaken as part of the project that these limitations are acceptable and that the model shows good indicative results in its current form.

Third party organisations are welcome to approach The Energy Saving Trust[26] in order to request modelling work to be completed on their behalf. As described above, the service will be chargeable in order to cover staff costs, and all results will be subject to a review process prior to agreement for the publication of results. Please contact the Energy Saving Trust for further details.

8.1.1.Further work

There are a number of areas in which it would make sense to do further work on the model in order to improve the accuracy of the results it can deliver. Recommended further developments include:

- Nesting: Developing the model further to include a nested structure in order to resolve the most significant limitation of the model in its current form, with regard to the independence of irrelevant alternatives issue.
- Addition of further vehicle segments: This is a recommended improvement in order to help more accurately model the effects of policy scenarios on different classes of vehicles (additional to the current C/D segment) and also to help allow modelling of up/down sizing.
- Further survey work and incorporation of consumer data with respect to real behaviour with respect to low carbon vehicles and CO_2 emissions. This will help to add an improved understanding and accurate application of the market feedbacks included within the model.
- Adding further data from manufacturers with regard to technological improvements of certain technologies.
- Increase the time period of the model from 2020 to 2030 and beyond.

[26] Contact David Kenington, Energy Saving Trust Evaluation Manager. Tel: 020 76542497 Email: david.kenington@est.org.uk