UK ENERGY RESEARCH CENTRE

UK Transport Carbon Model Reference Guide

Working Paper

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Executive Summary

Current debate focuses on the need for the transport sector to contribute to more ambitious carbon emission reduction targets. In the UK, various macro-economic and energy system wide, top-down models are used to explore the potential for energy demand and carbon emissions reduction in the transport sector. These models can lack the bottom-up, sectoral detail needed to simulate the effects of integrated demand and supply-side policy strategies to reduce emissions. Bridging the gap between short-term forecasting and long-term scenario “models”, the UK Transport Carbon Model (UKTCM) is a newly developed strategic transport, energy, emissions and environmental impacts model, covering a range of transport-energy-environment issues from socio-economic and policy influences on energy demand reduction through to lifecycle carbon emissions and external costs. Developed under the auspices of the UK Energy Research Centre (UKERC) the UKTCM can be used to develop transport policy scenarios that explore the full range of technological, fiscal, regulatory and behavioural change policy interventions to meet UK climate change and energy security goals. This reference guide describes the model in detail, including functional relationships, data flows and main data sources.

Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

GLOSSARY OF TERMS

UKTCM	UK Transport Carbon Model
TDM	Transport Demand Model
VSM	Vehicle Stock Model
DEEM	Direct Energy and Emissions Model
LCEIM	Life Cycle and Environmental Impacts Model
GDP	Gross Domestic Product
TEE	transport-energy-environment
CO_2	carbon dioxide
CO	carbon monoxide
VOC	volatile organic compound
NMVOC	non-methane volatile organic compound
NO_x	nitrogen oxides
PM_x	particulate matter (x=>10, <10, <2.5 micrometers)
C_6H_6	benzene
LH_2	liquefied hydrogen
GH_2	gaseous hydrogen
GHG	greenhouse gases
LPG	liquefied petroleum gas
CNG	compressed natural gas
LNG	liquefied natural gas
B100	100% biodiesel
HDV	heavy duty vehicle
POCP	photochemical ozone creation potential
GWP	global warming potential

Introduction

Aims and objectives

This reference guide describes the UK Transport Carbon Model (UKTCM) in detail. The UKTCM is a highly disaggregated, bottom-up model of transport energy use and life cycle carbon emissions in the UK. It provides annual projections of transport supply and demand, for all passenger and freight modes of transport, and calculates the corresponding energy use, life cycle emissions and environmental impacts year-by-year up to 2050. It takes a holistic view of the transport system, built around a set of exogenous scenarios of socio-economic and political developments.

The model is technology rich and, in its current version, provides projections of how different technologies evolve over time for more than 600 vehicle technology categories, including a wide range of alternative-fuelled vehicles such as more efficient gasoline cars, hybrid electric cars, plug-in hybrid vans, battery electric buses and advanced aircraft. However, the UKTCM is specifically designed to develop future scenarios to explore the full range and potential of not only technological, but fiscal, regulatory and behavioural change transport policy interventions. The UKTCM outputs include travel demand, vehicle stock, energy demand, annual and cumulative life cycle emissions, environmental impacts and external costs.

Background on strategic modelling

For strategic modelling of the transport-energy-environment (TEE) system, essentially three different approaches have been pursued in Europe (for an overview see e.g. Burgess et al., 2005), involving (1) *top-down* equilibrium or optimisation models such as PRIMES (Syri et al., 2001) and MoMo (Fulton et al., 2009); (2) *bottom-up* simulation models such as TRENDS (Georgakaki et al., 2005), TREMOVE (De Ceuster et al., 2004), Zachariadis (2005) and Schäfer and Jacoby (2006); and (3) transport *network* models such as ASTRA (Martino and Schade, 2000), SCENES (IWW et al., 2000) and EXPEDITE (de Jong et al., 2004).

The majority of these models were designed to explore specific policy questions, focusing on economic and technology policy interventions and their effects on transport demand, with some modelling of (direct) energy use and emissions. They often lack the detail necessary to model national low carbon policies that go beyond techno-economic policy options, e.g. policy aimed at changing travel behaviour. Models based *solely* on econometric approaches are deemed to be inappropriate for looking into the medium to long term future, as societies, preferences and habits (and thus elasticities) change.

At the national level a number of models exist, see e.g. de Jong et al. (2004). In the UK, no truly integrated TEE model exists at present, and policy makers rely on running different sets of models such as the (road) National Transport Model (NTM; DfT, 2005a), with separate models for rail, aviation and navigation. In addition, transport and climate mitigation policy is informed by energy and economy systems modes such as MARKAL (Loulou et al., 2004), seeking to explore intra-sector dynamics and trade-offs. Although the models cover the majority of GHG emissions sources and types, they do not project full life cycle emissions.

Finally, and crucially for the research community, assumptions and methods of government run models are often not explicit, making independent scenario planning and policy analysis difficult. The lack of an integrated policy-relevant life cycle model of carbon emissions from transport was the main motivation for the development of the UKTCM, which is outlined in the next Chapter.

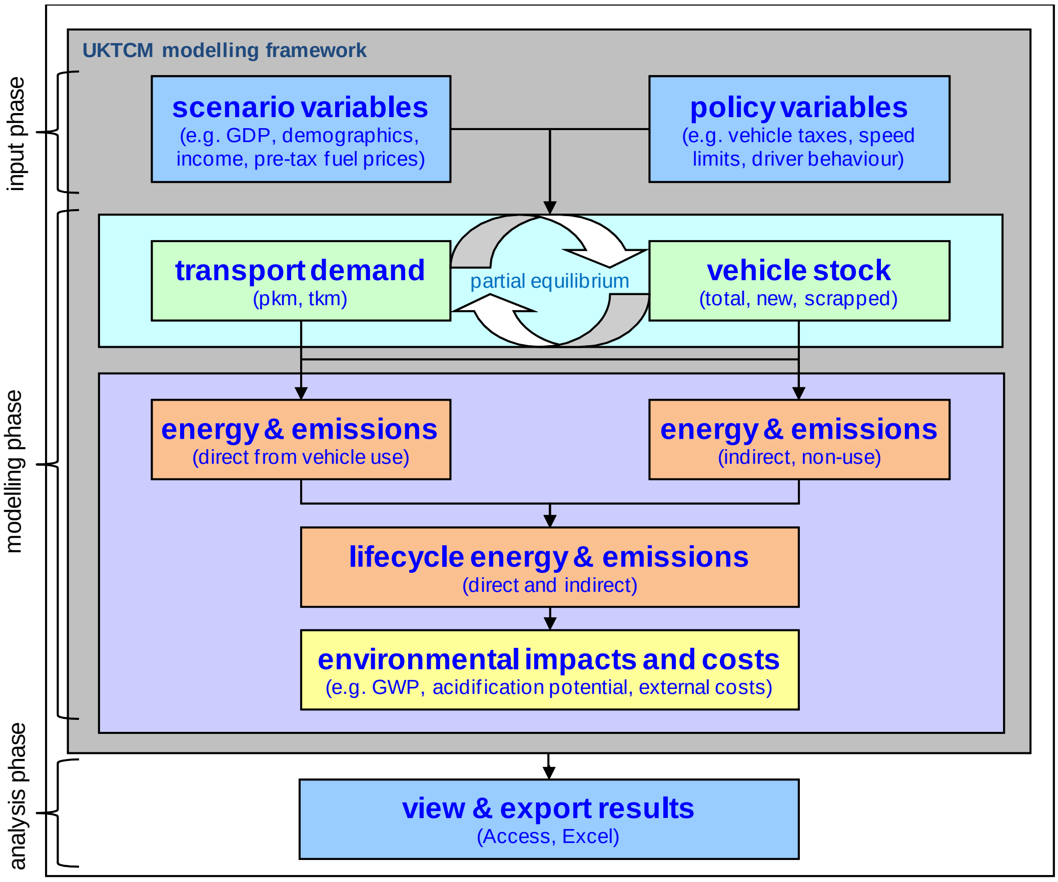
1 UKTCM overview

Approach

The UKTCM provides annual projections of transport supply and demand, for all passenger and freight modes of transport, and calculates the corresponding energy use, life cycle emissions and environmental impacts year-by-year up to 2050. It takes a holistic view of the transport system, built around a set of exogenous scenarios of socio-economic and political developments. The model is technology rich and, in its current version, provides projections of how different technologies evolve over time for more than 600 vehicle technology categories, including a wide range of alternative-fuelled vehicles such as more efficient gasoline cars, hybrid electric cars, plug-in hybrid vans, battery electric buses and advanced aircraft. However, the UKTCM is specifically designed to develop future scenarios to explore the full range and potential of not only technological, but fiscal, regulatory and behavioural change transport policy interventions. Figure 1 provides an overview of the system components which include:

1. a set of *quantified scenarios* which describe a range of possible external political and socioeconomic developments envisaged up to 2050;
2. a set of *single policy options* and *multiple policy packages* that include fiscal, technical, regulatory and demand management measures;
3. *four linked models* of the transport-energy-environment system, and;
4. a *graphical user interface*, to set up and run the model and view key modelling results.

Figure 1: Components of the UK Transport Carbon Model



Together with the policy and scenario components, the models are linked by:

- *common tables*, containing definitions of variables that are used in more than one model;
- *interface data tables*, containing all the variables and values which need to be transferred from one model to a subsequent model and to the results database;
- the *results database*, containing all the simulation modelling results the user might be interested in, calculated for a user-defined set of alternatives[1]. The main outputs include travel demand, vehicle stock, energy and fuel demand, fuel tax revenues, annual and cumulative life cycle emissions, environmental impacts and external costs.

Background scenarios

The basic idea of using background scenarios in UKTCM is to introduce wider *contextual factors* and consideration of *uncertainty* into the analysis of transport policy and technology take-up. The set of background scenarios describes a range of possible external political and socio-economic developments envisaged to 2050. In UKTCM, up to four exogenous scenarios can be developed as four internally consistent possible futures. The futures are quantitatively specified by a set of exogenous variables which may affect the outcomes of the models, while being outside the control of the transport-energy-environment system. These variables include changes in national GDP, pre-tax energy prices, demographics, household disposable income and maximum car ownership levels. The purpose of the scenarios is to provide a series of contexts within which the UK transport system may develop over time so that alternative policies can be tested for robustness against the uncertainties in the political, socio-economic and technological spheres.

Each background scenario in UKTCM can describe an internally consistent trajectory of *exogenous development* for the next 40 years or so. Together, the background scenarios are meant to span the credible range of uncertainties of interest to stakeholders. When talking about exogenous developments, we mean factors that are external relative to the transport system in the UK but nevertheless salient to its evolution, and specifically to the evolution of transport demand and the deployment of transport technologies. Factors internal to the British transport system are, in principle, to be dealt with in the modelling chain of the UKTCM system.

Driving forces, which are high in impact *and* uncertainty, are at the core of the scenarios. These can be identified and characterised through extensive consultation with external experts, as performed in similar exercises around the world (see e.g. the visioning work by Hickman and Banister, 2006). The resulting scenarios should highlight different developments along the “dimensions” of governance and people’s values and perceptions, primarily in the UK. In order that the set of scenarios covers a sufficiently wide range of possibilities, each scenario is relatively extreme – albeit plausible. Descriptions of the most likely developments would be of little help in coping with uncertainty.

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[1] Each alternative represents one combination of scenario and policy package. For example, different levels of gasoline and diesel taxation could be defined and calculated as a set of alternatives.

Of course, a set of four scenarios cannot cover all possible combinations of variations in external factors. Developments and occurrences that are weakly linked to the core features of any specific scenario may occur in any of the four scenarios. This could e.g. be shock events, a new oil crisis or different trajectories for demographic data.

In modelling terms, the set of scenarios provides input data to the UKTCM modelling system according to a vector of scenario variables, shown in Table 1. For each variable, scenario and year, data are given in a scenario database. The UKTCM system provides default data for all variables. The user can modify these variables that do not relate strongly to core features of the scenarios, within certain limits. (Such variation is actually recommended, to provide a sensitivity/uncertainty analysis.)

Table 1: Description of UKTCM background scenario variables

Description	*Form of variable*	*Modified by user?*
Annual rate of GDP growth	%, per year	Yes
Number of households index	Index relative to base year	Yes
Fuel price index (pre-tax): • Crude oil • Natural gas • Biomass • Electricity	Index relative to base year	Yes
Vehicle price index (pre-tax), for small, medium and large cars	Index relative to base year	Yes
Load factor index (by vehicle type, urban and non-urban)	Index relative to base year	Yes
Electricity generating mix	% share, for each year, of crude oil, coal, hydro, natural gas, photovoltaics on buildings, nuclear, biomass, wind & wave, imports to total electricity generated	Yes
Extra-UK freight growth rate	%, per year	Yes
Changes in • average speed (motorway, rural roads) • frequency of cold starts • idling time	% change over the period base year-2050. Used as a look-up table to guide user modification of assumptions entered in the DEEM, rather than as a direct quantitative input.	Yes
Change in transport intensity of GDP • passenger • freight	Index relative to base year, influencing the elasticity of transport demand	No
Index of passenger transport split • private car • public transport • air	Index relative to base year, influencing the elasticity of transport demand	No
Index of freight transport split • road • rail	Index relative to base year, influencing the elasticity of transport demand	No
Split of demand between journey segments for car trips • urban • rural • motorway	Index relative to base year	No

Policies and policy packages

The policy options include *fiscal measures* such as vehicles and fuel taxes, *regulatory measures* such as fuel economy standards, *information and education policies* and investment and planning policies. Table 1 provides a list of the main policy options that can be modelled in UKTCM, and their primary and secondary effects. Importantly, policy packages of two or more policies listed in the Table can be modelled at the same time in an integrated and internally consistent manner.

Table 2: List of the main policy options that can be modelled in UKTCM, and their effects

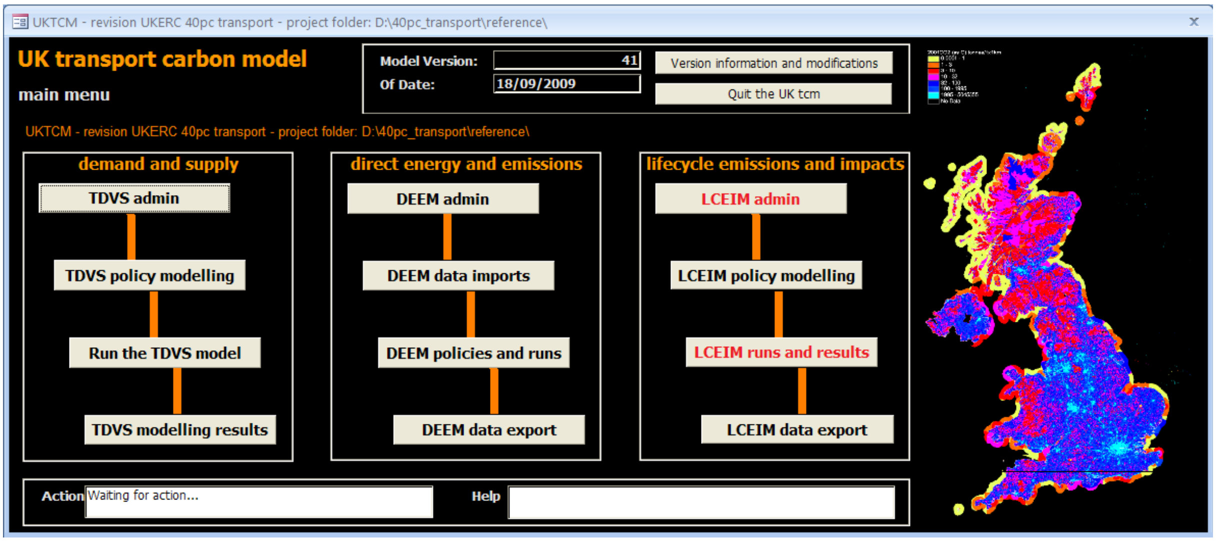
POLICY	PRIMARY (AND SECONDARY) EFFECTS	MODEL
Fiscal		
Company car tax	fleet car technology choice, (demand)	VSM/TDM
Vehicle circulation tax	road vehicle technology choice, (demand)	VSM/TDM
Vehicle purchase tax / feebates	vehicle technology choice, (demand)	VSM/TDM
Car scrappage incentive/rebate	private car technology choice, car ownership, (demand)	VSM/TDM
Fuel taxation (by volume or carbon content)	vehicle technology choice, (demand)	VSM/TDM
Road user/congestion charging (graduated)	vehicle technology choice, (demand)	VSM/TDM
Parking charges	vehicle technology choice, (demand)	VSM/TDM
Regulation		
Fuel economy standards (voluntary, compulsory)	vintaging of new vehicle fleets, (demand)	VSM/TDM
Regulation for low rolling resistance tyres and tyre pressure monitoring	vehicle emissions factors	DEEM
Speed limits and enforcement	road vehicle speed profiles and emissions factors	DEEM
Fuel obligations (e.g. Renewable Transport Fuel Obligation)	carbon content of blended fuel, vehicle emissions factors	DEEM
Low emission zones (carbon)	‘redistribution’ of traffic to low emissions vehicles in access areas (e.g. urban)	VSM
High occupancy vehicle lanes	average load factors, (average speeds and emissions)	VSM, (DEEM)
Information, education, smart/soft measures		
Travel plans (individualised, residential, workplace, schools)	travel activity, modal shift, average distance travelled by car	SCENARIO
Eco-driving / driver behaviour	vehicle emissions factors	DEEM
Labelling	technology choice (via preference parameter)	VSM
Car sharing / pooling	load factors, car demand	VSM/TDM
Planning and investment		
Parking space availability	car ownership (second, third+ car)	VSM/TDM
Rail electrification	direct emissions, indirect emissions (electricity generation)	
Changes in electricity generation	indirect emissions from (plug-in, battery) electric vehicle use	LCEIM
Additional public transport infrastructure, e.g. high speed rail investment	indirect emissions from manufacture, (modal shift, induced demand)	LCEIM, (SCENARIO)

Note: TDM = transport demand model, VSM = vehicle stock model, DEEM = direct energy use and emissions model, LCEIM = life cycle and environmental impacts model

The graphical user interface

The user accesses the model mainly via a newly developed graphical user interface (GUI) which serves as the main portal for setting up the exogenous scenarios, endogenous policies and policy packages, running of the modelling chain, visualisation of the results in tabular and graphical form, and semi-automated export to Excel or similar analysis software packages. UKTCM has been developed in Microsoft Access 2007 as a relational database system. The main menu form of the GUI is shown in Figure 2. For further information on how to use the UKTCM refer to the accompanying user guide (Brand, 2010) which is available to download from the UKERC website (www.ukerc.ac.uk).

Figure 2: Screenshot of the main menu of the UKTCM user interface



The core modelling system

The four linked simulation models represent the core of the modelling system and describe the transport system and calculate their impacts. They are:

1. the transport demand model (TDM);
2. the vehicle stock model (VSM);
3. the direct energy use and emissions model (DEEM) and;
4. the life cycle and environmental impacts model (LCEIM).

The TDM calculates the overall level of transport activity and modal shares for passenger and freight movements. The VSM tracks the changes in the vehicle stock brought about by the overall demand for vehicles, the scrapping of old vehicles and the purchasing of new vehicles – potentially using new or improved propulsion technologies. This is highly disaggregated and involves comparing hundreds of alternative vehicle technologies in any year (Table 3a for passenger and Table 3b for freight transport). The outputs of the VSM are the total vehicle kilometres and number of vehicles (split by technology) each year.

Table 3a: Summary of UKTCM vehicle technologies for passenger transport

Vehicle type	*Size*	*Primary fuel*	*Engines/ drivetrains*	*No. of vintages*
Car	Small	Gasoline	ICV, PHEV	21
		Diesel	ICV	10
		Electric	Battery EV	3
		H_2, biomethanol	FC	4
	Medium	Gasoline	ICV, HEV, PHEV	30
		Diesel	ICV, HEV	21
		Biodiesel (B100)	ICV	3
		Bioethanol (E85)	ICV	9
		LPG, CNG	ICV	12
		H_2, biomethanol	FC	6
	Large	Gasoline	ICV, HEV, PHEV	30
		Diesel	ICV, HEV	22
		Biodiesel (B100)	ICV	3
		Bioethanol (E85)	ICV	9
		LPG	ICV	11
		H_2, biomethanol	FC, ICV	11
Motorcycle	Average	Gasoline	ICV	3
		Electric	Battery EV	3
		H_2	FC	3
Bus	Mini	Gasoline	ICV	3
		Diesel	ICV, HEV	22
		LPG, CNG	ICV	6
		E85	ICV	9
		Biodiesel (B100)	ICV	3
		H_2	FC	1
	Urban	Diesel	ICV, HEV, PHEV	30
		Electric	Battery EV	3
		LPG, CNG	ICV	5
		E85	ICV	3
		Biodiesel (B100)	ICV	3
		H_2, biomethanol	FC	9
	Coach	Diesel	ICV, HEV	22
		Electric	Battery EV	3
		LPG, CNG	ICV	5
		Biodiesel (B100)	ICV	3
		H_2, biomethanol	FC	9
Rail	Light, metro	Grid electricity	Electric	6
	Regional	Diesel	ICV	3
		Grid electricity	Electric	3
	Intercity	Diesel	ICV	3
		Grid electricity	Electric	3
	High speed	Grid electricity	Electric	3
Air	General aviation	Jet A-1	Turboprop	1
	Short haul, dom.	Jet A-1, H_2	Turbine	9
	Medium haul, int.	Jet A-1, H_2	Turbine	9
	Long haul, int.	Jet A-1, H_2	Turbine	9
	Supersonic, int.	Jet A-1, H_2	Turbine	9

Table 3b: Summary of UKTCM vehicle technologies for freight transport

Vehicle type	***Size***	***Fuels***	***Engines/ drivetrains***	***No. of vintages***
Trucks	Light (vans, <7.5t GVW)	Gasoline	ICV	13
		Diesel	ICV, HEV, PHEV	30
		Battery electric	Electric	3
		Biodiesel (B100)	ICV	9
		Bioethanol (E85)	ICV	9
		LPG, CNG	ICV	6
		H_2	FC	3
	Medium (7.5t - 16t GVW)	Diesel	ICV, HEV	14
		Biodiesel (B100)	ICV	4
		H_2, biomethanol	FC, ICV	14
	Large (>16t GVW)	Diesel	ICV, HEV	15
		Biodiesel (B100)	ICV	4
		H_2, biomethanol	FC, ICV	14
Rail	Regional	Diesel	ICV	3
		Grid electricity	Electric	3
Shipping	Inland	Diesel	ICV	2
	Coastal	Diesel	ICV	2
	Maritime	Diesel	ICV	2
Air	Short haul, dom.	Jet A-1, H_2	Turbine	9
	Medium haul, int.	Jet A-1, H_2	Turbine	9
	Long haul, int.	Jet A-1, H_2	Turbine	9
	Supersonic, int.	Jet A-1, H_2	Turbine	8

Where: GVW=gross vehicle weight; ICV=internal combustion engine vehicle; HEV=hybrid electric vehicle; PHEV=plug-in hybrid electric vehicle; H2=hydrogen (gaseous or liquid); B100=100% biodiesel; E85=85% bioethanol-15% gasoline blend; LPG=liquefied petroleum gas; CNG=compressed natural gas; dom.=domestic; int.=international; Jet A-1=aviation jet fuel (kerosene)

The DEEM takes data from the VSM to calculate direct[2] emissions and energy consumption due to the different vehicle technologies that comprise the vehicle fleet. The model produces information on emissions of carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_X), sulphur dioxide (SO_2), total hydrocarbons (THC) and particulate matter (PM). (The DEEM can also be linked to a Traffic Noise Model (TNM) which estimates the areas affected by various levels of noise.) The LCEIM has two functions. First, it provides an energy and emissions life cycle inventory due to the manufacture, maintenance and disposal of vehicles, as well as infrastructure contributions (e.g. embedded emissions from building high speed rail tracks). The inventory also provides energy use and emissions over the fuel production cycles for the different fuels used by different vehicle technologies. Secondly, the LCEIM estimates the environmental impacts of the overall levels of emissions by providing a series of 'impact indicators', such as global warming potential, as well as monetary valuation of the damage associated with such emissions levels (external costs).

[2] 'Direct' also refers to 'tailpipe', 'source' or 'end use'.

2 Transport Demand Model

Approach

The function of the transport demand model (TDM) is to simulate transport demand for the years up to 2050. The aim is to develop a set of plausible developments of transport demand as a function of scenario variables (such as the GDP growth rate) and costs of current and future transport technologies. Given the timescale involved, the TDM is not intended to provide an accurate prediction of the most likely future development of transport demand. The choice of the appropriate modelling approach has been determined by a trade-off between the required high level of detail and the availability of data.

In order to disaggregate the results for about 20 transport demand categories, a typical econometric modelling framework is used. This comes with a twist, however, as the demand model is applied using a two-pronged approach. For each of the main modes of transport (Table 4), demand is either

- calculated endogenously year by year up to 2050 employing a typical econometric demand model ('forecasting mode') or
- simulated with exogenous assumptions on how travel activity, modal split and trip distances may evolve over time ('simulation mode').

In 'forecasting mode' (simple econometric model), the evolution of demand depends on exogenous scenario parameters such as GDP, the number of households and the population's propensity to travel. It is also affected by the evolution of energy prices and average ownership and operating costs for each vehicle type, dependent on the technologies in the vehicle fleet and the levels of taxation, via a feedback loop from the vehicle and policy cost sub-modules.

In 'simulation' mode, demand is decoupled from forecasting in that the user puts in an externally derived or otherwise published demand projection. This allows exploring slightly more radical changes in consumer preferences and system changes that are not easy to model using standard econometric techniques based on historic consumer preferences (revealed through elasticities of demand). This two-pronged approach aims to provide a set of *plausible developments* of transport demand – it is not intended to provide an *accurate prediction* of the most likely future development of transport demand.

Table 4: The UKTCM transport demand segments

Passenger demand segments		***Freight demand segments***	
Mode	***Journey segment***	***Mode***	***Journey segment***
Walking	Urban	LDV (vans)	Urban
Cycling	Urban / non-urban		Rural
Motorcycle	Urban		Motorway
	Rural	HGV (trucks)	Urban
	Motorway		Rural
Car	Urban		Motorway
	Rural	Rail	Dedicated rail freight
	Motorway	Navigation	Inland / domestic
Bus	Local bus (urban)		Coastal / domestic
	Coach (motorway)		Maritime / intern.
	Minibus (rural)	Air freight	Domestic short haul
Rail	Light rail and underground		International medium haul / Europe
	Regional rail		International long haul / intercontinental
	Intercity rail		International supersonic
	High speed rail		
Passenger air	Domestic short haul		
	International medium haul / Europe		
	International long haul / intercontinental		
	International supersonic		

The amount of demand calculated in the TDM influences the development of prices in the Vehicle Stock Model (VSM) in the same year. The development of prices in the VSM then influences the development of demand in the TDM in the following year. This allows us to calculate a near-equilibrium between supply and demand. The use of optimisation software to model defined states of equilibrium in a single year has not been realised, for two reasons:

- The design strategy for the integration of the modelling chain in UKTCM required all software to be coded on a common database system like Microsoft Access.
- The whole concept of UKTCM is to provide a simple and rapid calculation of a large set of outcomes, which the users can then explore for themselves. The use of a lengthy optimisation routine to provide accurate forecasts for single policy scenarios is not consistent with this concept.

The final outputs of the demand model are passenger transport demand (expressed in passenger-kilometres) and freight transport demand (expressed in tonne-kilometres) for the demand segments summarised in Table 2.

The approach outlined above is deemed appropriate for the following reasons:

- The development of transport demand, especially freight transport demand, is strongly dependent on the GDP growth.

- The elasticities used in the TDM can vary from year to year. This reflects a change in people's behaviour and avoids a simple translation of the developments of the past into the future.
- The income and population elasticities used are short-run elasticities and reflect the dependence of transport demand on income and population growth in a given period – in a single year in UKTCM. Studies have shown that there is a difference between short-run and long-run transport demand elasticities. In the short run, incomes/prices influence the spontaneous decision of making a trip and also the decision concerning which transport mode is used (e.g. in the short run, a car has already been purchased and only the variable costs of a trip are decisive). In contrast, in the long-run, changes in income and in prices can lead to a lasting change in people's behaviour and can also influence the vehicle purchase decision. This difference between short-run and long-run effects has been taken into account in an indirect way in UKTCM. On the one hand, the elasticities used in the TDM reflect the short-run effects of prices/costs on transport demand. On the other hand, the VSM handles long-run effects on transport demand like vehicle purchasing cost, which are transmitted to the TDM via the average transport costs.
- The design of the UKTCM does not allow for a feedback between transport prices and GDP. This is desirable from a theoretical point of view, but can only be realised with a complex (combined economic and transport demand) modelling approach performed by an equilibrium modelling software like GAMS, and not in MS-Access. However, from a practical point of view this is not necessary as long as the policy effects (of raising fuel duty, for example) are moderate. A good way to estimate the effect of the missing feedback would be to compare UKTCM with an economic model. The transport demand results, the changes in transport costs and the amount of transport taxes over the modelling years obtained from a UKTCM modelling run could be used as input for an economic model. This would show the effect on the development of GDP and a possible correction to the GDP scenario to be used in a repeat of the modelling run.

Overview of the demand modelling specification

At the top level transport demand is split into passenger transport (the demand for transporting people) and freight transport (the demand for transporting goods). For both types of transport overall demand is derived using a simple transport demand function that relates demand (dependent variable) with explanatory variables such as scenario context variables, policy variables and other UKTCM input variables.

Figure 3: Outline structure of the TDM

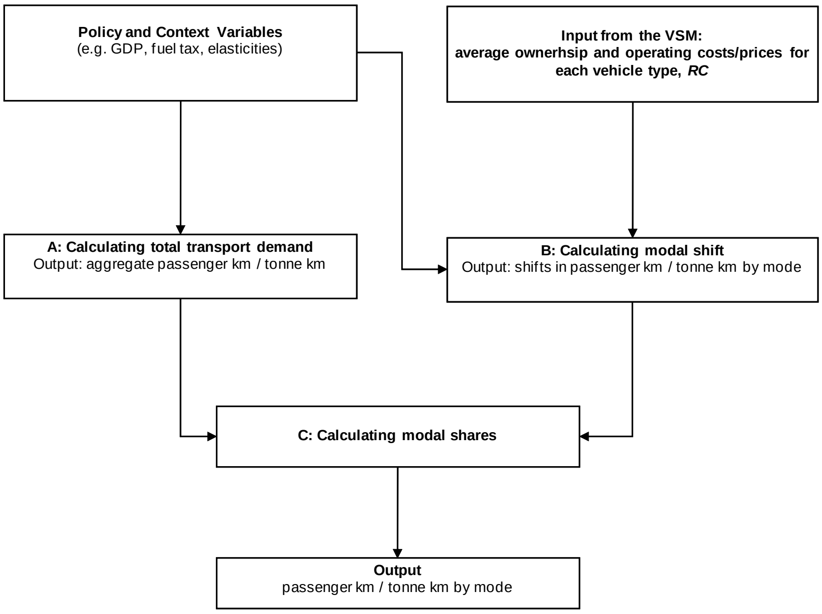


Figure 3 outlines the structure of the TDM. Based on scenario, context and policy variables such as GDP and population forecasts, step A calculates overall transport demand for passenger and freight. In step B changes in modal (e.g. car, bus, truck, passenger air) make up of total demand are derived on the basis of relative changes in average ownership and operating costs for each mode. The relative changes of supply costs for each mode of transport fed back from the VSM lead to an income effect influencing the level of demand and a substitution effect causing a change in the relative transport volume shares for each mode. Step C merges the outputs of steps A and B, checks for internal consistency and finally provides modal shares for each demand segment.

Steps A and B can be summarised in an econometric function of exogenous parameters, together with their respective elasticities of demand. This takes on the form shown in Equation 1:

Equation 1: The main UKTCM demand function

$$\left[\frac{T_n}{T_{n-1}}\right] = \left[\frac{GDP_n}{GDP_{n-1}}\right]^{EGDP} * \left[\frac{NHH_n}{NHH_{n-1}}\right]^{ENHH} * \left[\frac{RC_n}{RC_{n-1}}\right]^{-ERC}$$

where *T* = demand for travel (expressed in passenger-km and tonne-km)
GDP = Gross Domestic Product
NHH = total number of households
RC = relative vehicle ownership and operating costs
EX = elasticity with respect to X
n = modelling year (currently 1996, 1997, …, 2050)

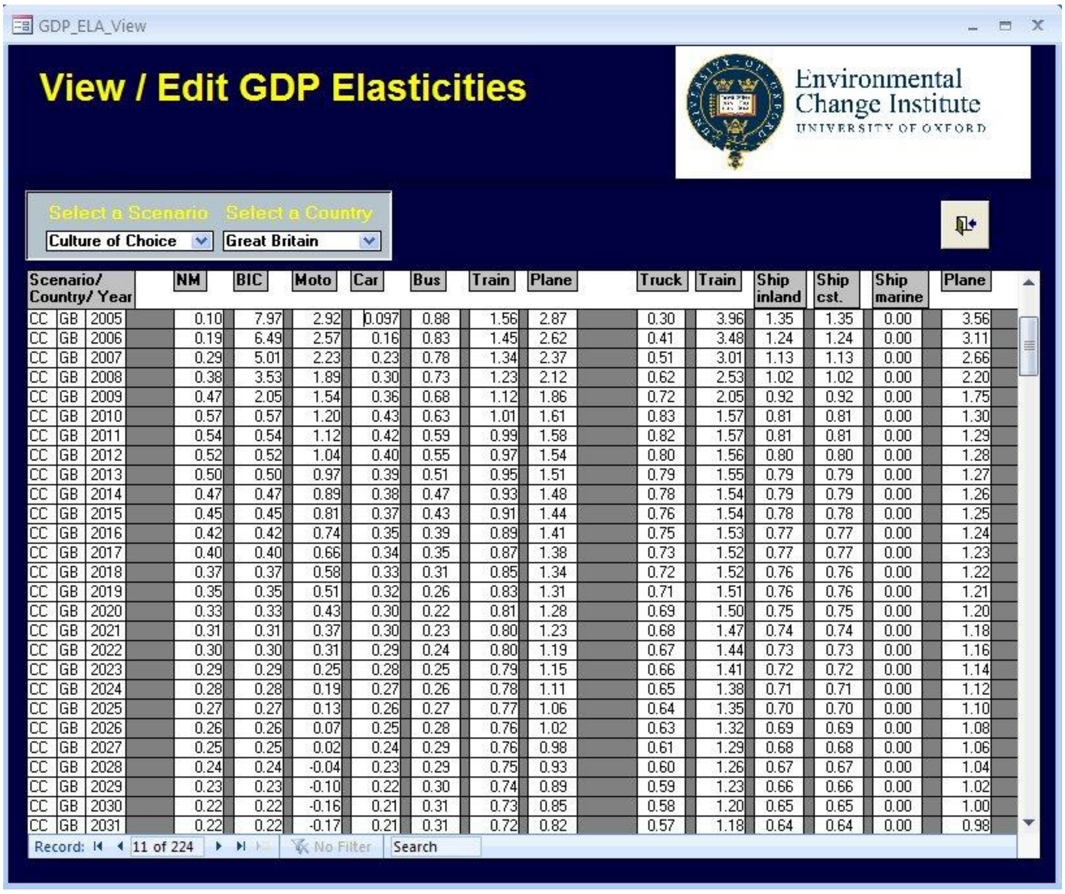
As mentioned above, in the short run incomes/prices influence the spontaneous decision of making a trip and also the decision concerning which transport mode is used. In contrast, in the long-run, changes in income and in prices can lead to a lasting change in people's behaviour and can also influence vehicle purchase decisions (for a good review see Goodwin et al., 2004). The difference between short-run and long-run effects has been taken into account in an indirect way in UKTCM. The first two elasticities in Equation 1 reflect the short-run effects of changes in prices/costs/population on transport demand. The third elasticity reflects the long-run effects of relative changes of vehicle ownership and operating costs as fed back by the vehicle stock model.

To avoid a simple static approach the elasticities can take different values for each future year up to 2050. This dynamic approach allows modelling change in behaviour and preferences and avoids a simple projection of the past into the future. The estimation of the parameters for the calculation of future demand is based on statistical data for previous years and on transport demand forecasts taken from other studies. This allows the researcher and user to specify a 'base case' or 'reference' scenario against which alternative scenarios are compared.

The main TDM inputs

The TDM uses a number of parameters to determine transport demand, which can all be readily modified by the user. The parameters can be divided into four groups. In the first group are *income elasticities* and *population growth elasticities* for each of the demand segments listed in Table 4. The income elasticities represent the dependence of transport demand growth on growth of income measured as *GDP*. The population growth elasticities reflect the dependence of transport demand on the development of the population measured as the *number of households*. An example is shown for income elasticities in Figure 4.

Figure 4: TDM form to view and edit income elasticities



GDP_ELA_View

View / Edit GDP Elasticities

Environmental Change Institute
UNIVERSITY OF OXFORD

Select a Scenario: Culture of Choice
Select a Country: Great Britain

Scenario/ Country/ Year			NM	BIC	Moto	Car	Bus	Train	Plane	Truck	Train	Ship inland	Ship cst.	Ship marine	Plane
CC	GB	2005	0.10	7.97	2.92	0.097	0.88	1.56	2.87	0.30	3.96	1.35	1.35	0.00	3.56
CC	GB	2006	0.19	6.49	2.57	0.16	0.83	1.45	2.62	0.41	3.48	1.24	1.24	0.00	3.11
CC	GB	2007	0.29	5.01	2.23	0.23	0.78	1.34	2.37	0.51	3.01	1.13	1.13	0.00	2.66
CC	GB	2008	0.38	3.53	1.89	0.30	0.73	1.23	2.12	0.62	2.53	1.02	1.02	0.00	2.20
CC	GB	2009	0.47	2.05	1.54	0.36	0.68	1.12	1.86	0.72	2.05	0.92	0.92	0.00	1.75
CC	GB	2010	0.57	0.57	1.20	0.43	0.63	1.01	1.61	0.83	1.57	0.81	0.81	0.00	1.30
CC	GB	2011	0.54	0.54	1.12	0.42	0.59	0.99	1.58	0.82	1.57	0.81	0.81	0.00	1.29
CC	GB	2012	0.52	0.52	1.04	0.40	0.55	0.97	1.54	0.80	1.56	0.80	0.80	0.00	1.28
CC	GB	2013	0.50	0.50	0.97	0.39	0.51	0.95	1.51	0.79	1.55	0.79	0.79	0.00	1.27
CC	GB	2014	0.47	0.47	0.89	0.38	0.47	0.93	1.48	0.78	1.54	0.79	0.79	0.00	1.26
CC	GB	2015	0.45	0.45	0.81	0.37	0.43	0.91	1.44	0.76	1.54	0.78	0.78	0.00	1.25
CC	GB	2016	0.42	0.42	0.74	0.35	0.39	0.89	1.41	0.75	1.53	0.77	0.77	0.00	1.24
CC	GB	2017	0.40	0.40	0.66	0.34	0.35	0.87	1.38	0.73	1.52	0.77	0.77	0.00	1.23
CC	GB	2018	0.37	0.37	0.58	0.33	0.31	0.85	1.34	0.72	1.52	0.76	0.76	0.00	1.22
CC	GB	2019	0.35	0.35	0.51	0.32	0.26	0.83	1.31	0.71	1.51	0.76	0.76	0.00	1.21
CC	GB	2020	0.33	0.33	0.43	0.30	0.22	0.81	1.28	0.69	1.50	0.75	0.75	0.00	1.20
CC	GB	2021	0.31	0.31	0.37	0.30	0.23	0.80	1.23	0.68	1.47	0.74	0.74	0.00	1.18
CC	GB	2022	0.30	0.30	0.31	0.29	0.24	0.80	1.19	0.67	1.44	0.73	0.73	0.00	1.16
CC	GB	2023	0.29	0.29	0.25	0.28	0.25	0.79	1.15	0.66	1.41	0.72	0.72	0.00	1.14
CC	GB	2024	0.28	0.28	0.19	0.27	0.26	0.78	1.11	0.65	1.38	0.71	0.71	0.00	1.12
CC	GB	2025	0.27	0.27	0.13	0.26	0.27	0.77	1.06	0.64	1.35	0.70	0.70	0.00	1.10
CC	GB	2026	0.26	0.26	0.07	0.25	0.28	0.76	1.02	0.63	1.32	0.69	0.69	0.00	1.08
CC	GB	2027	0.25	0.25	0.02	0.24	0.29	0.76	0.98	0.61	1.29	0.68	0.68	0.00	1.06
CC	GB	2028	0.24	0.24	-0.04	0.23	0.29	0.75	0.93	0.60	1.26	0.67	0.67	0.00	1.04
CC	GB	2029	0.23	0.23	-0.10	0.22	0.30	0.74	0.89	0.59	1.23	0.66	0.66	0.00	1.02
CC	GB	2030	0.22	0.22	-0.16	0.21	0.31	0.73	0.85	0.58	1.20	0.65	0.65	0.00	1.00
CC	GB	2031	0.22	0.22	-0.17	0.21	0.31	0.72	0.82	0.57	1.18	0.64	0.64	0.00	0.98

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The second group of parameters provides values for the spatial disaggregation of transport demand. Three values are given for each for the vehicle types motorcycle, car, bus, train and truck, which express the share of transport demand for the journey segment types urban, rural and highway. Passenger rail is disaggregated by urban rail (light rail, underground), regional rail (slow to medium regional services), intercity rail (fast inter-regional services) and high speed rail (currently only Eurostar services operating from London St Pancras International). Air travel is spatially disaggregated by domestic short haul, international medium haul (Europe), international long haul (intercontinental) and international supersonic (intercontinental).

The third group of parameters provides yearly values for the average trip length for the vehicle types car, bus, motorcycle, plane and truck. These are used in the DEEM to calculate cold start emissions as well as disaggregation of aircraft emissions by flight phases ‘cruise’ and ‘landing and take-off’ (LTO).

The fourth group gives the cost elasticities of transport demand. These elasticities represent the dependence of transport demand growth on the change of relative costs provided by the VSM. Again the elasticities can be specified for each year to avoid a simple static approach. The TDM takes average weighted cost information for all motorised vehicle types (passenger transport: car, train, bus, plane; freight transport: truck, train, shipping, plane). The cost figures represent a weighted average of the running costs and purchase costs for a given vehicle type and year. The development of the costs over time is used in the TDM to determine the shift of demand between the vehicle types, for passenger and freight transport respectively. An example is shown for income elasticities in Figure 5.

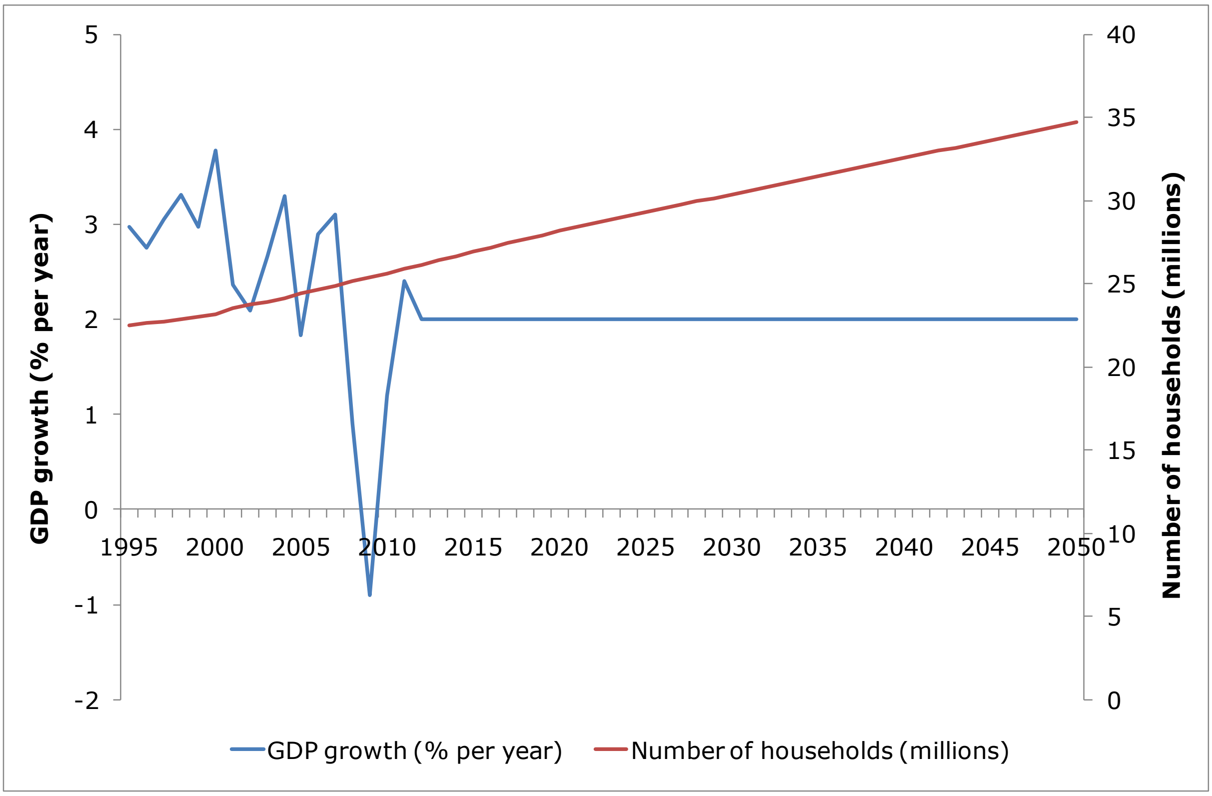
Figure 5: TDM form to view and edit average transport cost elasticities

Scenario/	Country/	Year	Passenger total	Car	Bus	Train	Plane	Freight total	Truck	Train	Ship inland	Plane
CC	GB	2007	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2008	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2009	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2010	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2011	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2012	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2013	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2014	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2015	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2016	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2017	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2018	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2019	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2020	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2021	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2022	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2023	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2024	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38
CC	GB	2025	0.38	0.54	0.38	0.24	0.38	0.35	0.61	0.24	0.18	0.38

Demand model calibration

The demand elasticities were calibrated for the base year (1995) and subsequent years up to 2007, based on published statistics of transport (DfT, 2008b), demographic (ONS, 2008) and economic (HM Treasury, 2008) data. For future years up to 2050, the elasticities were either set to historic averages ('forecasting mode') or derived once the user had specified an exogenous set of demand projections ('simulation mode'). The GDP growth rates and population projections used in the calibration are shown in Figure 6.

Figure 6: Historic and projected GDP growth rates and number of households for the reference scenario



Sources: demographic (ONS, 2008) and economic (HM Treasury, 2008) data, and own assumptions for GDP beyond 2012

In 'simulation mode' internal consistency checks can be carried out by comparing the elasticities implicit in the exogenous demand, GDP and population projections with published figures. For instance, Wohlgemuth (1997) provides short-run income elasticities of demand of between 0.23 (Europe) and 0.78 (US) for distance travelled by cars, 0.39 (Europe) for tonne-km by trucks and between 1.35 (Europe) and 1.75 (US) for passenger air miles travelled. These are comparable with other studies such as Goodwin et al. (2004). Assuming a long term GDP growth rate of just 2% per year, Government projections of population growth and taking current demand projections based on DfT (2008a), the UKTCM demand model calibration implied short term (2010-2020) elasticities in the range between 0.3 and 0.4 for distance travelled by car, between 0.7 and 0.8 for tonne-km by trucks and between 1.3 and 1.6 for passenger air miles – a reasonable fit with published data (Clements, 2008; see e.g. Goodwin et al., 2004; Wohlgemuth, 1997).

2 Vehicle Stock Model

Overview

The vehicle stock model (VSM) is the most complex of the four models employed in UKTCM. It provides two key functions within the UKTCM system:

1. a breakdown of the numbers of vehicles present in the population, by vehicle type, size, technology and age, as input to the LCEIM;
2. detailed disaggregation of the vehicle-kilometres produced in the TDM, in terms of vehicle size, technology and age, as input to the DEEM and the LCEIM.

A crucial attribute of the stock model is that the user can test the effects of policy levers on the deployment of different technologies within the vehicle population.

The basis of the vehicle stock model is the evolution of the vehicle stock, in size, age and technology terms, over time. In each year the structure of the vehicle population will change due to a combination of two processes: the purchase of new vehicles and the scrapping of old vehicles. The process is iterative, with changes year-on-year against the vehicle population distribution for the base year. New technologies enter the population through the purchase of new vehicles. For all vehicle types there is a common equation which describes the way the vehicle stock evolves over time (Equation 2).

Equation 2: The basic formula for vehicle stock evolution

$$NewVehicles(y) = TotalVehicles(y) - TotalVehicles(y-1) + ScrappedVehicles\ (y-1)$$

where y = modelling year, from (base year + 1) to end of modelling horizon

To understand the processes for modelling vehicle supply and linking supply to demand, the processes are split into five separate modules:

1. Vehicle supply (for cars at level of car ownership);
2. Vehicle scrappage;
3. Technology availability for new vehicles;
4. Technology choice for new vehicles;
5. Vehicle-kilometre distribution.

The key steps in calculating the vehicle stock for each vehicle type are summarised in the box and in Figure 7 below. During model run time, they are repeated for each year, background scenario, policy package and transport mode (car, bus, rail, etc).

Key steps in calculating vehicle stock

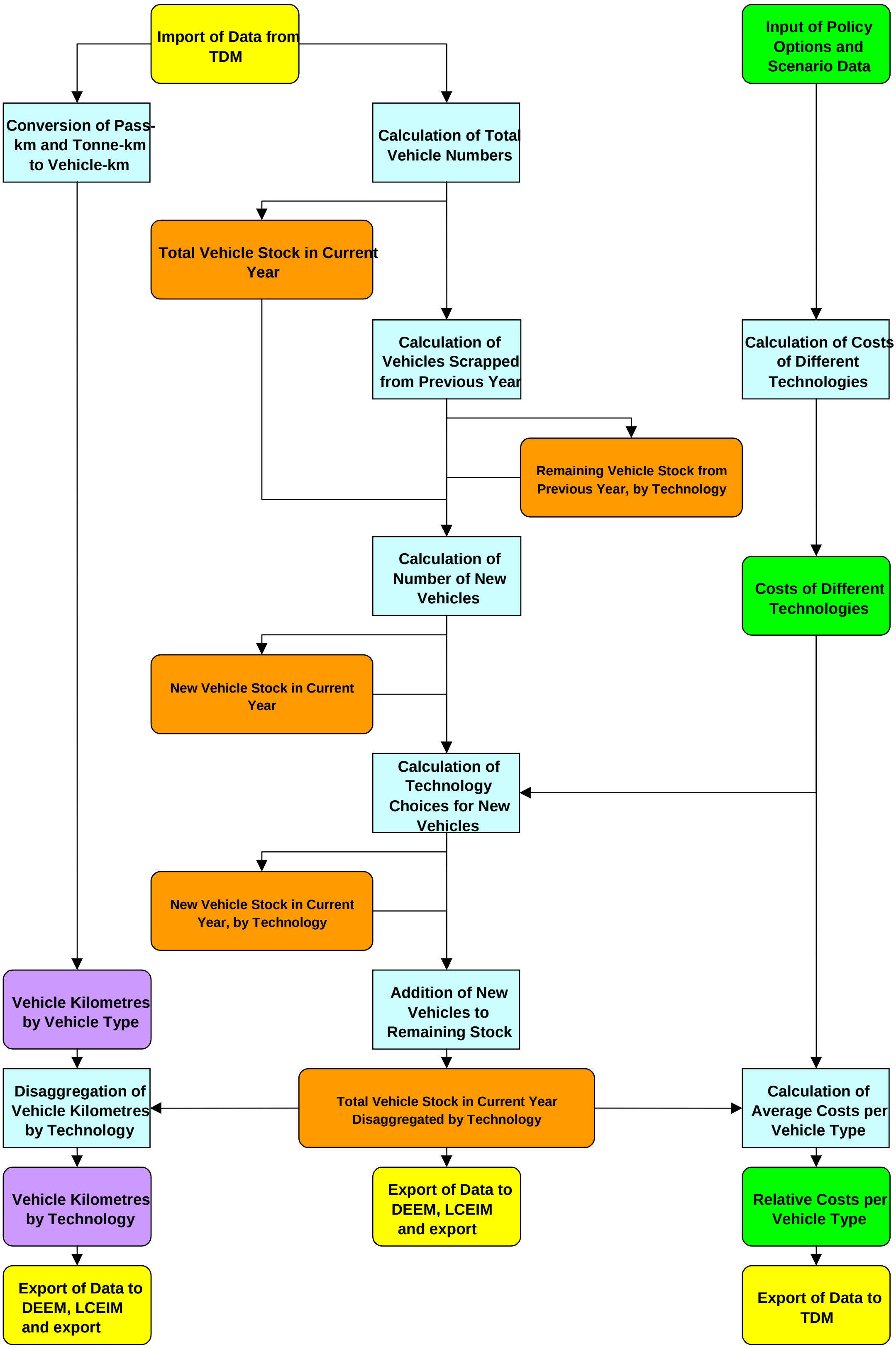
1. Import of passenger-kilometres and tonne-kilometres from the demand model
2. Conversion of passenger-kilometres or tonne-kilometres produced by the demand model into vehicle-kilometres, based on average load factors
3. Calculation of total vehicle numbers
4. Calculation of total number of vehicles scrapped
5. Calculation of total number of new vehicles needed to meet demand
6. Calculation of vehicle costs for each technology based on technology costs and policy inputs
7. Disaggregation of new vehicles by size
8. Disaggregation of new vehicles by technology (engine type, fuel)
9. Addition of new vehicles to the remaining vehicle stock from the previous year
10. Disaggregation of vehicle-kilometres by technology
11. Calculation of average costs per vehicle type, based on disaggregated vehicle numbers and vehicle kilometres
12. Output of vehicle numbers and vehicle kilometres by technology and travel type to the DEEM and LCEIM
13. Output of relative operating costs (RC) to TDM by vehicle type

Within the VSM, the calculation of the total number of different vehicle types in the stock each year is treated separately, as different forces are assumed to affect the entry of new vehicles into the stock. The background scenarios, which describe the societal factors and attitudes that partly determine vehicle ownership, affect the overall vehicle numbers in each year. The vehicle types modelled are motorcycles, three passenger car sizes, urban buses, express coaches, mini buses, vans, medium and large trucks, four aircraft sizes, four train sizes and three shipping vessel sizes.

The entry of new car technologies into the population is modelled slightly differently from the entry of other new vehicle technologies by splitting the private car market from the fleet market and by assuming a higher discount rate (“hurdle” rate) for annuitizing upfront costs. Vehicle scrappage is essentially treated in the same way for all vehicle types and uses a modified statistical approach.

The following sections provide the detailed model specification of each module, starting with the vehicle ownership modules.

Figure 7: Flow of calculations in the Vehicle Stock Model



Vehicle ownership

The purpose of this module is to estimate the total number of vehicles necessary to fulfil demand in a given year. The number is obtained in a different way for each vehicle type. In particular, the more complicated procedure is that one used for cars. The others are slightly simpler and similar to each other. The description is reported separately for each vehicle type.

Definitions

The whole set of years considered is defined as $Y = \{1,...,n\}$. The expression $\forall y \in Y$ means that all the years are taking into consideration, otherwise the equation reports explicitly which one it refers to. The base year is indicated with $y = 0$ or directly with 0. In the current version of the VSM, the base year is 1995.

In the same way, the whole set of transport modes considered is indicated with $M = \{1,...,m\}$. $E = \{1,...,r\}$ represents the set of scenarios. In addition, two others set were defined; one, *Z*, representing vehicle size (NB: not all vehicle types are broken down further by size), and the other, *T*, representing all available technologies for each vehicle type.

1.1.1 Passenger cars

The purpose of this module is to estimate the total level of car ownership for each modelled year. It draws upon previous household car ownership models following the development of the 1997 UK National Road Traffic Forecast model (DETR, 1997) and its improvements as specified by ITS Leeds (2001) and Whelan (2007). The module treats household ownership of a first, second and third or more car separately and draws on a number of explanatory variables such as changes in average new car prices, car ownership saturation levels, household location (urban, non-urban), household disposable income and availability of public transport.

Overall levels of car ownership are expected to continue growing until a "saturation point" is reached. To date no country in the world has reached such a saturation point, which is assumed to occur when all those able to drive have their own vehicle (leading to a level of car ownership of approximately 650 vehicles per 1000 population). European levels of car ownership vary considerably. In 2001, Greece had the lowest car ownership level at 312 cars per 1000 inhabitants, with Luxembourg (635) the highest and the UK below the median at 433 cars per 1000 inhabitants (EUROSTAT, 2003).

The difference between overall levels of car ownership at the start of year *n+1*, levels of ownership at the start of year *n* and the number of vehicles scrapped during year *n* provides the number of new cars purchased in year *n*, for each successive year.

Car ownership is mostly modelled on a household basis, as it is considered to be at this level at which decisions are made. The level of car ownership is considered to be linked directly with changes in disposable incomes, which are in turn linked to changes in GDP, fuel prices and other household expenditure. The serious drawback of using a GDP-based model for levels of car ownership is that this precludes the option of de-coupling transport and vehicle demand from economic growth through policy intervention.

The key variables used for modelling household car ownership are:

- household structure (number of adults, number and age of children);
- household disposable income (by year);
- average new car price;
- household location (urban and non-urban), linked to public transport availability;
- car ownership saturation level (urban and non-urban).

Apart from the average new car price all of the above listed variables are scenario variables, i.e. they are assumed to be external to the transport system. The average new car price in year *n+1*, on the other hand, is derived based on the average car price in year *n*, weighted by the vehicle-km for each car technology in year *n*. This includes any scenario and policy options applied, e.g. cost reduction of technology 'x' assumed in background scenario 'y', or graded purchase taxes or rebates assumed in policy scenario 'z'. For example, the lower average car purchase price brought about by a national car scrappage scheme increases overall car ownership levels as long as the scheme is in place. Once the scheme is abolished the average car purchase price goes up again relative to no policy option, thus decreasing overall car ownership.

The households are divided into three "ownership groups", namely:

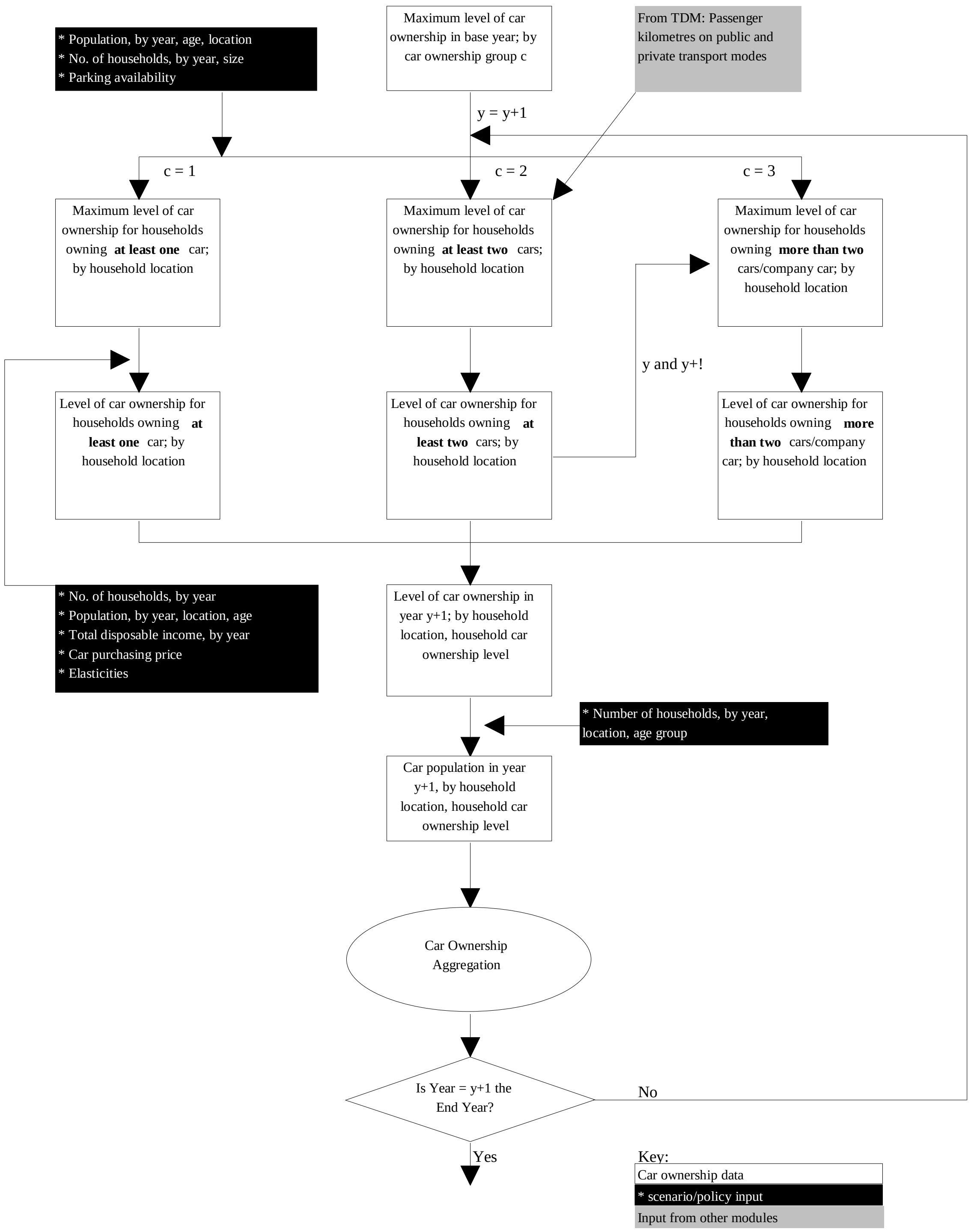
1. households owning at least one car;
2. households owning at least two cars; and
3. households owning more than two cars or having a business car at their disposal.

They are treated separately and a subscript letter c indicates which one has been considered, while the whole set is represented with $C = \{1,...,3\}$. The expression $\forall c \in C$ means that there is an equation for each group otherwise the equation reports explicitly which one it refers to.

As a further twist, households in different locations (urban/non-urban) are treated differently and in the same way a subscript letter *l* indicates which one has been considered, while the whole set is represented with $L = \{1,.2\}$. The product $|L| \cdot |C|$ gives a total of six household categories.

A schematic presentation of how total car ownership is derived in UKTCM is shown in Figure 8.

Figure 8: Flow chart of how total car ownership is derived in UKTCM



As specified in Equation 3, the total stock of cars $V_{y,v=1}$ for each year y is calculated by:

- multiplying the share of households owning cars by the total number of households, disaggregated by ownership level and household location;
- aggregating over household location and car ownership level.

Equation 3: Calculation of total car ownership

$$V_{y,v=1} = \sum_{\substack{l \in L; \\ c \in C;}} P_{c,l,y} * NumHH_{l,y} \quad \forall y \in Y$$

where $NumHH_{l,y}$ is the number of households for each year and location, and $P_{c,l,y}$ represents the share of households falling in each category.

While $NumHH_{l,y}$ is the user's preferred population projection/forecast, the household hares $P_{c,l,y}$ are endogenously modelled. The equations used to calculate the proportion of household with one, two or more than two cars ($P_{c,l,y}$) are slightly different since buying a first car is considered to be a different type of decision than the purchase of a second, third or business car.

In order to present the equations to calculate *P*, it is necessary to define a maximum level of the proportion of car ownership: $MaxOwn_{c,l,y}$. It limits the overall growth level and it depends on many factors such as the proportion of the population able to drive and the household size distribution.

The base maximum levels of car ownership in urban and rural areas are assumed to be 100% for at least one car, 70% for at least 2 cars and 30% for three or more cars. Rural shares are slightly higher at 100% (at least one car), 80% (at least two cars) and 40% (three or more cars). The base year levels for urban areas in the UK are 65% for at least one car, 17% for at least two cars and 3% for three or more cars. Rural shares are slightly higher at 78% (at least one car), 27% (at least two cars) and 4% (three or more cars).

The maximum level of car ownership (i.e. the saturation level of the Sigmoid curve) is dependent on:

- the share of the population who cannot drive (people below legal driving age);
- the household size, which takes three values of: 1 person, more than 1 person;
- the parking availability, a user-defined index (only applied to households in urban areas);
- the availability of public transport (for households in non-urban areas).

The equation to calculate the maximum level of car ownership varies with the number of cars owned (dimension c).

Calculating maximum car ownership for households owning at least one car

For households owning at least one car, the equation used is the same for both urban and non-urban areas (Equation 4).

Equation 4: Maximum car ownership for households owning at least one car

$$MaxOwn_{c=1,l,y} = MaxOwn_{c=1,l,0} * f^2$$

where

$$f^2 = \frac{D_y}{D_0}$$

is the change of the share of the population able to drive relative to the base year. D_y is an exogenous scenario variable and can be changed by the user for each modelling year.

Calculating maximum car ownership for households owning at least two cars

For households owning at least two cars, the methods to calculate maximum car ownership are different for urban and non-urban areas.

In *urban areas* (*l = 1*), this maximum level is given by a combination of the availability of parking space with the change in proportion of households with more than one person, as shown in Equation 5.

Equation 5: Maximum car ownership for households owning at least two cars, in urban areas

$$MaxOwn_{c=2,l=1,y} = MaxOwn_{c=2,l=1,0} * f^3 * ParkIndex$$

where

$$f^3 = \frac{mop_y}{mop_0}$$

is the ratio of the share of households with more than one person in the current year (mop_y) to the share of households with more than one person in the base year (mop_0), and

$$ParkIndex = \frac{PA_y}{PA_0}$$

is the *parking availability index*, related to base year availability. The index is an internal parameter of the VSM, and $PA_0 = 100$ is assumed as the base year value.

In *non-urban areas* (*l = 2*), on the other hand, the maximum level is given by Equation 6.

Equation 6: Maximum car ownership for households owning at least two cars, in non-urban areas

$$MaxOwn_{c=2,l=2,y} = MaxOwn_{c=2,l=2,0} * f^3 * f^4$$

where the first function, f^3, is the same as in the sub-model for urban areas, representing the change in the proportion of household with more than one adult with respect to the base year, while the second one represents the *availability of public transport in non-urban areas*:

$$f^4 = \frac{PK_{l=2,0}}{PK_{l=2,y}}$$

where $PK_{l=2,y}$ is calculated as total bus and train passenger-km driven in non-urban areas:

$$PK_{l=2,y} = PKM_{bus,rural,y} + PKM_{bus,motorway,y} + PKM_{rail,regional,y} + PKM_{rail,intercity,y}$$

The maximum level of car ownership for households owning at least two cars is then aggregated over household locations, as shown in Equation 7.

Equation 7: Maximum car ownership for households owning at least two cars, aggregated over geographical areas

$$MaxOwn_{c=2,y} = \sum_{l=1}^{2} MaxOwn_{c=2,l,y} \times \frac{NumHH_{l,y}}{NumHH_y}$$

Calculating maximum car ownership for households owning at least three cars

The maximum car ownership level for households owning at least three cars is assumed to stay constant over the modelling period, as specified in Equation 8.

Equation 8: Maximum car ownership for households owning at least three cars

$$MaxOwn_{c=3,l,y} = MaxOwn_{c=3,l,0}$$

Once the maximum level of car ownership is derived, the actual levels of ownership can be calculated as follows.

Calculation of the share of households owning a least one or two cars

The proportion of households owning at least one car or two cars is mainly determined by the ratio of *disposable income for each household (I_y)* to the *average new car purchase price (R_y)* through a sigmoid (S-shaped) curve. As disposable income grows (or shrinks) the total level of car ownership will also grow (or shrink), but the rate at which this occurs depends on the car ownership elasticity (e_y). Moreover, to define the sigmoid function it is necessary to define the point where the slope changes. In this case, the point is defined through the function f^5 which represents the car ownership elasticity parameter; it is calibrated internally in VSM for the base year ($y = 0$) and stays constant over the modelling horizon.

For each year, y, the *share of households owning at least one or two cars* is given by Equation 9 below.

Equation 9: Car ownership for households owning at least one or two cars

$$P_{c,l,y} = MaxOwn_{c,l,y} * \left[\frac{\left(f_y^1\right)^{e_y}}{\left(f_y^1\right)^{e_y} + f_{c,l,0}^5} \right] \quad \forall c = 1,2; l \in L; y \in Y$$

where

$$f_y{}^1 = \frac{I_y}{R_y}$$

and

$$f^5_{c,l,0} = \left(\frac{MaxOwn_{c,l,0}}{H_{c,l,0}} - 1\right) * \left(f^1_0\right)^{e_0}$$

$$e_y = e_0\left[1 + g * \left(\frac{MaxOwn_{c,l,y}}{f^7} - 1\right)\right]$$

The latter function updates the base value of the car ownership elasticity e_0 for each car ownership type, household location and year. It is a function of the calibration parameter *g* and f^7, which is given by:

$$f^7 = (MaxOwn_{c,l=1,y} * Sh_{c,l=1,y} + MaxOwn_{c,l=2,y} * Sh_{c,l=2,y})$$

<u>Share of households owning at least three cars</u>

For each year the share of households owning more than two cars or having a company car at their disposal is given by Equation 10:

Equation 10: Car ownership for households owning at least three cars

$$P_{c=3,l,y} = MaxOwn_{c=3,l,0} + \left(P_{c=3,l,y-1} - MaxOwn_{c=3,l,0}\right) * f^6_y \quad \forall l \in L; y \in Y$$

where

$$f_y{}^6 = \frac{H_{c=2,l=2,y} - MaxOwn_{c=2,l=2,y}}{H_{c=2,l=2,y-1} - MaxOwn_{c=2,l=2,y-1}}$$

F_y^6 is the relative change in the share of households owning two cars. The idea is that the proportion of household owning three cars increases (or decreases) in the same way that the proportion of household with two cars increases (or decreases).

1.1.1 Motorcycles

When compared to the car model the motorcycle module is fairly simple and matches demand and supply (total ownership) by mapping the single motorcycle demand segment to the single ‘average motorcycle’ size category. Table 5 gives the main assumptions on vehicle capacities and load factors for the year 2008. These assumptions were derived from calibrating the model to national transport statistics (DfT, 2009a).

Table 5: The main motorcycle model assumptions

Vehicle size category	*Average capacity (AvgCap), in pass/vehicle*	*Average load (AvgLF)* [(1)]	*Average annual vehicle distance travelled (AveAnnKM)*
Average motorcycle	2	54%	5,272

Notes: [(1)] the figures shown are for the year 2008. *AvgLF* taken from (DfT, 2009a).

These parameters feed into the calculation of total vehicle-km travelled, as shown in Equation 13.

Equation 11: Bus traffic by vehicle size category

$$VKM_{y,v=1,s} = \frac{PKM_{y,v=1,d}}{AvgCap_s \times AvgLF_s}$$

where: $VKM_{y,v=2,s}$ = vehicle-km for year y
$PKM_{y,v=2,d}$ = passenger-km for year y
$AvgCap_s$ = average capacity (in passengers per vehicle)
$AvgLF_s$ = average load factor (in % of capacity)

The average load factor, *AvgLF*, and average annual distance travelled, *AveAnnKM*, are scenario variables and determine the total number of buses needed to fulfil demand (expressed in vehicle-km). Both *AvgLF* and *AveAnnKM* can be changed for each future year, thus making it possible to simulate futures with different vehicle utilisations and travel patterns.

From this it is straightforward to calculate the total number of buses needed to fulfil demand by applying Equation 12.

Equation 12: Total motorcycle ownership

$$V_{y,v=1,s} = \frac{VKM_{y,v=1,s}}{AveAnnKM_{y,s}}$$

where: $V_{y,v=2,s}$ = vehicle stock for year y
$VKM_{y,v=2,s}$ = vehicle-km for year y
$AveAnnKM_{y,s}$ = average annual vehicle distance travelled for year y

1.1.2 Non-private vehicles

The number of vehicles needed for commercial purposes (which includes all vehicles other than private cars and motorcycles) is dependent on the level of activity demanded coupled with the efficiency of vehicle operation, or the level of vehicle utilisation. For passenger transport (including air) this depends on the number of passenger-kilometres demanded by the travelling public, together with vehicle capacities, loading factors on vehicles, service frequencies and timetabling considerations. For freight transport this depends on the tonne-kilometres needed, together with vehicle sizes, loading factors and vehicle scheduling. For road freight, overall truck and van ownership is also strongly linked to economic activity (GDP).

The level of activity is an input from the TDM. However, vehicle utilisation is affected by possible policy options, such as:

- deregulation/ regulation of services (e.g. airlines in Europe);
- any fiscal measures affecting the balance of costs in the freight industry.

The scenario and policy variables used for modelling 'other' vehicle ownership include:

- GDP growth rates;
- vehicle utilisation in the commercial sector.

Note vehicle purchase price is not usually taken into consideration when calculating overall vehicle ownership levels for other vehicles than cars; it is considered that as GDP grows the relative price of a new vehicle is dropping and this is explained by the elasticity between GDP and vehicle ownership levels.

1.1.3 Buses and coaches

The TDM provides the number of passenger-km for three bus demand segments namely urban, rural and motorway/dual-carriageway. The bus module makes the simple assumption of mapping these demand segments to the three bus size categories included in the model, namely urban bus, mini bus (scheduled community bus in rural areas) and express coach (e.g. National Express, Airport links). Table 6 shows this mapping together with assumptions on vehicle capacities and load factors for the year 2008. These assumptions were derived from calibrating the model to national transport statistics (DfT, 2009a).

Table 6: The main bus model assumptions

Demand segment	*Vehicle size category*	*Average capacity (AvgCap), in pass/vehicle*	*Average load (AvgLF)* [(1)]	*Average annual vehicle distance travelled (AveAnnKM)*
Bus, Urban	Urban bus	40	23.8%	57,052
Bus, Rural	Mini bus	8	40%	50,000
Bus, Motorway	Express coach	40	23.8%	143,337

Notes: [(1)] the figures shown are for the year 2008. The reference scenario assumes load factors for urban buses and coaches improve gradually over time to about 30% by 2050.

These parameters feed into calculation of total vehicle-km travelled by each bus size category, as shown in Equation 13.

Equation 13: Bus traffic by vehicle size category

$$VKM_{y,v=2,s} = \frac{PKM_{y,v=2,d}}{AvgCap_s \times AvgLF_s}$$

where: $VKM_{y,v=2,s}$ = vehicle-km for year y, by size s (urban, mini, coach)
$PKM_{y,v=2,d}$ = passenger-km for year y, by demand segment d

AvgCap$_s$	= average capacity (in passengers per vehicle), by size *s*
AvgLF$_s$	= average load factor (in % of capacity), by size *s*

The average annual distance travelled, *AveAnnKM*, is a scenario variable and determines the total number of buses needed to fulfil demand (expressed in vehicle-km). *AveAnnKM* can be changed for each future year, thus making it possible to simulate different operational utilisations. From this it is straightforward to calculate the total number of buses needed to fulfil demand by applying Equation 14.

Equation 14: Total bus ownership

$$V_{y,v=2,s} = \frac{VKM_{y,v=2,s}}{AveAnnKM_{y,s}}$$

where: $V_{y,v=2,s}$ = vehicle stock for year *y*, by size *s* (urban, mini, coach)
$VKM_{y,v=2,s}$ = vehicle-km for year *y*, by size *s* (urban, mini, coach)
$AveAnnKM_{y,s}$ = average annual vehicle distance travelled for year *y*, by size *s*

1.1.4 Vans and trucks

Total road freight vehicle stock is treated differently to buses. The number of businesses operating in each year and scenario largely determines the truck populations. Growth in van and truck numbers is closely related with growth in GDP. As is common practice in other simulation models a linear regression method has been used to calculate the total truck numbers for each year, shown in Equation 15. This is done separately for the three size categories: vans or light trucks (up to 3.5t gross vehicle weight, GVW), medium (3.5t to 12t GVW) and heavy (above 12t GVW) trucks.

Equation 15: total number of vans and trucks

$$V_{y,v=3} = V_{y-1,v=3} \times \left(1 + \beta + \gamma \times \Delta GDP_y\right)$$

where β and *g* are regression parameters which have been calibrated for historic years 1980 to 2007 based on GDP data (HM Treasury, 2008) and vehicle licensing statistics (DfT, 2009b) for vans (up to 3.5t gross vehicle weight, GVW), medium (3.5t to 12t GVW) and heavy (above 12t GVW) trucks.

The TDM provides the number of tonne-km for the three truck demand segments namely urban, rural and motorway/dual-carriageway. The truck module maps these demand segments to the three truck size categories included in the model, in *pro rata* shares. Table 7 shows the main assumptions on vehicle capacities and load factors. Note these are calibrated figures for 2008 based on vehicle licensing (DfT, 2009b), traffic (DfT, 2009a) and economic (HM Treasury, 2008) statistics.

Table 7: The main truck model assumptions [1]

Vehicle size category	*Average capacity (AvgCap), in tons/veh.*	*Average load (AvgLF)*	*Average annual distance travelled (AveAnnKM)*	*Constant β*	*GDP coefficient g*
Vans	1.6	11%	20,073	-0.000209	0.999017
Medium trucks	8.0	16%	80,411	-0.020562	0.716725
Heavy trucks	16.0	55%	55,237	-0.011026	0.653407

Notes: [1] the figures shown are for the year 2008. The reference scenario assumes these do not change over time.

These parameters feed into the calculation of total vehicle-km travelled by each truck size category, as shown in Equation 16.

Equation 16: Truck traffic by vehicle size category

$$VKM_{y,v=3,s} = \frac{PKM_{y,v=3,d}}{AvgCap_s \times AvgLF_s}$$

where: $VKM_{y,v=3,s}$ = vehicle-km for year *y*, by size *s* (light, medium, heavy)
$PKM_{y,v=3,d}$ = tonne-km for year *y*, by demand segment *d*
$AvgCap_s$ = average capacity (in tonnes per vehicle), by size *s*
$AvgLF_s$ = average load factor (in % of capacity), by size *s*

1.1.5 Passenger aircraft

Passenger aircraft are bought on a commercial basis in a highly competitive market. Any change in passenger numbers (trips) and destinations (trip lengths) will have a direct effect on total vehicle numbers. Aircraft numbers have therefore been assumed to depend on the ratio of the total annual vehicle kilometres (based on passenger-km from the TDM, which are divided by the average load factors from the scenario module) and the average number of kilometres per plane and year.

The TDM provides the number of passenger-km for domestic and international aviation. The aircraft module maps these demand segments to the four aircraft size categories included in the model, namely domestic short haul, international medium haul / Europe, international long haul / intercontinental and international supersonic. Table 8 shows this mapping together with assumptions on vehicle capacities, load factors, the annual number of trips per aircraft and the average distance per aircraft per flight for the year 2008. These assumptions were derived from calibrating the model to national transport statistics (CAA, 2006; DfT, 2009a). The reference scenario assumes that these input parameters stay constant over the modelling horizon. These assumptions can be modified for simulation of alternative scenarios.

Table 8: The main passenger aircraft modelling assumptions [(1)]

Demand segment	*Aircraft size category*	*Average capacity (AvgCap), pass./plane*	*Average load (AvgLF)*	*Average annual trips per aircraft (AvgAnnTrips)*	*Average distance per trip (AvgTripDist), km*
Domestic	Short distance	104	65%	782	500
International, medium haul / Europe	Medium distance	215	65%	1164	2,500
International, long haul / intercontinental	Long distance	275	76%	551	7,000
International, supersonic	Supersonic	100	76%	639	6,000

Notes: [(1)] the figures shown are for the year 2008. The reference scenario assumes that these parameters stay constant over the modelling horizon.

Total vehicle-km travelled are derived for each aircraft size category according to Equation 17.

Equation 17: Aircraft traffic by size category

$$VKM_{y,v=4,s} = \frac{PKM_{y,v=4,d}}{AvgCap_s \times AvgLF_s}$$

where: $VKM_{y,v=4,s}$ = vehicle-km for year *y*, by aircraft size *s*
$PKM_{y,v=4,d}$ = passenger-km for year *y*, by air demand segment *d*
$AvgCap_s$ = average capacity (in passengers per vehicle), by aircraft size *s*
$AvgLF_s$ = average load factor (in % of capacity), by aircraft size *s*

The total number of aircraft needed to fulfil demand is then derived by dividing total annual aircraft-km by the product of the average annual trips per aircraft and the average distance per aircraft and per trip, as shown in Equation 18.

Equation 18: Total aircraft numbers

$$V_{y,v=4,s} = \frac{VKM_{y,v=4,s}}{AvgAnnTrips_{y,s} \times AvgTripDist_{y,s}}$$

where: $V_{y,v=4,s}$ = vehicle stock for year *y*, by aircraft size *s*
$VKM_{y,v=4,s}$ = vehicle-km for year *y*, by aircraft size *s*
$AvgAnnTrips_{y,s}$ = average annual number of trips for year *y*, by size *s*
$AvgTripDist_{y,s}$ = average trip distance per aircraft for year *y*, by size *s*

1.1.6 Freight aircraft

Freight aircraft are also bought on a commercial basis in a highly competitive market. Any change in freight lifted and destinations (trip lengths) will have a direct effect on total vehicle numbers. As with the passenger aircraft module, freight aircraft numbers are assumed to depend on the ratio of the total annual vehicle kilometres (based on tonne-km from the TDM, which are divided by the average load factors from the scenario module) and the average number of kilometres per plane and year.

Domestic and international air freight demand is mapped onto the three freight aircraft size categories included in the model (Table 9). The reference scenario assumes that the input parameters shown in Table 9 stay constant over the modelling horizon. The parameter figures were derived from calibrating the model to national transport statistics (CAA, 2006; DfT, 2009a). These assumptions can be modified for simulation of alternative scenarios.

Table 9: The main freight aircraft modelling assumptions [(1)]

Demand segment	*Aircraft size category*	*Average capacity (AvgCap), tons/plane*	*Average load (AvgLF)*	*Average annual trips per aircraft (AvgAnnTrips)*	*Average distance per trip (AvgTripDist), km*
Domestic	Short distance	9	60%	911	350
International, medium haul / Europe	Medium distance	30	73%	757	3,500
International, long haul / intercontinental	Long distance	45	73%	471	7,500

Notes: [(1)] the figures shown are for the year 2008. The reference scenario assumes that these parameters stay constant over the modelling horizon.

Total vehicle-km travelled and total vehicle stock are derived for each freight aircraft size category using Equation 17 and Equation 18, similar to the passenger aircraft model.

1.1.7 Passenger and freight trains

In contrast to other models, the number of new trains that will enter the population is determined by the national investment in motorised rail rolling stock (i.e. locomotives and motorised carriages). In UKTCM this is achieved for each of the four passenger rail categories and the rail freight category shown in Table 4. The user has the option to alter this assumption for the testing of policies including, for example, large-scale investment in rail stock. Thus, the overall number of vehicles is calculated as the sum of previous vehicles, minus scrapped, plus new vehicles, as shown in Equation 19.

Equation 19: Total rail rolling stock

$$V_{y,v} = NV_{y,v} + V_{y-1,v} - S_{y-1,v} \qquad \forall y \in Y, v \in M$$

where

$$NV_{y,v} = \frac{AnnRollingStockInvestment_{y,v}}{AvgRollingStockPrice_{y,v}}$$

Note with this approach it could easily happen that if investment were too low (and scrappage would continue at historic rate) total rail traction stock would *decline* over time, with the added effect that the average annual distance travelled by rail traction stock would *increase* (provided demand stays the same).

As for the calculation of total train-km, the TDM produces the number of passenger/tonne-km for four passenger rail categories and the rail freight category demand segments, which are mapped onto the appropriate train size categories (Table 10). Vehicle capacities, load factors and average rolling stock prices were derived from calibrating the model to national transport statistics (DfT, 2009a). The latter gives annual rolling stock investment for various segments of the national rail rolling stock.

Table 10: The main train model assumptions [1]

Vehicle size category	*Average capacity, pass./train or tons/train*	*Average load*	*Average annual vehicle distance travelled*	*Average Rolling Stock Price, £million per train*	*Annual Rolling Stock Investment, £million*
Light rail, underground	500	19%	67,041	2.5	79
Regional rail	200	42%	47,653	5	865
Intercity rail	350	43%	150,194	10	182
High speed rail	750	60%	100,000	20	0
Rail freight	408	79%	48,929	10	248

Notes: [1] the figures shown are for the year 2008. The reference scenario assumes the parameter values stay constant for the modelling period.

These parameters feed into the calculation of total vehicle-km travelled by each train size category, as shown in Equation 20.

Equation 20: Train traffic by vehicle size category

$$VKM_{y,v=5,s} = \frac{PTKM_{y,v=5,d}}{AvgCap_s \times AvgLF_s}$$

where: $VKM_{y,v=5,s}$ = vehicle-km for year *y*, by size *s*
$PTKM_{y,v=5,d}$ = passenger/tonne-km for year *y*, by demand segment *d*
$AvgCap_s$ = average capacity (in passengers/tons per vehicle), by size *s*
$AvgLF_s$ = average load factor (in % of capacity), by size *s*

1.1.8 Freight shipping

The number of freight ships in the vehicle population is assumed to remain constant, and new ships will enter the population only as replacements for ships that are scrapped (Equation 21). This is clearly a gross simplification, which could be modified as a later refinement of the VSM. The user has the option to alter this assumption for the testing of policies including, for example, large-scale investment in canal or port infrastructure.

Equation 21: Total shipping stock

$$NV_{y,v=6,s} = S_{y-1,v=6,s}$$

where: $NV_{y,v=6,s}$ = new vehicle stock for year *y*, by ship size *s*
$S_{y-1,v=6,s}$ = scrapped ship stock, by ship size *s*

The demand model provides projections of demand for three freight shipping demand segments (domestic inland, domestic coastal, international maritime), which are mapped onto the appropriate ship size categories (Table 10). The limited amount of appropriate data on ship capacities and load factors were based on UK shipping statistics (DfT, 2005b, 2009a) and adjusted to UKTCM categories to ensure internal consistency within the model.

Table 11: The main shipping model assumptions [(1)]

Vehicle size category	*Average capacity, tons/ship*	*Average load*	*Average annual vehicle distance travelled*
Inland	4,054	0.5	2,757
Coastal	23,164	0.5	27,457
Maritime	46,329	0.5	41,262

Notes: [(1)] the figures shown are for the year 2008. The reference scenario assumes the parameter values stay constant for the modelling period.

These parameters feed into the calculation of total vehicle-km travelled by each ship size category, as shown in Equation 20.

Equation 22: Shipping traffic by vehicle size category

$$VKM_{y,v=6,s} = \frac{TKM_{y,v=6,d}}{AvgCap_s \times AvgLF_s}$$

where: $VKM_{y,v=6,s}$ = vehicle-km for year *y*, by ship size *s*
$TKM_{y,v=6,d}$ = tonne-km for year *y*, by demand segment *d*
$AvgCap_s$ = average capacity (in tons per vehicle), by size *s*
$AvgLF_s$ = average load factor (in % of capacity), by size *s*

Vehicle scrappage

1.1.9 Approach

Vehicles are scrapped at the end of their usable life. This can occur for the following reasons:

- insurance "write-off" following an accident;
- bodywork deterioration beyond economic repair;
- engine or other mechanical deterioration beyond economic repair;
- voluntary scrappage due to price incentives;
- prescribed scrappage due to legislation.

<u>Cars</u>

Within a saturated car market, where the number of cars per person remains constant (a state not yet reached in any market in the world), the rate of vehicle scrappage is crucial to the rate of deployment of new technologies. Within the UK car market, where rates of growth in car ownership are assumed to decline as saturation levels are approached, vehicle scrappage rates are extremely important in determining the turnover of technologies within the vehicle parc.

With the improving build quality of modern vehicles, the average lifespan of vehicles may increase, decreasing stock turnover and slowing the introduction of new vehicle technologies. Possible options for introducing new propulsion or emissions control technologies include replacing the engine, engine management systems and/or exhaust systems in older vehicles rather than scrapping them altogether when their propulsion technology fails or becomes obsolete. Other options include incentives for scrapping vehicles over a certain age (a.k.a. scrappage schemes). In addition, as the tailpipe emissions from vehicles are reduced, the environmental impacts of vehicle construction and disposal will start to form a larger proportion of their overall life cycle impact. Encouraging longer lifespans could be a strategy for reducing this effect.

<u>Other vehicles</u>

For vehicles other than cars (commercial vehicles) the life is more often determined in advance, and the investment in the vehicle is depreciated over its expected life. The scrappage of commercial vehicles takes place when they are considered "life expired" by their owners. This will be a commercial decision, based on the needs of the business, rather than (necessarily) because the vehicle can no longer perform a function at all. In many cases vehicles have a set life, over which they will be depreciated by the organisation that owns them. Once they are fully depreciated they may have some years of useful life left, or they may be scrapped to make way for a more modern vehicle that provides an improved level of service to the organisation.

Once again S-shaped life curves have been used for estimating the scrappage rate of vehicles. These are very different for each vehicle type (for example the average life of a train is far higher than that of a commercial truck). Apart from the vehicle type average life expectancy (probably the single largest explanatory factor), the average life expectancy might also be related to:

- scrappage incentives;
- inspection and maintenance standards;
- investment policy (public transport);

- safety requirements;
- World trade levels (for shipping).

The variables used in UKTCM for modelling vehicle scrappage are:
- average vehicle lifespan;
- financial incentives/disincentives for scrappage;
- changing real price of vehicles.

1.1.10 Model specification

The decommissioning of vehicles from the vehicle stock due to scrappage is modelled using a modified Weibull distribution. The Weibull distribution is often used to model the likelihood of component failure with age (see e.g. de Jong et al., 2004).

The scrappage function is based on two parameters: *failure steepness*, which is the rate at which the likelihood of vehicles being scrapped increases with age, and the *characteristic service life*. The approach closely follows the FOREMOVE model (Zachariadis et al., 1995).

The calculation of scrappage of vehicles is carried out in the same manner for all vehicle types, but the scrappage parameters vary by vehicle type. The characteristic service life varies by technology and can be changed by the technical user to take account of policy options such as the introduction of long term scrappage incentives (that may or may not have an effect on *average* service lives) or, conversely, the encouragement of buying vehicles with a longer life (e.g. battery EVs).

The first function f^9 shown in Equation 23 provides the share of vehicles of a specific type *v* that remain operating *A* years after first registration (i.e. *A* is the age of the vehicle). f^9 is a sigmoid function (S-shaped curve) defined by the *failure steepness* and the *characteristic service life*.

Equation 23: Modified Weibull distribution

$$f^{9}_{y,a,v,k} = e^{-\left[\left(\frac{A_{v,y}+\delta_v}{\gamma_v}\right)^{\delta_v}\right]}$$

where: $A_{v,y}$ = age of vehicle type *v* in year *y*

d = failure steepness for vehicle type *v*

g = characteristic service life for vehicle type *v*

The **scrappage probability function** ϑ can then be specified as a ratio of the share of vehicles of a specific age remaining in the current year to the share of vehicles one year younger being present in the population:

Equation 24: Scrappage probability function

$$\vartheta = 1 - \frac{f_{a,v,k}^{9}}{f_{a-1,v,k}^{9}}$$

where ϑ provides the *probability* of vehicles of each type and age to be scrapped in a specific year (i.e. $0 \leq \vartheta \leq 1$).

This probability is finally multiplied by the number of vehicles present in the previous year to provide the total number of vehicles scrapped. This calculation is performed first for each vehicle type, age and year, and then filtered through to all vehicle technologies.

$$S_{a,y,v,z,g} = \vartheta \cdot V_{a-1,y-1,v,z,g} \qquad \forall y \in Y, v \in M, a \in A, z \in Z, g \in G \tag{1}$$

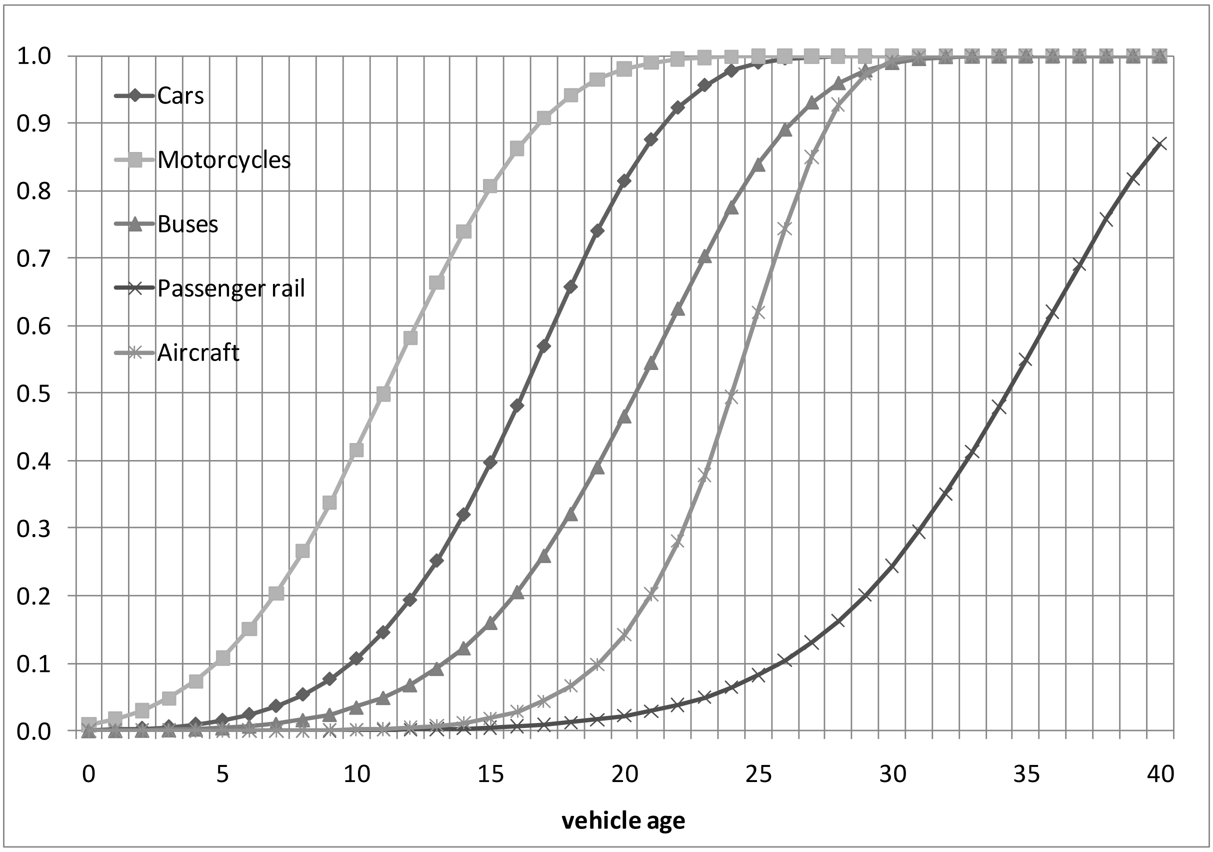
The parameters used are dependent on the type of vehicle and the country, based on data used in the model described in FOREMOVE (Zachariadis et al., 1995). For the model to perform effectively (and for calibration of the parameters used) a detailed age breakdown of the fleet in the base year is required. National vehicle licensing statistics (DfT, 2009b) were used to calibrate the UK figures for *failure steepness* and *characteristic service life*. The parameters are listed in Table 12 for the main vehicle types in UKTCM.

Table 12: Scrappage parameters by vehicle type

Vehicle type	*Characteristic service life*	*Failure steepness*
Passenger vehicles		
Motorcycle	14	5
Car	21	7
Bus & coach	25	7.5
Passenger train	40	10
Passenger aircraft	38	15
Freight vehicles		
Vans	21	7
Tucks	15	5
Freight train	40	10
Ships	30	6.5
Freight aircraft	38	15

The shapes of the sigmoid curves are illustrated for the main passenger vehicle types in Figure 9.

Figure 9: Scrappage function for passenger vehicle types



Calculation of the total new vehicle stock

As already indicated earlier the number of new vehicles needed to enter the fleet in any given year is simply derived by taking the difference between the number calculated as remaining from the previous year (V_{y-1} – S_{y-1}) and the total number of vehicles calculated to meet demand in the current year V_y (Equation 25). The number of vehicles remaining from the previous year is obtained as the difference between the vehicle stock of the previous year minus the vehicles scrapped at the end of the previous year.

Equation 25: Number of new vehicles needed

$$NV_{y,v} = V_{y,v} - \left(V_{y-1,v} - S_{y-1,v}\right) \qquad \forall y \in Y, v \in M$$

where NV_y represents the number of new vehicle needed for the current year *y*, V_y and V_{y-1} represent, respectively, the vehicle stock of the current and the previous year and S_{y-1} represents the number of vehicles scrapped.

Equation 25 is the same for each vehicle type and is applied for each year. Note, however that for shipping vessels ($v = 6$) the assumption made is that $V_y = V_{y-1}$ (see above).

Disaggregation of the Total Number of New Vehicles by Size

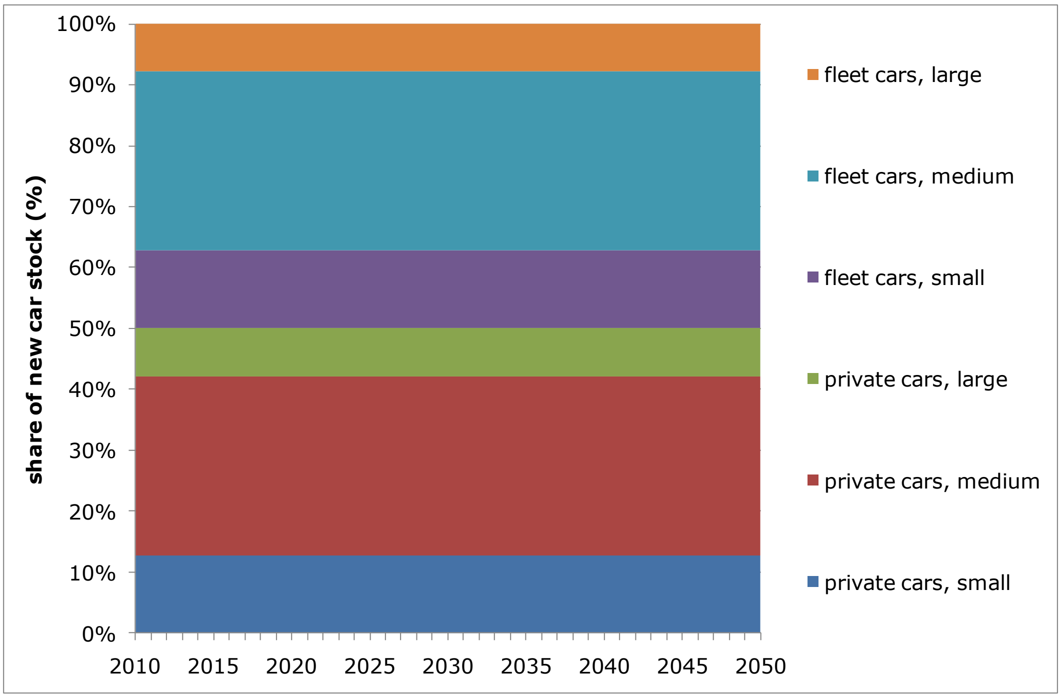
Again, the car model is the most disaggregated as new cars are modelled by size (defined by three vehicle size categories) and ownership (private and fleet/company).

Over the last 10 years, the UK new car size split has been nearly constant, with small cars taking up around 25% of the market, medium 60% and large 15%. Small and medium car shares have fallen slightly over the past 10 years, while large cars have been on the increase. Vehicle size split is a scenario input variable so can be changed for future years for sensitivity analysis or exploration of scenario variants.

Car purchasing decisions can be quite different for the three main market segments of private, fleet and business car buyers. New fleet and business cars made up more than 50% of all new cars sold in 2007 and 2008 (DfT, 2009b; SMMT, 2009). The high share of fleet and business cars is largely a UK phenomenon. The UKTCM simulates this feature of the UK market by putting more emphasis on up-front costs in the private car model (high discount rate, or hurdle rate, of 30%) while the fleet buyer sees the commercial rate of 10%. The distinction makes it possible to simulate policies affecting different market segments (e.g. company car tax, scrappage rebate for private buyers).

The default values (Figure 10) assume that the new car size split and market segmentation stays constant over the time horizon.

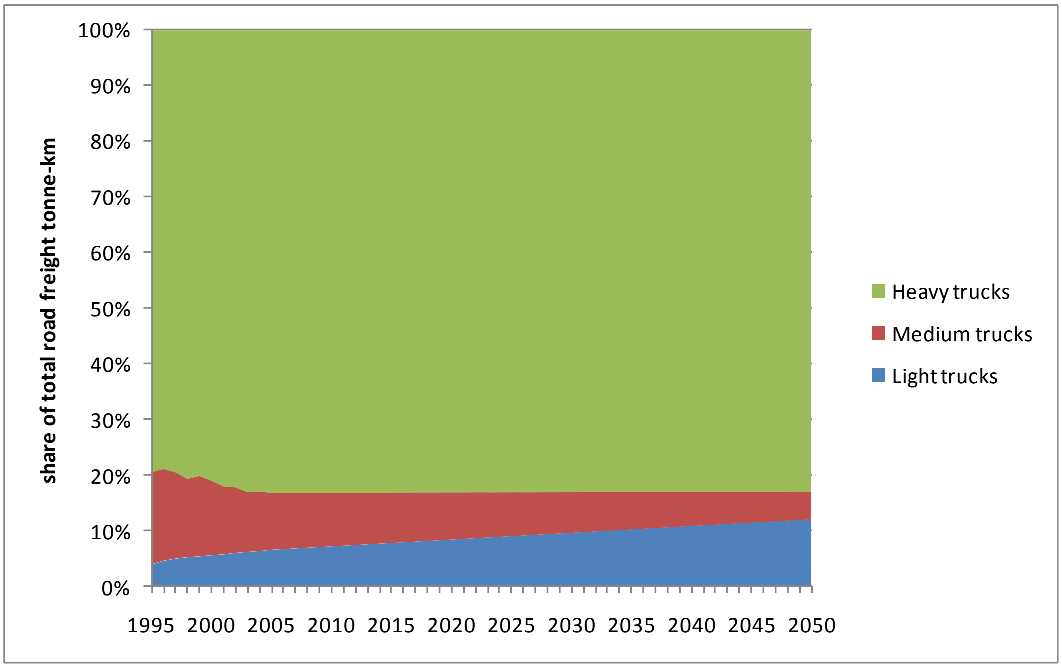
Figure 10: Projected car market segmentation by size and ownership, reference scenario



Note: the projections are based on historic data obtained from Vehicle Licensing Statistics (DfT, 2009b) and SMMT (2009)

Trucks are split by size according to the demand segments (NB: demand segments and trucks sizes are mapped 1:1, see above), as shown in Figure 11.

Figure 11: Historic (1995-2007) and projected road freight market segmentation (in shares of total *tonne*-km) by size, reference scenario



The 'reference' size distributions for new buses and ships are assumed to remain constant over the time horizon. In other words, the proportion of vehicles of each size obtained from the most recent statistics determines the split of sizes of new vehicles in each of the following modelled years. Crucially, size split is a scenario variable and can be modified by the user to simulate, say, 'banning' one vehicle size from entering the total vehicle fleet. Similarly, in a future where consumers prefer smaller cars over larger ones, the availability of large cars can be phased out over time.

The size distribution of new trains is dependent on the investment in rail rolling stock, which is disaggregated by vehicle size and a key policy input variable. So for example, if the decision is made to invest heavily in high speed rail in the period from 2010-2012, a number of new trains entering the fleet in those years will be high speed trains.

The approach for new aircraft stock assumes a constant size distribution of the aircraft fleet, identical with the size distribution obtained from the most recent statistics. Size split is a scenario variable and can be modified by the user. Within each size category, however, the user can change the capacity of aircraft. In one exogenous scenario of the UKTCM, aircraft capacity is assumed to increase slowly over time while average load factors stay constant.

Technology Availability

For each year a number of alternative vehicle technologies will be available in the market place, both for privately owned and commercial vehicles. The drivers of the availability of different technologies are:

- consumer demand;
- legislation on vehicle emissions, energy consumption, safety and noise;
- differential taxation (by technology/fuel), on either fuel or vehicle;

- technological breakthrough.

Different scenarios within UKTCM clearly have different pathways of technological development. The default values developed here are included in the reference scenario. Note that any policies can of course alter these development pathways. All vehicle technologies have been specified in terms of technological and economic characteristics that are relevant to the modelling of vehicle technology choice, including:

- propulsion technology;
- purchase price, purchase tax, technology incentive subsidy;
- fuel price and fuel tax;
- (non fuel) operation and maintenance costs, e.g. fixed insurance and maintenance costs, depreciation costs for commercial vehicles;
- expected vehicle life (e.g., higher expected life for electric vehicles);
- discount rate (private, fleet, commercial) for calculating annuities.

This module is common to both parts of the VSM (cars and other vehicles). It determines the vehicle technologies available in any given year, and contains the variables that describe the vehicles, to enable them to be selected through the vehicle choice modules.

The main technology characteristics used in the VSM are:

- price excluding tax;
- taxation levels (affected by policy users) for fuels, vehicle purchase, annual vehicle ownership, emissions levy or carbon tax;
- costs of operation, per vehicle-km, including fuel used, road pricing charges, parking charges, pre tax fuel price.

Table 24 in Appendix A lists the 604 vehicle technologies included in UKTCM v1, including first and last year of availability and the average purchase price.

Vehicle Technology Choice

The purpose of the technology choice module is to split the demand for *new* vehicles (in terms of numbers) among the different available technologies, for any specific vehicle type (such as light goods vehicles or medium-sized cars).

Technology choice is a very complex and poorly understood process, particularly with regard to the private consumer. The choices made by the private consumer are much less likely to be driven by business-focused types of considerations. To the private individual a car represents much more than a means of travelling from A to B. The individual is likely to buy the most expensive vehicle they can afford (i.e. they will set a capital budget at the outset of the choice process), and within that price range seek to satisfy a number of personal desires.

In contrast, commercial organisations procure vehicles that will provide the best return on their investment. Thus they must balance the total lifetime benefits of a particular vehicle against the total lifetime cost. To model their decisions accurately it would therefore be necessary to model both the differences in benefits provided by different technologies, and also the differences in cost. However too little is known about the benefits side of this equation to provide a model of the way different organisations would assess marginally different technologies. Therefore a simplifying assumption was made, that the different technologies available for the same vehicle mode and size offer the same level of utility to the organisation - i.e. the only difference may lie in the cost of purchase and operation. This gives more weight to costs. However in addition to costs, market availability, infrastructure availability, vehicle performance and technology preference of a commercial organisations have been included via the same non-cost factors described for private cars.

This choice process may have been modelled most appropriately with a behavioural choice model, based on socio-economic characteristics of the individual (or household) making the purchase decision, technology availability, performance, etc. However, this kind of discrete choice modelling is still underdeveloped when alternative fuelled vehicles are part of the choice set (Brownstone et al., 2000; Train, 1980). Thus the UKTCM technology choice module has taken a simpler approach: it considers annual vehicle costs within a discrete choice modelling framework (Train, 2009) as well as non cost factors simulating ‘perceived vehicle performance’, ‘consumer preference’ and ‘market/infrastructure availability’.

The basic idea behind the model is that a vehicle of technology *i* (specified in Table 24, Appendix A) is chosen with probability ($prob_i$) which is related to cost and non-cost factors of the vehicle with that technology. Cost factors are simulated by calculating the equivalent annual cost EAC_i for each technology *i*. Non-cost factors are simulated by a *preference and performance parameter*, P_i, which is an aggregate function of *perceived performance (perf), market presence (pres)* and *consumer preference (pref)* of the vehicle technology. From the mathematical point of view, the probability is modelled as a linear function of the preference and performance parameter and a logit probability function (commonly used in behavioural modelling, see e.g. Train, 2009) of the cost factors, as shown in Equation 26.

Equation 26: Technology choice probability function

$$prob_i = \frac{P_i \times \exp\left(-c \times \frac{EAC_i}{\min(EAC_i)}\right)}{\sum_{j=1}^{m} P_j \times \exp\left(-c \times \frac{EAC_j}{\min(EAC_j)}\right)}$$

with

$$P_i = perf_i \times pres_i \times pref_i$$

where P_i = preference and performance parameter for vehicle technology *i*
EAC_i = equivalent annual cost of vehicle technology *i*
c = modelling constant (preset value of c=10 used for model calibrations)
m = number of vehicle technologies available in modelling year
$perf_i$ = perceived performance of vehicle technology *i*
$pres_i$ = market presence at maturity of vehicle technology *i*
$pref_i$ = consumer preference for vehicle technology *i*

The price and non-price factors underpinning Equation 26 are described in more detail as follows.

1.1.11 Price Factors

The **equivalent annual cost *EAC_i*** is the cost per year of owning and operating a vehicle over its entire (economic) lifespan (Equation 27). It is the sum of the annuity of owning the vehicle over its economic lifetime and any annual operating and maintenance costs (e.g. fuel, road user charging, circulation taxes, insurance, maintenance and depreciation) to the consumer or operator. The annuity represents the annual payment of paying off a loan for all up-front costs (purchase price, purchase taxes and rebates). The applied discount (or interest) rate can vary by vehicle type (car, van, aircraft, etc.) and, to avoid a purely static approach, by year. Implicitly the *EAC* can vary by scenario (e.g. via changes in pre-tax fuel price) and policy (via e.g. changes in fuel duty).[3]

Equation 27: Annual cost of ownership and operation

$$EAC_i = -PMT(DRate_i, AvgEconLife_i, InvCost_i) + AnnFixCost_i + AnnVarCost_i$$

where: EAC_i = equivalent annual cost of owning a vehicle of technology *i*
$PMT()$ = the payment for an annuity based on periodic, fixed payments and a fixed interest rate
$DRate_i$ = discount (or interest) rate for technology *i*
$AvgEconLife_i$ = average economic lifetime of vehicle technology *i*
$InvCost_i$ = net investment or upfront cost of owning a vehicle technology *i*
$AnnFixCost_i$ = annual fixed costs
$AnnVarCost_i$ = annual variable costs.

Net ownership costs are simply the vehicle purchase price (after tax, incentives, rebates, etc.) calculated as an annuity over the economic lifetime of the vehicle. Fixed costs are costs of insurance, maintenance, depreciation, VED, etc. Variable costs are mainly determined by fuel costs, plus variable taxes such as road pricing and congestion charges. Specifically, annual fuel costs are calculated according to Equation 28.

Equation 28: Annual fuel costs

$$AnnFuelCost_{y,i} = \left(ResCost_{y,i} + FuelDuty_{y,i}\right) \times VAT \times SFC_i \times AveAnnKM_{y,i}$$

where: $AnnFuelCost_{y,i}$ = estimated annual fuel costs for technology *i*
$ResCost_{y,i}$ = pre-tax fuel price for technology *i*
$FuelDuty_{y,i}$ = transport fuel duty for technology *i*
VAT = *Value Added Tax rate (e.g. 1.175 for current 17.5% rate)*
SFC_i = specific fuel consumption for technology *i*, in litres per 100km
$AveAnnKM_{y,i}$ = average annual distance travelled per vehicle technology *i*

To populate the model, and to ensure that the full spectrum of the vehicle range is reflected in the purchase decisions, a detailed price distribution is needed. The variables needed for such an approach are:

- Distribution of vehicles purchased, by annuitized lifetime cost (by year);

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[3] EAC_i is also the basis for calculating relative transport costs (*RC* in Equation 1) which feeds back from the VSM to the TDM.

- Purchase price of the new vehicle, including any taxes imposed (by year, vehicle type, size, engine type, fuel type);
- Running costs of the new vehicle, based on:
    - fuel price, with tax;
    - annual taxes such as vehicle excise duty (VED);
    - insurance and maintenance costs;
    - any other charges imposed by the policy maker (e.g. parking charges, road pricing differentiated by technology);
    - average annual mileage (by technology);
- Average vehicle life (by technology).

The key variables are specified in the vehicle technology tables, summarised in Table 24 in Appendix A.

In addition, to simulate the differences in financial considerations and investment risk for the private (higher private rates) and fleet/company (commercial rates) car markets, the discount rate can vary by vehicle ownership type (private or fleet/company). The default discount rate for the private car market is 30%, simulating higher cost of capital, risk aversion and the relative importance of up-front costs in the decision making process of the private consumer. In contrast, the default discount rate for the fleet/company car market is 10%, simulating lower cost of capital and investment risk.

1.1.12 Non-price Factors

The *P* factor is an aggregate of three key factors that can influence purchasing decisions, based on market research by the UK Energy Saving Trust (2008). First, the factor of perceived performance *perf* is an aggregate of perceived safety and security, speed, acceleration, range between refuelling, space available and comfort. Secondly, the market presence factor *pres* represents the potential market presence of the vehicle technology at market maturity, including factors such as availability of and access to fuel as well as market coverage (i.e. is the technology widely available across the different market segments such as 'super mini', 'small family', executive' and 'multi-purpose vehicles'?). Thirdly, the consumer preference factor *pref* simulates non-cost factors that cannot be explained by cost, performance and market factors, e.g. vehicle colour, style and 'technology loyalty'.

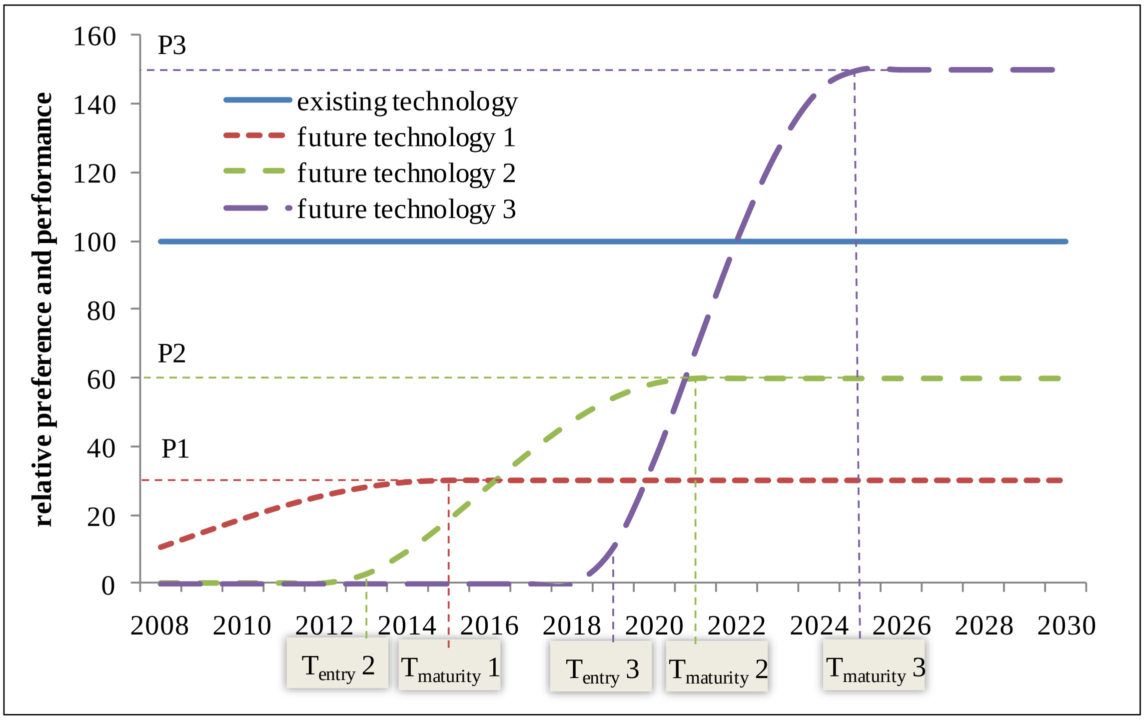
The obvious challenge of defining *P* has been approached in two different ways. First, in the case where the *vehicle technology is an established one*, with a consolidated market share such as gasoline and diesel cars, *P* can be derived using Equation 26 on the basis of observed, historical data such as the UK's Vehicle Licensing Statistics (DfT, 2009b). Since the values of *P* are not constant, but could change over time, it is necessary to verify their trends on the basis of observed data. In UKTCM, this verification process was performed for the base year and subsequent modelling years where licensing statistics exist (from 1995 to 2007). For example, the share of new diesel cars has increased significantly from around 20% in the late 1990s to around 50% in 2008 (SMMT, 2009). As the cost difference between gasoline and diesel cars has not changed dramatically, this trend implies that over this time period the non-cost factors for diesel cars increased relative to gasoline cars, indicating a relative improvement in performance (higher power, better acceleration, lower specific emissions), preference (decrease in perception of diesel being a dirty technology) and market potential (emergence of small diesel cars, technology availability now similar to gasoline technology).

Secondly, for *new and alternative vehicle technologies*, neither cost nor preference and performance data are well established or can be observed directly. In addition, both cost and non-cost factors may change more radically in future years than for their conventional counterparts. Costs may decrease as production achieves economies of scale, technological developments cut intrinsic costs and vehicle life increases. Similarly, vehicle performance may increase as technological developments improve utility and public perceptions change. Perceptions will be influenced by information such as marketing and technology demonstration, and also by the number of vehicles already in use. Market potentials may increase by the market providing larger ranges of models across the vehicle classes (e.g. hybrid electric cars may in future be available more widely across the market segments). Thus for each new and alternative vehicle technology the change in P over time is modelled as an S-curve using a logistic function (Note: this is distinct from the S-curve of market penetration, i.e. vehicle numbers.). We assume that the new technology improves from a market entry year T_{entry} to a product maturity year $T_{maturity}$, reaching a maximum level P at maturity (Figure 3). T_{entry} is defined as the entry year for the first commercially available vehicles (albeit these may also be regarded as commercial prototypes, likely to be used primarily in demonstration projects). $T_{maturity}$ is the year when the vehicle technology performance and consumer preference are expected to level off (or at least become parallel with the trend line for conventional technologies).[4] P is estimated based on the expected *relative* market share of the new vehicle technology (in terms of new vehicle sales) in year T_2, compared to some specified conventional comparator, that might be anticipated *if the annualised costs of the conventional and new technologies were the same*. Figure 3 illustrates this by showing four hypothetical curves comparing an existing reference technology to three new vehicle technologies with three different entry years, maturity years and levels of preference and performance.

---

[4] Note $T_{maturity}$ is not the date when market penetration (share of new vehicle sales) levels off for the new technology. Growth in new vehicle sales may lag behind the rise in P, as the number of sales will also be critically dependent on differences in technology costs and taxes.

Figure 12: Comparison of four hypothetical preference and performance parameter curves



Notes: P = preference and performance at market maturity; T_{entry} = expected entry year for the first commercially available vehicles; $T_{maturity}$ = expected maturity year i.e. year when the preference for and performance of the new vehicle technology are expected to level off (or at least become parallel with the trend line for existing technologies). $T_{entry}1$ is 2005 hence not shown in this Figure.

Vehicle technology 1 represents a rather slowly progressing conventional technology where market entry happened in the past and maturity is expected in 2015, e.g. a gasoline hybrid electric medium-sized car. Vehicle technologies 2 and 3 represent future technologies (with market entries of 2013 and 2019), with comparatively faster rates and at maturity higher expected performance and preference than technology 1. Technology 3 takes only 6 years to mature and even outstrips the reference technology.

Clearly the specification of future vehicle costs and *P* parameter curves are crucial to the medium to long term outcomes of the vehicle technology choice module. While default values for cost and non-cost parameters have been developed based on best available knowledge in the literature and in consultation with policy and industry experts, UKTCM users can modify them according to their market expectations or for simple 'what-if' analysis.

The set of *P* parameters, T_{entry} and $T_{maturity}$ for the reference scenario are given in Table 24 in Appendix A.

1.1.13 Technology distribution of the new vehicle fleet

Taking the total number of new vehicles from Equation 25, the technology distribution of new cars finally derived using Equation 29.

Equation 29: Distribution of new vehicles by technology

$$NV_{t,y,A=0} = NV_{y,A=0} \times prob_{t,y,A=0}$$

for all years y, technologies t that are available in that year, and age A = 0 (i.e. new).

Main Outputs and Links to Other Models

1.1.14 Vehicle fleet distributions

This module first combines the remaining vehicle population (disaggregated by vehicle age, size and technology) with the new vehicle population (disaggregated by size and technology) to provide a total population distribution, in each year (disaggregated by vehicle age, size and technology). The output tables are large in size, containing typically around 30-40 thousand records for a single scenario run. Table 13 shows the number of new (*N*), scrapped (*S*) and total (*T*) vehicles for technology ID 322 (i.e. "Road - Car - Medium - Gasoline – 'Euro 7' (2020-24) – Passenger Transport – Hybrid EV") for policy package 0, exogenous scenario 1, region 9 and year 2024.

Table 13: Sample entry in output table *Interface_VSM_NumVeh*

Vehicle Stock output						
Policy package	Scenario	Region	Year	Technology	Vehicle Category	Number of Vehicles
...	...	...	...	...	...	...
0	1	9	2024	322	New	54,732
0	1	9	2024	322	Scrapped	24,532
0	1	9	2024	322	Total	675,501
...	...	...	...	...	...	...

The vehicle distributions are exported to the DEEM and LCEIM.

1.1.15 Vehicle traffic distributions

The final stage of the vehicle supply model provides some of the output required for calculating emissions levels, namely the total vehicle-kilometres disaggregated by vehicle type, year, age, size, engine type and fuel type. In its current version, the model takes the vehicle-kilometres computed by vehicle type and journey segment type (e.g. urban car travel) from the TDM and splits each vehicle type according to the proportion of vehicle stock of that vehicle type in each technology category, modified to take account of factors such as age and technology. For cars it is known that the distribution of vehicle-km by age is skewed towards newer cars (ONS, 2007).

The basic pro rata formula is shown in Equation 30.

Equation 30: Vehicle-km distribution by technology, basic formula

$$VKM_{y,t,v,s} = VKM_{y,v,s} \times \frac{V_{y,t,v,s}}{V_{y,v,s}}$$

where: *VKM* = vehicle-km
V = total number of vehicles

y	= year
t	= technology
v	= vehicle type
s	= vehicle size

Certain vehicles may be expected to be used for a smaller number of miles than the average, particularly BEV. The current version UKTCM ignores this disaggregation. It is planned, however, to include this feature in later versions by including a simple weighting factor that reduces the number of vehicle-kilometres assigned to BEV.

The relationship between car age and mileage is taken into account using an age dependent scaling factor, as shown in Equation 31. The annual percentage change in mileage as car ages is assumed to be 1% p.a. for the reference case. The model normalises to the total vehicle-km before final outputs are written to the database.

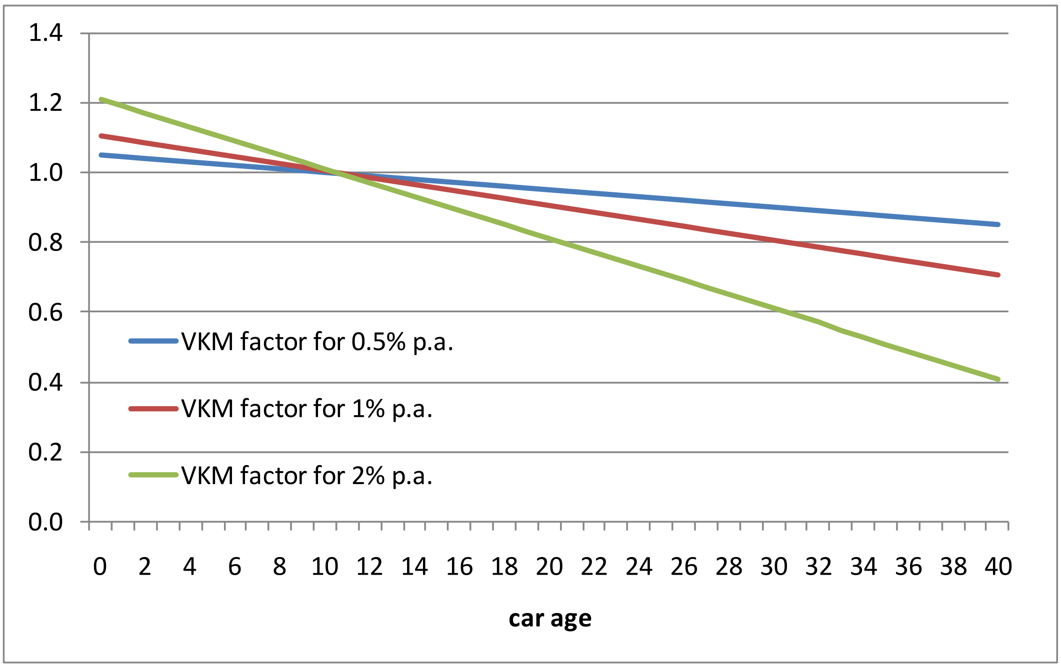
Equation 31: Car vehicle-km distribution by technology and age

$$VKM_{y,t,v=2,s,a} = \left(1 + \varepsilon \times \left(\frac{AveEconLife_{v=2,y}}{2} - VehAge_{y,t,v=2,a}\right)\right) \times VKM_{y,v=2,s} \times \frac{V_{y,t,v=2,s}}{V_{y,v=2,s}}$$

where:	*VKM*	= vehicle-km
	e	= annual percentage change in mileage as car ages
	AveEconLife	= characteristic vehicle service life
	y	= year
	t	= technology
	v	= vehicle type (v=2 is cars only)
	a	= vehicle age (0=new, 1 year old, …, 40 years old)
	s	= vehicle size

The age-dependent scaling factor for different annual percentage changes is illustrated in Figure 13.

Figure 13: Scaling factor for simulating age dependence of car vehicle-km



Notes: This assumes a characteristic service life of 21 years (see also Table 12).

1.1.16 Feedback to TDM

Operating costs of vehicles affect the generalised travel costs that are traditionally used to determine modal split and journey distances in demand modelling. The choice of vehicle technologies, and taxation changes, are therefore fed back into the mode choice model to affect the modal split. As presented earlier these generalised costs are computed as the *relative* change compared to the previous modelling year of the *average annual transport costs per passenger/tonne-km* (RC in Equation 1), weighted over the vehicle-km driven each year. For instance, increasing the fuel costs for 50% of the car fleet by 5% will increase the average-weighted transport costs by 2.5%, resulting in a relative cost factor of 1.025. If there is no cost increase for motorcycle, bus, rail and domestic air, the model will calculate (a) a reduction in total passenger transport demand and (b) modal shift from car to the other modes based on assumed cross elasticities.

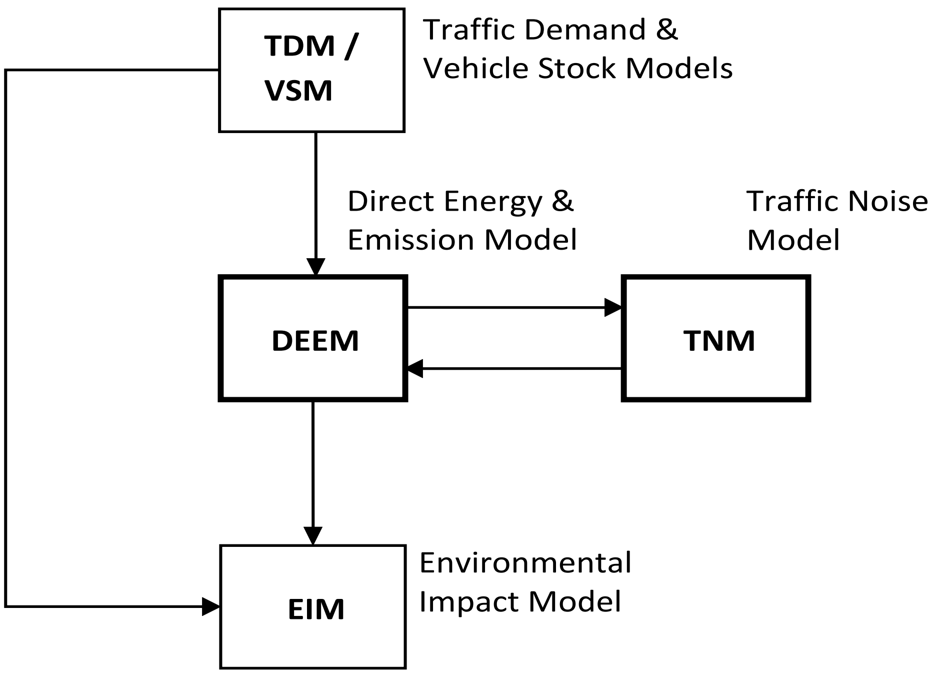
2 Direct Energy and Emissions Model

Overview

The TDM and VSM provide vehicle-kilometres and average trip lengths, disaggregated by passenger/freight, vehicle type, size, propulsion technology and 'route segment types' (such as urban, rural and motorway for road, urban/light and high speed for rail, and take-off and cruise for air). From this, the DEEM calculates fuel and energy consumption (in volume and energy units) as well as greenhouse gas pollutant emissions arising from the operation of vehicles by using the established emissions factor method. It is able to model the combined effects of different fleet compositions, different sets of emission factors, traffic characteristics, cold starts, fuel quality and driver behaviour.

The DEEM interfaces with other modelling components in UKTCM as illustrated in Figure 14.

Figure 14: Interfacing of the DEEM and TNM models within UKTCM



Model specification, data sources and calibration

The basis for all calculations of energy consumption and exhaust emission are disaggregate sets of emission factors (e-factors) based on the results of large scale vehicle emissions testing programmes. For road transport, speed distributions for each vehicle type (car, motorcycle, van, HGV) and route segment type (urban, rural, motorway) are used to calculate the energy consumption and emissions, based on average speed-emissions curves developed in previous research and emissions inventories such as COPERT (EEA, 1998, 2000), MEET (Hickman et al., 1999), HBEFA (INFRAS, 2004) and NAEI (NETCEN, 2003). These datasets provide a base set of emissions factors (mostly for conventional vehicle technologies), which is mapped onto UKTCM vehicle technologies and then scaled for future technologies – thus providing the default set of emissions factors for UKTCM. The user can change both mapping and scaling to simulate effects of policy such as fuel efficiency standards.

Emissions factors for road vehicles at normal operating temperatures (often called 'hot') are a polynomial function of average speed, with up to ten coefficients for each pollutant. The UKTCM base emissions factors are based on HBEFA (INFRAS, 2004) coefficients, which were originally calibrated in extensive vehicle emissions testing. The road transport module also takes account of cold start effects. Cold start emissions mainly depend on ambient temperatures and trip distances.

The default speed distributions are based on observed data for Great Britain (DfT, 2008b: Tables 7.10 and 7.11). To take account of effects such as congestion and speed limits the user can alter the speed distributions.

For all other modes, average emissions factors are used to calculate energy use and emissions. For air, emissions factors are split into the different flight stages 'landing/take-off' (LTO) and 'cruise'. The share of the LTO phase compared to the total flight distance is estimated based on the international CORINAIR/SNAP classification (code 08 05), where the flight distance up to an altitude of 1000 metres – about 30 km – is allocated to airport traffic.

Apart from direct energy use, the emissions types included in the DEEM are the direct greenhouse gases (GHG) carbon dioxide (CO_2) and methane (CH4) as well as the indirect GHG carbon monoxide (CO), sulphur dioxide (SO_2), nitrogen oxides (NO_X), non-methane volatile organic compounds (NMVOC) and particulates (PM).[5]

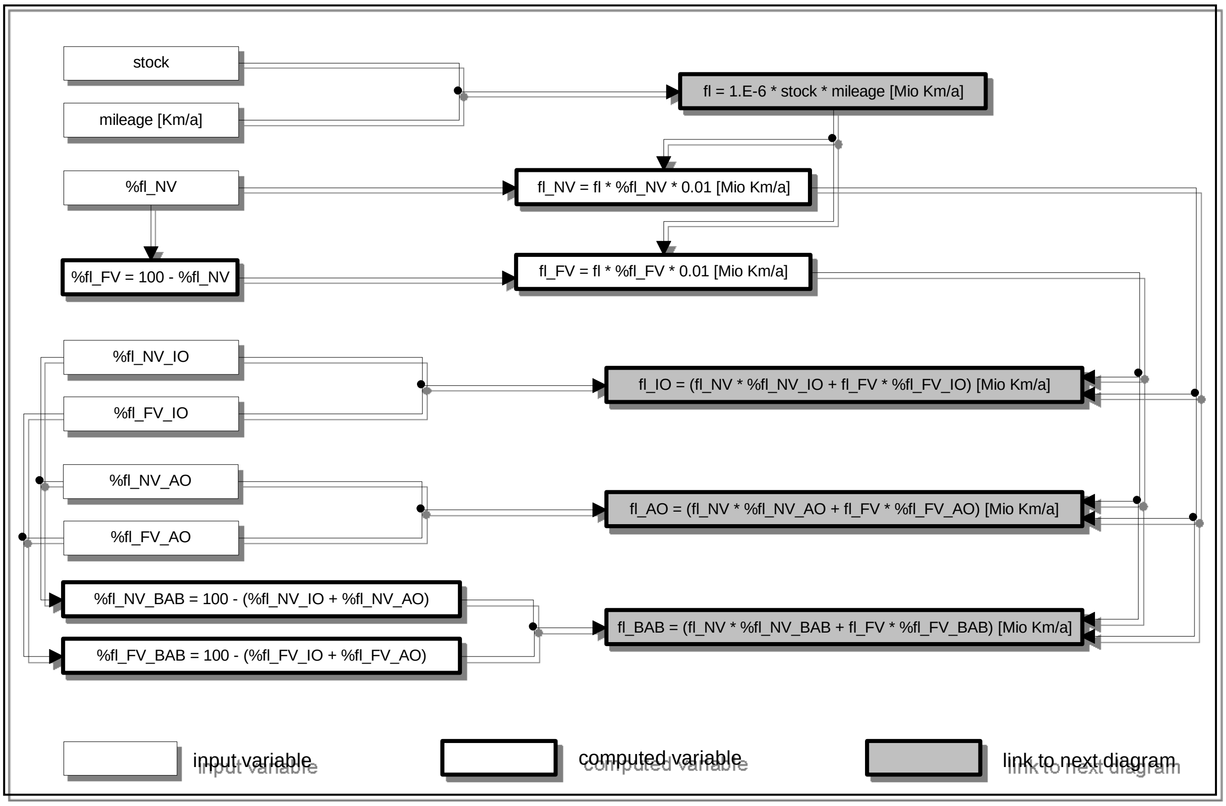
2.1.1 Functional linkages for road transport

The dependencies of variables are outlined in two schematic overviews:

- Figure 15: functional linkages for calculating road traffic volumes;
- Figure 16: functional linkages for calculating energy consumption and exhaust emissions for road transport.

[5] Nitrous oxide (N_2O), the other direct GHG, is accounted for in the LCEIM.

Figure 15: Schematic overview of the functional linkages for road traffic

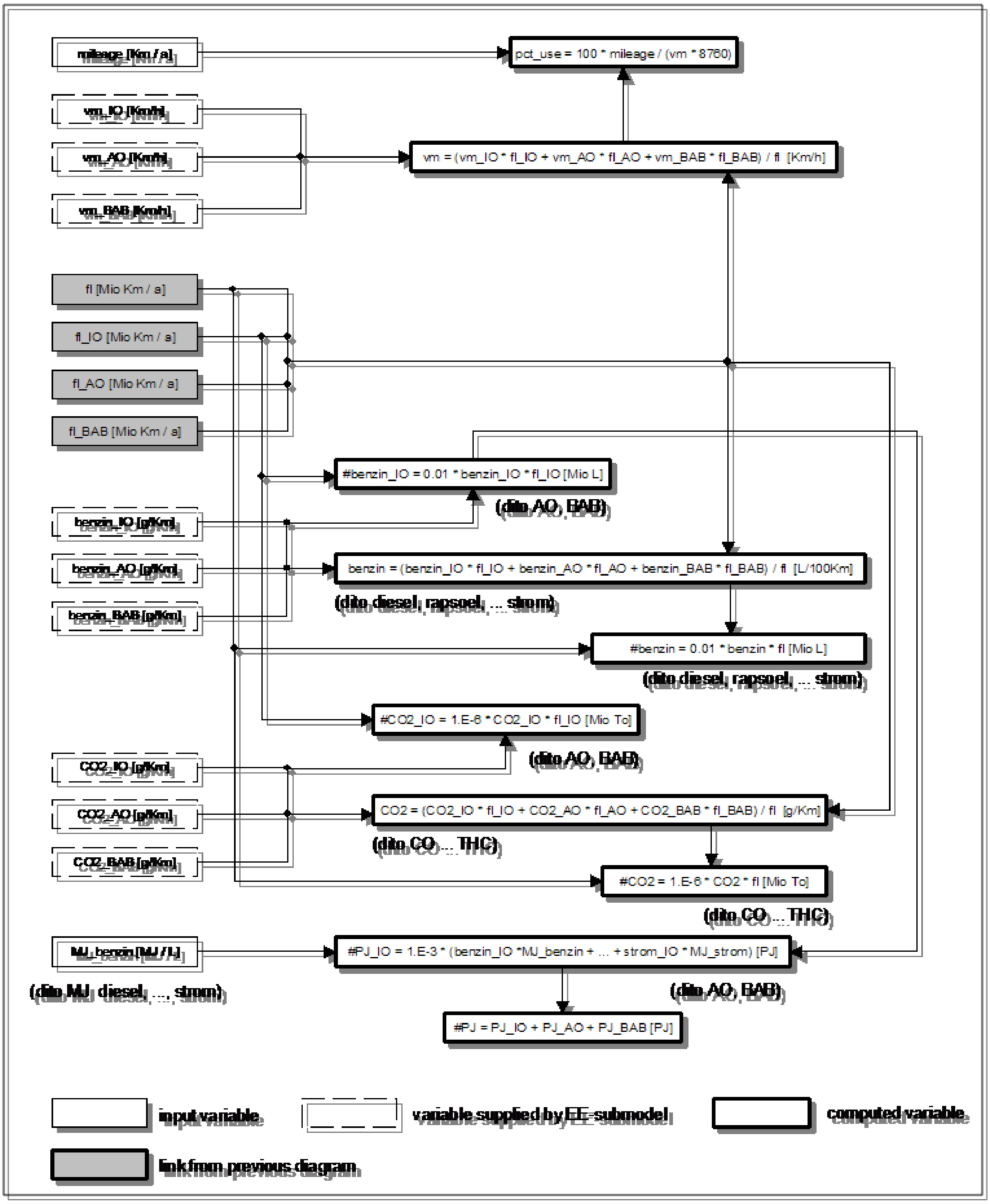


Notes: ‘fl’ stands for mileage

IO / AO / BAB stands for urban / rural / motorway

NV / FV stands for local traffic / long distance traffic

Figure 16: Schematic overview of the functional linkages for energy consumption and exhaust emissions from road transport



Notes: 'fl' stands for mileage

IO / AO / BAB stands for urban / rural / motorway

NV / FV stands for local traffic / long distance traffic

MJ = Megajoule / PJ = Petajoule

'vm' stands for 'mean velocity' or 'average speed'

2.1.2 Speed-emissions curves

The speed dependence of 'hot' e-factors for all road vehicle types is managed by polynomial regression up to a maximum degree of 9th order as shown in Equation 32.

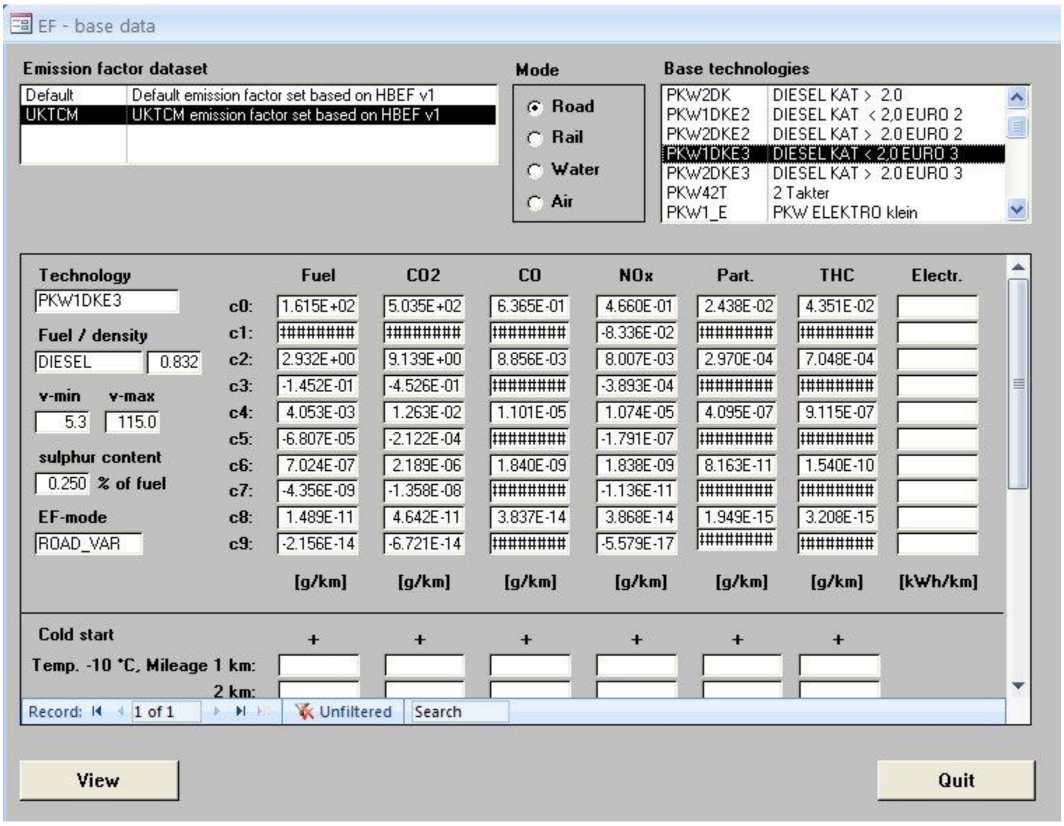
Equation 32: Dependence of energy use and emissions on average speed

$$EF_{i,j} = c_{i,j,0} + c_{i,j,1} * S_j + c_{i,j,2} * S_j^2 + \ldots + c_{i,j,9} * S_j^9$$

where $EF_{i,j}$ = energy use or emissions factor for pollutant *i* and vehicle type *j*
S_j = average speed for vehicle type *j*
$c_{i,j,x}$ = polynomial coefficients (x=0,…,9) for pollutant *i* and vehicle type *j*

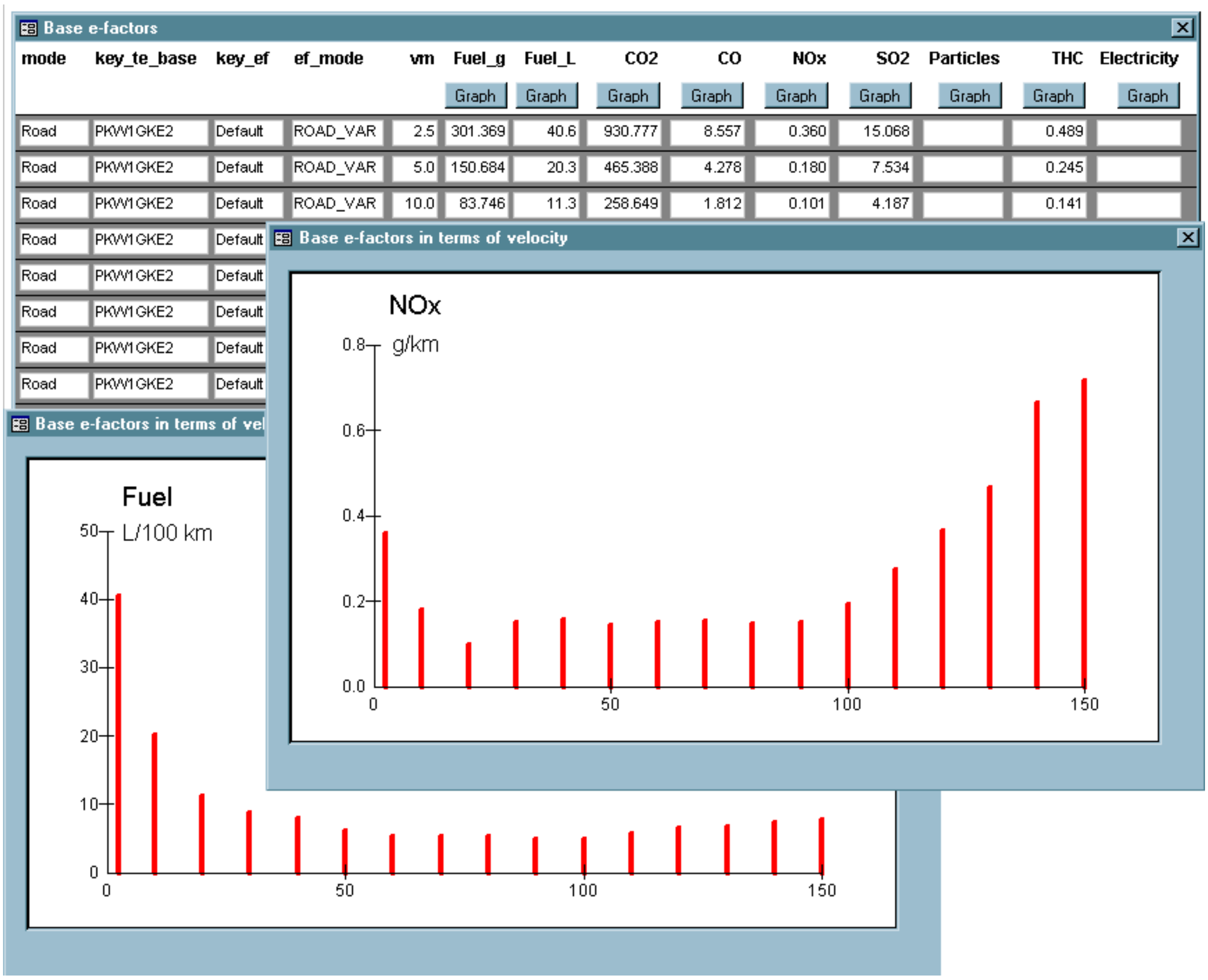
As mentioned above all emissions factors used in UKTCM are based on a set of *base* or *primary* emissions factors which are parameterised according to Equation 32. An example is shown in Figure 17.

Figure 17: View and edit 'base' emissions factors in DEEM



Examples of the resultant speed emissions curves are shown in Figure 18 for two medium sized petrol car technologies (ICE and HEV). The somewhat flatter curve at lower average speeds for HEV cars is a result of better fuel economy and CO_2 emissions at lower, urban speeds.

Figure 18: Base speed-emissions curves for fuel use and NO_X emissions for small petrol cars



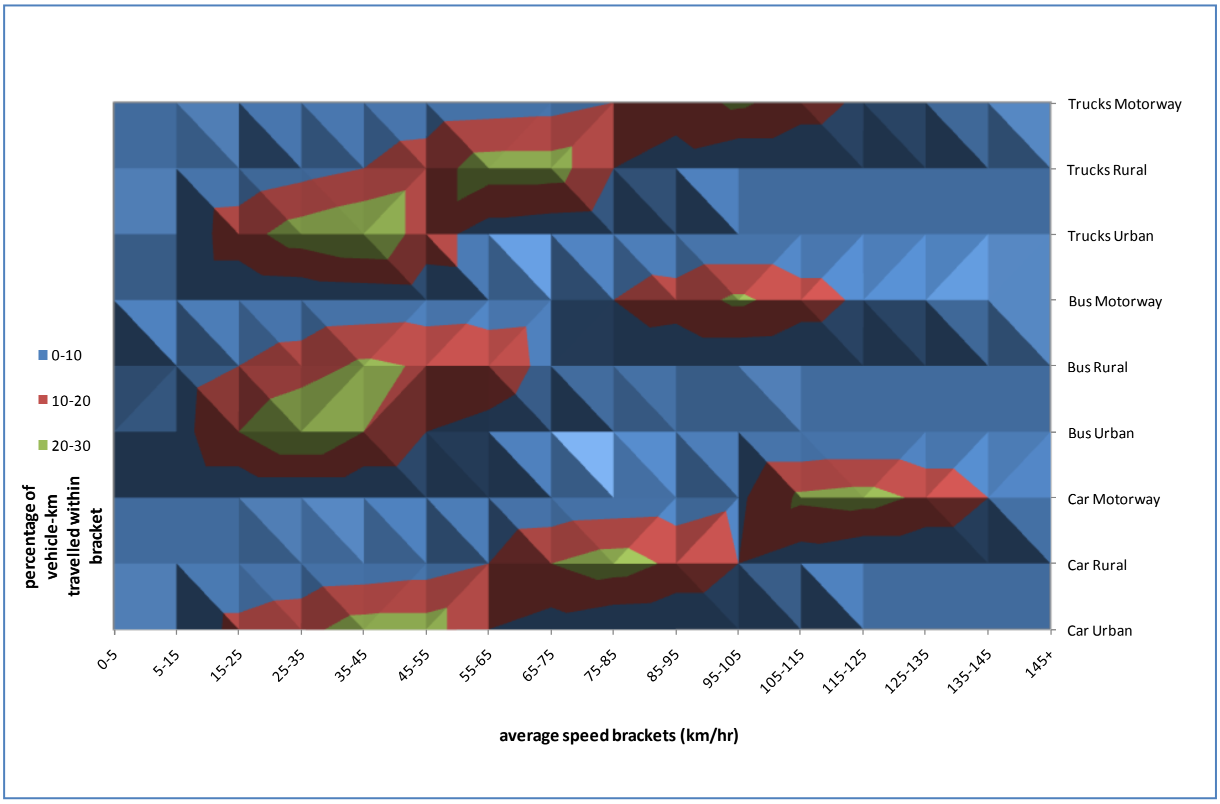
Note for non-road modes of transport (air, rail, shipping) speed independent e-factors are used. This implies that only the constants (coefficients c_0) are used in the above equation.

2.1.3 Speed profiles

The other key component in the methodology is the use of speed profiles disaggregated by vehicle type and road type (urban road, rural road, etc). The default speed profiles are observed distributions of speed, in this case taken from national statistics such as DfT (2009a). The default or reference scenario speed profiles are given in Appendix B and illustrated in Figure 19. Note on motorways more than half of all cars travel at speeds higher than the current speed limit (70 mph).

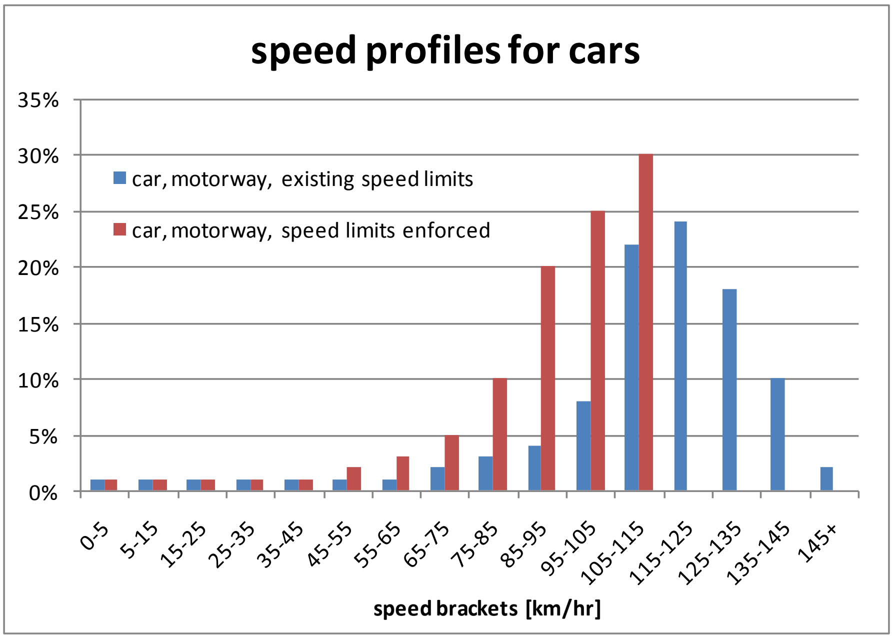
Alternative speed profiles for cars on motorways/double carriageways can be developed for policy analysis. Figure 20 shows one alternative scenario for cars on motorways/double carriageways. The blue distribution represents currently observed data; the red distribution represents one possible distribution if the speed limit would be enforced more effectively.

Figure 19: Reference road speed profiles for cars, buses and trucks



Source: Road traffic speed distribution for 2008 (DfT, 2009a)

Figure 20: Example speed profiles for cars on motorways/double carriageways



Source: Road traffic speed distribution for 2008 (DfT, 2009a), and own assumptions for enforced speed limits

2.1.4 Integration

By using scaling and cross-referencing factors in the process of matching the UKTCM specific set of vehicle technologies with the external base e-factor sets, as illustrated in Figure 21 and Figure 22, the DEEM can handle any new technology the policy maker may wish to examine – as long as it can be referenced to an existing vehicle technology.

Figure 21: Cross referencing and scaling of energy use and emissions factor datasets in the UKTCM

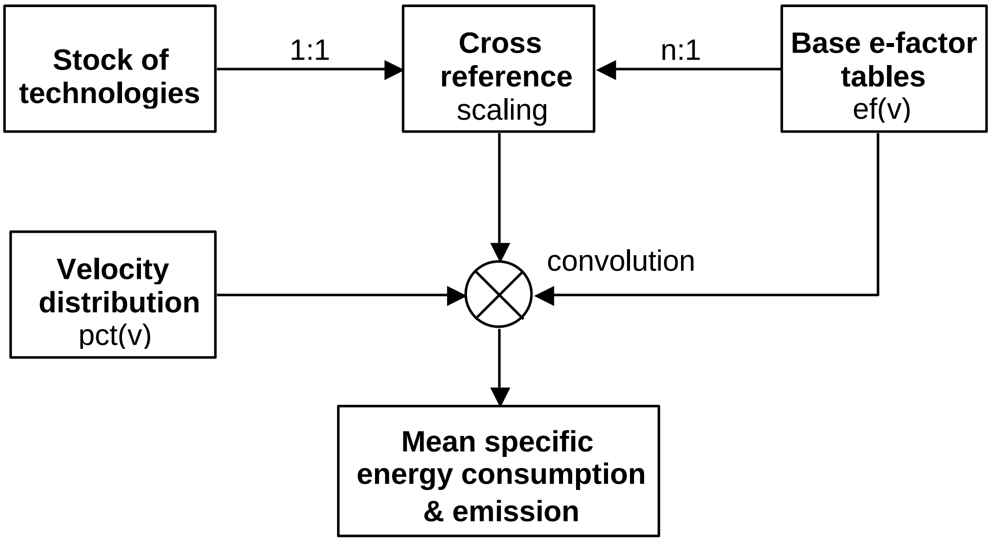
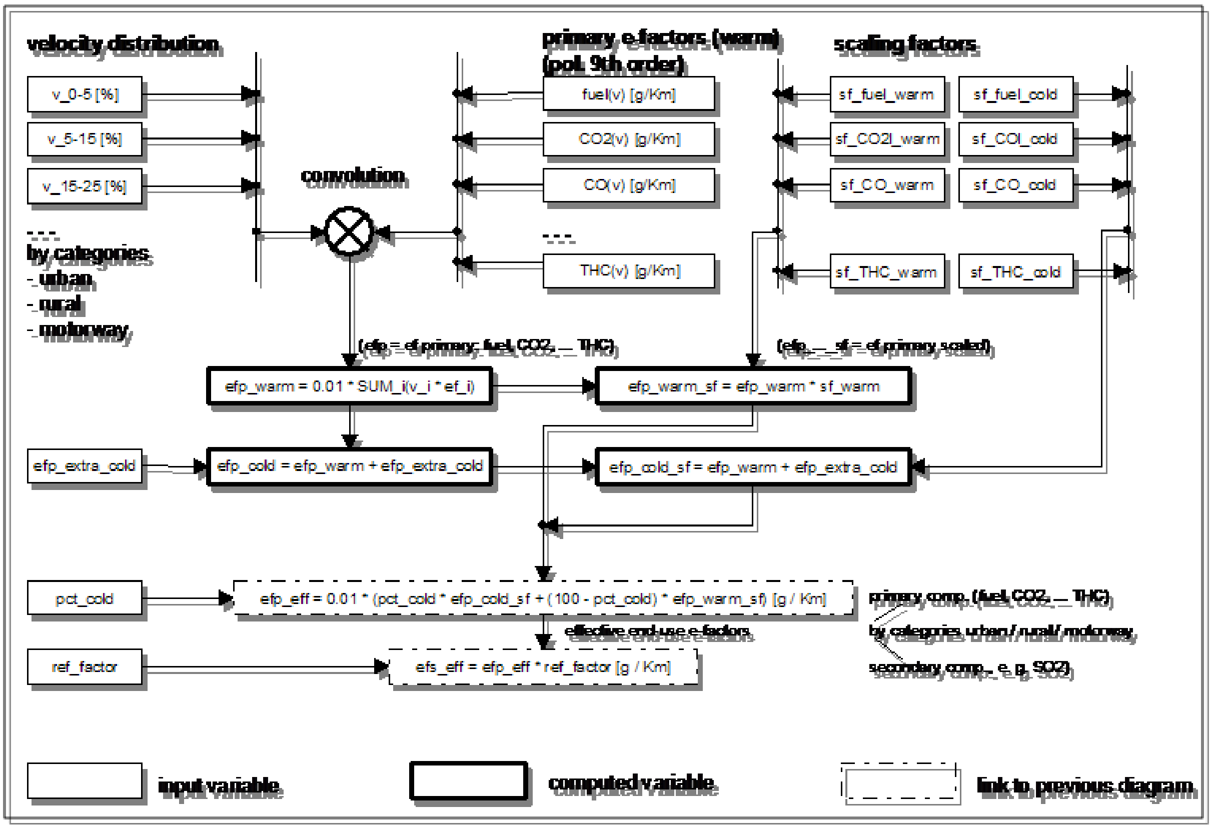


Figure 22: Variable linkages for modelling energy consumption and emissions



Notes: sf stands for scaling factor

v_5-15 indicates share of speed distribution in speed bracket '5-15 kph'

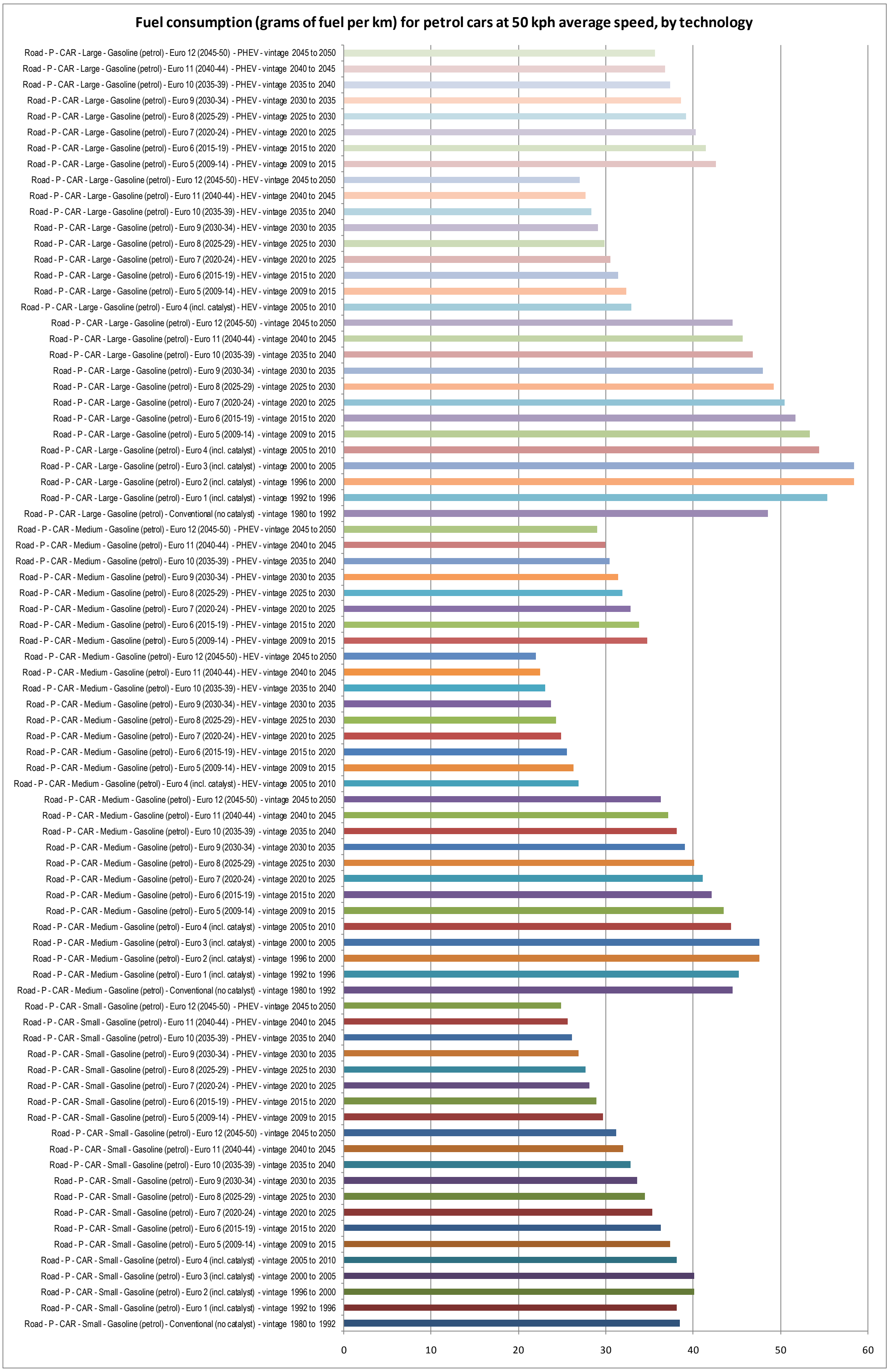
efp stands for emissions factor (primary emissions type i.e. fuel use, CO_2, etc.)

warm and cold stand for 'hot' and 'excess cold' emissions factors respectively

pct stands for percentage

Figure 23 provides average fuel consumption factors (in g of fuel per vehicle-km) for a range of petrol car technologies, disaggregated by propulsion technology (ICE, HEV, PHEV) and vintage. This set of factors represents only 13% of the vehicle technologies currently modelled in UKTCM. Similar figures exist for other vehicle types and technologies.

Figure 23: Average fuel consumption for petrol cars at 50 kph average speed



2.1.5 Calibration

As the methodologies used in the DEEM differ slightly from those used to derive national statistics, the DEEM was calibrated at the levels of modal energy use and emissions to national statistics (DfT, 2008b, 2009a) for each year between 1995 and 2007 by applying scaling factors to the DEEM energy use and emissions factors shown above. In most cases the scaling factor was within 5% of unity.

Scenario and policy modelling in the DEEM

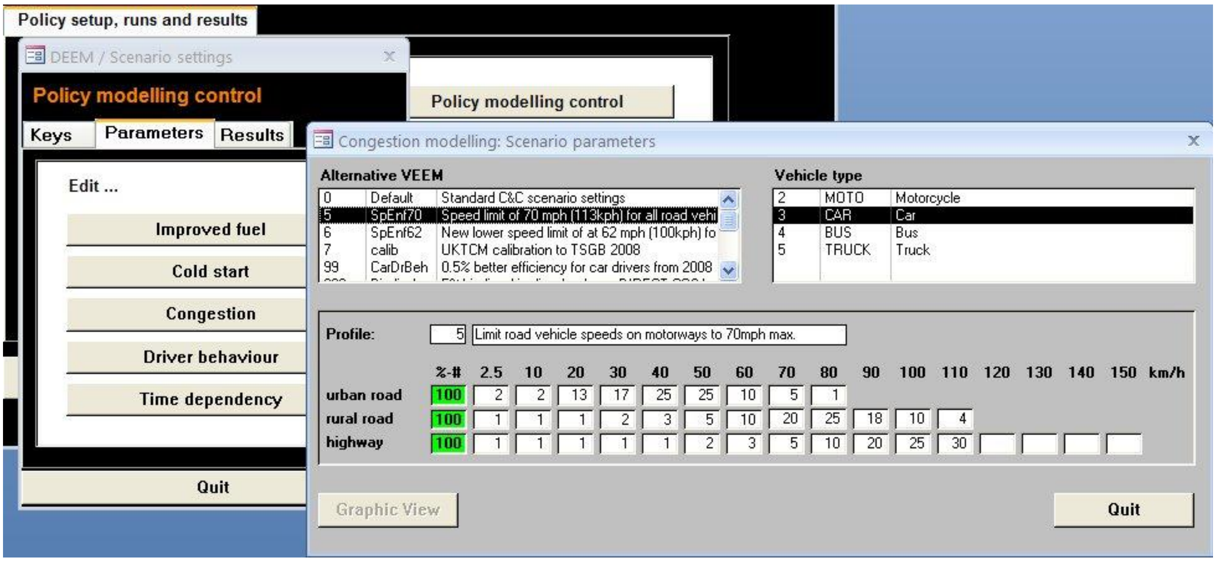
The DEEM is able to model scenario and policy options relating to:

- Improved fuels with lower content of key pollutants (carbon, sulphur, etc)
- Speed and congestion modelling
- Driver behaviour
- Cold start influence
- Any time dependency of e-factors.

This functionality has been implemented by incorporating into the modelling chain a complex set of scaling factors which are applied to the calibrated UKTCM fuel use and emissions factors from the previous Section.

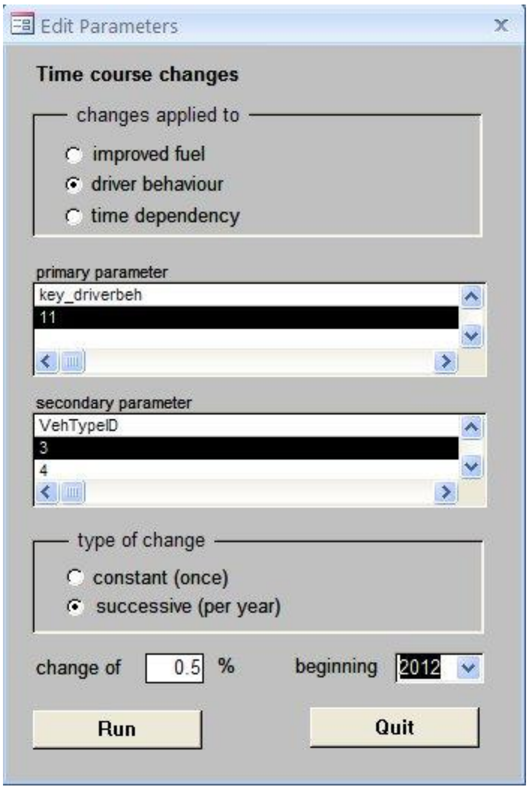
For instance, in order to model alternative scenarios/policies that affect average speeds and levels of congestion the user has the option to define alternative speed profiles. Congestion can be modelled at the national level by shifting the distribution to lower speed brackets. While speed profiles are defined by vehicle type and road type, all technologies belonging to the specified class of vehicle types are affected by the settings. Figure 24 shows a screenshot of the user forms relevant to speed/congestion modelling in DEEM.

Figure 24: Screenshot of the DEEM user forms for speed/congestion modelling



As a further example, driver behaviour can be simulated by applying a set of scaling factors that allow to consider how specific emissions change (in this case decrease) over time as a result of, say, a national eco-driving programmes (Figure 25).

Figure 25: User set up for driver behaviour change



More details on how the user can define and run alternative scenarios and policies affecting energy use and emissions are given in the UKTCM User Guide (Brand, 2010).

3 Life Cycle and Environmental Impacts Model

Approach

As far as the transport sector is concerned the basic principle of life cycle analysis (LCA) is to take into account all relevant up- and downstream processes within a defined system boundary. Based on a typical environmental life cycle assessment framework (ICO, 2006), the Life Cycle and Environmental Impacts Model (LCEIM) comprises:

1. A life cycle inventory model and;
2. An environmental impacts assessment model.

The life cycle inventory model calculates *indirect* energy use and emissions (including primary energy and land use) for the manufacture, maintenance and disposal of vehicles; the construction, maintenance, and disposal of infrastructure; and the supply of energy (fuels). The environmental impacts assessment model then provides an assessment of the damage caused by calculating impact indicators (e.g. global warming potential, GWP) and external costs.

The life cycle inventory model uses the 'hybrid approach' of process-chain analysis and input-output analysis developed by Marheineke et al. (1998; 1996). Process chain analysis is used for the main supply paths, and aggregated values for complete process chains are used within the model. For additional upstream processes, considered to be second or third-order effects, input-output analysis is used. This hybrid approach is seen as appropriate as much of the evidence in the literature suggests that, in most cases, over the lifetime of a vehicle, vehicle operation produces the vast majority of energy use and GHG emissions (Lane, 2006; MacLean and Lave, 2003). While the fuel supply and vehicle manufacture stages account for about 20% of total lifetime GHG emissions – being roughly equal in magnitude – vehicle maintenance and disposal account for a much smaller share (ibid.).

The environmental impacts assessment model converts direct (from the DEEM) and indirect (from the life cycle inventory model) emissions into impacts, which include a number of common impact indicators and external costs. Impact indicators are a means to describe environmental damage and to compare different pollutants with respect to a certain impact using different weighting factors. For example, the GWP_{100} (100-year Global Warming Potential) describes the warming impact of emissions over the next 100 years, and the POCP (Photochemical Ozone Creation Potential) refers to the formation of photochemical oxidants. The methodology for determining external costs is based on an evaluation of marginal effects. To estimate marginal effects an *Impact Pathway Approach* has been used, building on previous research on the European *ExternE* project (Bickel et al., 2003; EC, 2005).

The LCEIM allows the user to simulate the effects on energy use and emissions of e.g. adding new infrastructure (e.g. high speed rail), changes in the electricity generation mix and an alternative set of impact potentials (IPCC, 2007, is current default).

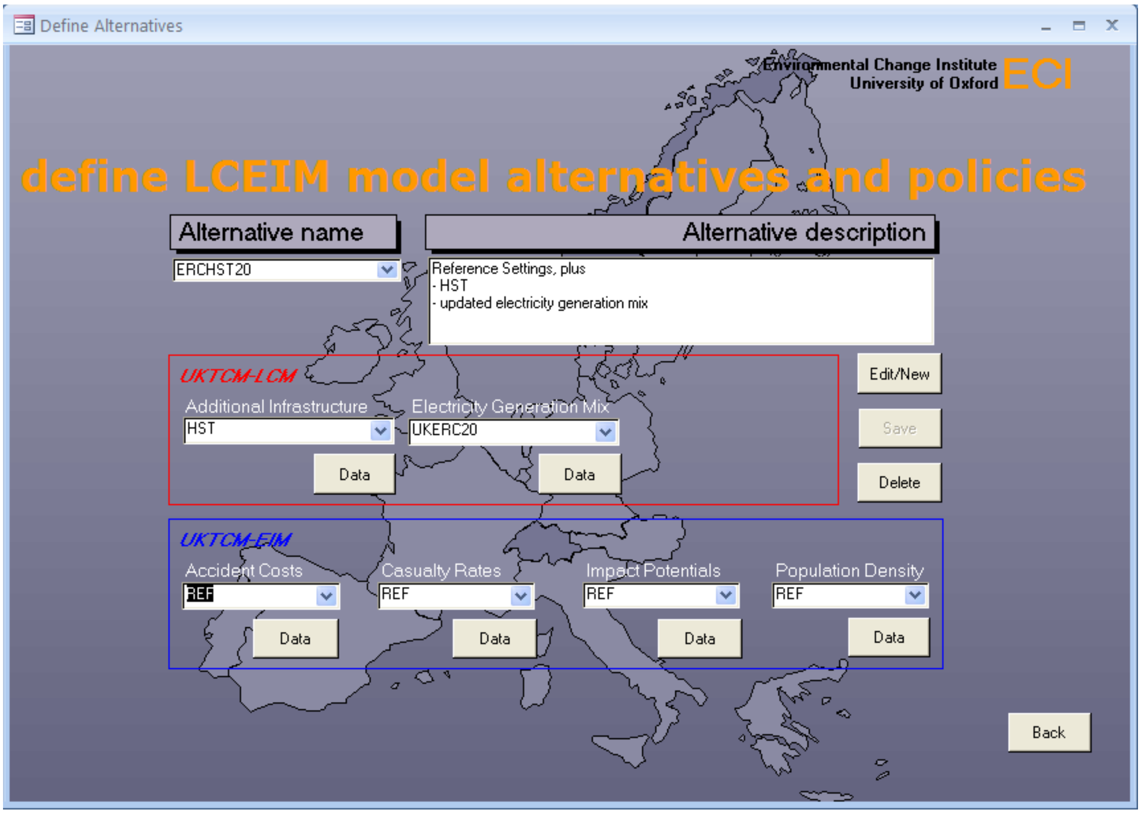
What the User Can and 'Should Not' Change

There are six parameter sets in the current version of the LCEIM that may be edited/defined by the user. For all other life cycle or environmental impact data, user access is not recommended. This is due to the fact that most of the model data inputs are generated elsewhere in the modelling chain. Hence, it is simply not possible for the user to define their own data at this point, since the user data would not be consistent with other model data.

The parameters that the user can edit/define via the graphical user interface (Figure 26) of the UKTCM are:

- additional transport infrastructure (this parameter will exclusively be defined by the user; there are no default/reference data for this parameter);
- electricity generation mix (in 10 year intervals to 2050);
- accident costs (monetary values for fatalities, minor and serious casualties);
- average accident rates (fatalities, minor and serious casualties);
- impact potentials (e.g. GWP100 figures for CH4 and N2O), and;
- population density for spatial demand segments (urban | motorway | intercity rail | etc.).

Figure 26: LCEIM user interface, definition of model alternatives and policies



In addition the user has the option to change the default data sets that are internal to the LCEIM and that were produced off-line using separate databases and/or by using other models. This includes:

- indirect emissions, primary energy demand and land use for the production, maintenance, and scrappage of vehicles;

- indirect emissions, primary energy demand and land use for the construction, maintenance, and disposal of infrastructure;
- energy use and emissions factors for electricity generation;
- indirect emissions, primary energy demand and land use for the production and supply of all 13 fuels considered in UKTCM;
- the VOC-split of exhaust emissions from conventional and alternative fuelled vehicles, and;
- external cost and monetary valuation rates for emissions, accidents and noise.

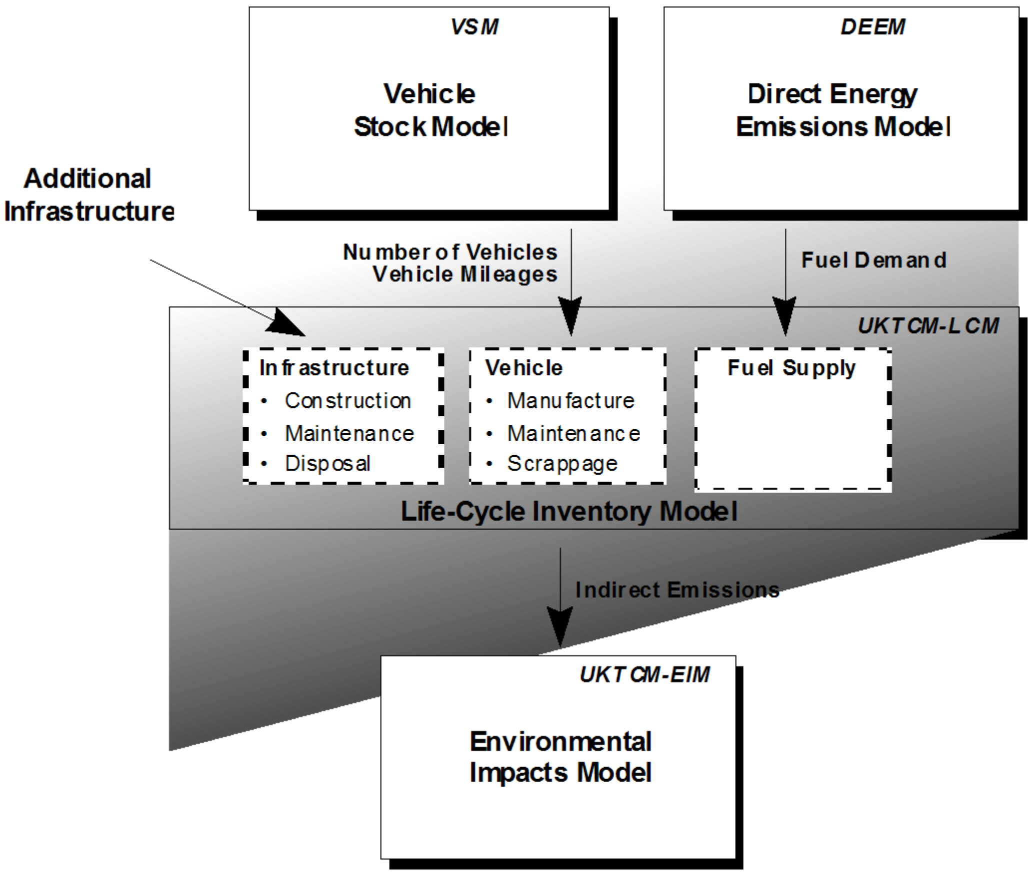
Modelling Methodology

3.1.1 Life Cycle Inventory Model

The necessary data sets for LCA such as emission factors for the provision of materials and the provision of energy carriers are modelled in UKTCM as aggregated values for an entire process chain.

The LCEIM is directly connected in terms of data flow (i.e. interface databases) to the VSM, the DEEM and the UKTCM User Interface, as illustrated in Figure 27.

Figure 27: Life Cycle Inventory Model Linkages



<u>Vehicle Manufacture, Maintenance and Scrappage</u>
Life cycle analysis of vehicles includes the manufacture, the maintenance and the scrappage of the vehicles. Herein of crucial importance is the interface from previous

UKTCM component models to the LCA model with emphasis on the conversion from technology data (i. e. number of vehicles) to LCA data (i. e. mass of materials needed).

The calculation of indirect emissions from the manufacture, maintenance and disposal of vehicles follows two main steps:

1. First, each vehicle type (e.g. medium sized internal combustion car) is broken down into its components in terms of mass of materials needed to manufacture the vehicle and for vehicle maintenance (e.g. tyres, lubricants etc.). Some 15 materials are modelled for each vehicle, including alkyd resin varnish, aluminium, glass, polypropylene, rubber and three types of steel. Based on this materials breakdown, the emissions, primary energy use and land use changes embedded in each kg of material are derived, for up to 25 emissions categories including embedded CO_2, nitrous oxide (N_2O, a direct GHG), 'land use conversion from undeveloped to cultivated' (in metre square/kilogram of material) and 'crude oil' (in kilogram of oil/kilogram of material).[6]
2. Secondly, the energy use and emissions for the *processes* involved in manufacturing, maintenance and disposal are derived by multiplying energy requirements for each process category with process emissions factors.

For step one for example, the embedded CO_2 emissions factors for unalloyed, low-alloy and high-alloy steel are 1.61, 1.97 and 5.28 kg of CO_2 per kg of material respectively. For aluminium this is even higher at 9.97 kg of CO_2 per kg of material.

To perform this conversion the technologies considered in UKTCM needed to be classified by mass category (essentially vehicle size) and by material category. Two different categories are used since two technologies may be of different weight but have the same percentage of materials. The disaggregation level of the mass classification of vehicles is such that all types of vehicles are clearly distinguished concerning emissions and energy demand for vehicle manufacture. The disaggregation level of the material structure of vehicles is such that all main components of vehicles are considered.

Another crucial point is the temporal system boundary for life cycle analysis of vehicles – temporal with regards to the vehicle fleet which is subject to evolution and continuous change. New vehicles are added and old vehicles are scrapped. Since the UKTCM is designed to evaluate the uptake of new transport technologies, only new vehicles are considered for life cycle analysis.

Although energy requirements and emissions related to the manufacture of a vehicle can be seen as values that should be distributed over the whole lifetime of the vehicles, UKTCM allocates all manufacturing emissions to the year of first registration. This was deemed the most feasible method for the following reasons:

- Independent modelling of a certain year will be possible.
- A direct evaluation of new technologies is possible as all effects (including LCA) are considered in one year and it is not necessary to compare discounted values over a time horizon of about 10 years.

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[6] For example, the embedded CO_2 emissions factors for unalloyed, low-alloy and high-alloy steel are 1.61, 1.97 and 5.28 kg of CO_2 per kg of material respectively. For aluminium this is even higher at 9.97 kg of CO_2 per kg of material.

Infrastructure Construction and Maintenance
Data availability or data procurement is a fundamental issue concerning infrastructure construction and maintenance. Detailed infrastructure modelling would require an infrastructure-demand model to consider the following effects:

- changes in infrastructure may have a considerable influence on congestion;
- heavy duty vehicles for example cause by far more damage to roads than cars;
- a higher transport demand does not necessarily lead to new infrastructure.

However, appropriate data and an infrastructure demand model were not available. Hence the modelling of these effects was deemed to be beyond the scope of UKTCM. Nevertheless, it is desirable for UKTCM to allow an analysis of significant changes in modal split or the introduction of new transport technologies (such as a High Speed Train network). To consider this, the user has the option to specify any *additional infrastructure* to the existing infrastructure network. Although modelled separately, the relevant LCEIM assumptions on additional infrastructure need to be consistent with the assumptions made in the TDM.

The calculation of indirect emissions for the construction, maintenance and disposal of *additional infrastructure* follows the same methodology as for life cycle assessment of vehicles. The underlying data are based on a number of life cycle studies, where available based on UK context, including more generic inventories on fuels and powertrains (Brinkman et al., 2005; DTI, 2000; Joint Research Centre, 2006) and vehicle manufacturing and disposal (Lane, 2006; Schäfer et al., 2006; Zamel and Li, 2006a) as well as more specific ones on vehicle materials (International Iron and Steel Institute, 2002), infrastructure materials (e.g. cement, Nemuth and Kreißig, 2007) and process emissions (e.g. freight transport, Höpfner et al., 2007).

The allocation of emissions from additional infrastructure is weighted by vehicle-km, which presents a simplification as, for example, heavy trucks (doing fewer miles than cars overall) are responsible for a larger share of the damage. Double counting within the hybrid life cycle inventory was avoided as much as possible following Strømman et al. (2009). In addition to energy consumption and emissions caused by infrastructure construction the corresponding land use impacts are derived as an impact indicator.

Energy Supply
Emissions from energy supply are calculated by converting energy and fuel use provided by the DEEM into emissions using well-to-tank emissions factors. The fuels and energy carriers covered are:

- Gasoline (petrol),
- Diesel (DERV),
- LPG (liquefied petroleum gas),
- Bio-methanol,
- Bio-ethanol petrol blend (E85),
- Biodiesel (from woody biomass) (B100),
- CNG (compressed natural gas),
- Electricity,
- GH_2 (gaseous hydrogen),
- LH_2 (liquid hydrogen),
- Kerosene (Jet-A aviation fuel) and

- Bio-kerosene.

The fuel supply emission factors used in the life cycle inventory model are pre-determined based on an extensive literature review (Brinkman et al., 2005; Frischknecht et al., 1997; JRC and CONCAWE EUCAR, 2006). For example, the indirect CO_2 emissions factors for the above fuels are provided in Table 14 below.

Table 14: Transport fuel specifications and indirect CO_2 emissions factors

Fuel type	*Embedded CO_2*	*Unit*	*Density (kg/litre)*	*Cal. Value (MJ/litre)*
Gasoline (petrol)	540	kg/ton	0.75	32.18
Diesel (DERV)	612	kg/ton	0.83	35.86
Liquefied Petrol Gas	400	kg/ton	0.54	24.80
Biomethanol	-15108	kg/TJ	0.79	15.78
Bioethanol-petrol blend (E85)	-15108	kg/TJ	0.79	29.26
Biodiesel (B100) 2^{nd} gen.	-55930	kg/TJ	0.89	33.11
Compressed Natural Gas (1)	5170	kg/TJ	0.16	7.72
Compressed Bio Gas (1)	-38490	kg/TJ	0.16	7.72
Gaseous Hydrogen (2)	8000	kg/TJ	0.06	7.00
Liquefied Hydrogen (3)	552	kg/ton	0.08	9.20
Aviation fuel (BP Jet A-1)	561	kg/ton	0.80	34.69
Bio jet fuel (100%)	-55930	kg/TJ	0.79	34.00

Notes: (1) At 200 bar (20 MPa) pressure. (2) At 600 bar (60 MPa) pressure. (3) At -253 deg C (20 K).

Sources: primarily JRC and CONCAWE EUCAR (2006), supplemented by Brinkman et al. (2005) and Gover et al. (1996).

In the case of biofuels, the DEEM calculates direct (or tank-to-wheel) emissions, while the LCEIM calculates well-to-tank emissions, which in the case of GHG may be *negative* (when growing the crops takes up more GHG from the atmosphere than fuel harvesting, production and distribution emits back into it).

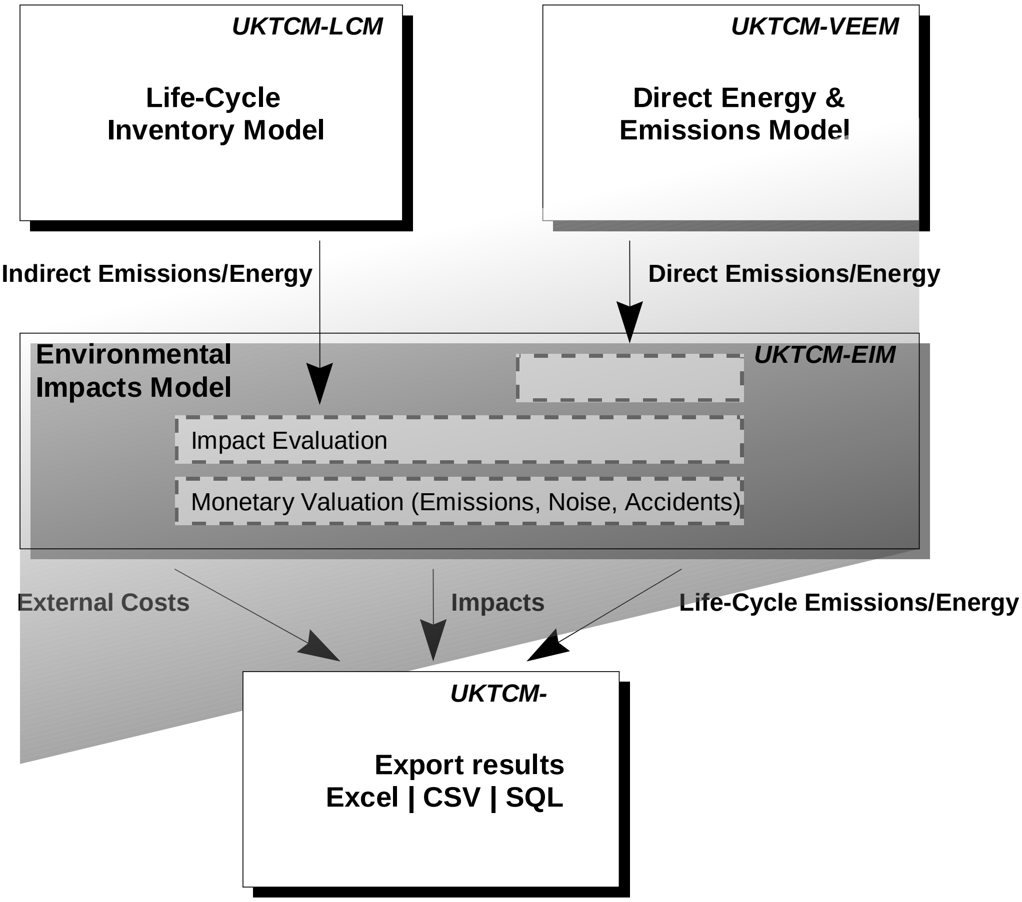
For electricity as a fuel, the LCEIM uses upstream emissions factors by generation fuel, taking into account the national electricity generation mix, transmission and distribution losses (around 10%) and imports from other countries (mainly France). In 2007, on an electricity supplied basis, 40% was generated by gas-fired power stations, 35% from coal, 16% from nuclear, 6% from renewables and 2% from imports (DECC, 2009). This results in a CO_2 content of electricity of 541 gCO_2/kWh end-use (including transmissions and distribution losses). The UKTCM incorporates default projections of the generation mix based on central Government projections to 2025 (DECC, 2008) and constant extrapolation to 2050. These can be changed by the user for scenario analysis.

The complete list of emissions species covered in LCEIM is provided in Table 16 below.

3.1.2 Environmental Impact Assessment Model

Environmental impact assessment in the UKTCM involves the provision of several impact quantities including impact indicators (e. g. global warming potential etc.) as well as monetary valuation of transport related damages (i.e. external costs). The linkages with other UKTCM modules are illustrated in Figure 28.

Figure 28: Environmental Impact Assessment Model Linkages



<u>Damage Types</u>

There are a variety of damage types. With regards to airborne emissions these are impacts on human health, damages to buildings (e.g. by soiling, corrosion etc.), damages to crops (i.e. yield losses), damages to forests and global warming. Further damages are accidents, fatalities, and injuries (Krewitt et al., 1996a). The damage types considered within the Environmental Impact Assessment Model are shown in Table 15.

Note on effects on forests

Effects on forests are not considered within the LCEIM for the following reasons. Fuel cycle impacts on forests have been the subject of much controversy. Within Europe there is now agreement that pollutants are capable of damaging trees at concentrations previously thought to be safe. Recent evidence suggests that pollutants are also capable of improving forest growth, principally through fertilisation with nitrogen. Hence, effects of pollution on natural ecosystems are reviewed but not quantified. There is very little information available for assessment of pollution effects on such systems other than critical loads. Therefore, forest damage will not be assessed within UKTCM due to the existing lack of knowledge.

Table 15: Damage types covered by the Environmental Impact Assessment Model

Damage type	*Description*
Global Warming	Greenhouse gas emissions from each fuel cycle are relatively well known and dominated by CO_2 emissions. The impacts of global warming affect a huge range of receptors. They are complex, scenario dependent, very uncertain, long term and potentially very large. Estimation of the impacts is rendered difficult by poor understanding of the likely regional variation in climatic change. Quantification is therefore difficult. Monetary valuation is even more problematic, because of the macro-scale of the impacts and interactions between them. The most comprehensive assessments of the impacts by the IPCC suggest impact values for different pollutant types relative to CO_2 based on their relative global warming potentials (e.g. 1 for CO_2, 23 for CH_4, 296 for N_2O). The quantification of global warming impacts in terms of monetary values 'low' and 'high' estimates of the social cost of carbon (Watkiss et al., 2005) have been included in the LCEIM.
Public Health Impacts	The most important effects on the general public are likely to arise from exposure to air pollution. The approach adopted here follows a no-threshold model, based on the results of a large number of epidemiological studies. Noise potentially affects both human health and amenity where hearing damage occurs only at high noise levels. Occupational health impacts are not considered in the UKTCM.
Direct Transport Related Health Impacts	Direct transport related health impacts in particular result from accidents. Hence a monetary valuation of accidents, fatalities, and injuries will be applied where the valuation of fatalities will be expressed by the Value of Statistical Life. This approach of using the number of accidents, fatalities and serious/minor injuries will implicitly used as a measure of safety.
Effects on Agriculture	Direct effects of sulphur dioxide (SO_2) on wheat, barley, oats, rye, peas and beans are assessed, while other major crops like potatoes, oilseed rape etc. are assumed to be tolerant of SO_2. Dose-response functions are used which estimate both fertilisational and deleterious effects.
Effects on Building Materials	Material surfaces are mostly affected by SO_2 or wet acid deposition. Increased maintenance costs to natural stone, mortar, rendering, zinc, galvanised steel and paintings on European dwelling houses are evaluated. The dose-response functions to acid attack are derived from an expert assessment of the relevant literature. They consider only uniform corrosion over the whole surface, which is often, but not always the dominant damage mechanism. The rates of corrosion are converted into a repair or replacement frequency using expert judgements and the repair is valued using market prices.

Emission Species

The selection of emission species for the LCEIM was based on the significance of the pollutants with respect to environmental impacts, in particular health effects. Some of these species cannot be modelled “directly” in terms of technology specific emission factors (within the DEEM). For example, some volatile organic compounds (VOC) are derived in UKTCM from total VOC emissions (from DEEM) using corresponding VOC-split factors.

Human health is affected by particulates (measured as $PM_{2.5}$ or PM_{10}, the fraction of air-borne particulate matter with a diameter less than 2.5 μm or 10 μm respectively) with a wide range of acute (i.e. immediate) health impacts, ranging from major events that require admission to hospital to lesser effects such as shortness of breath in asthmatics. Health effects of sulphur dioxide (SO_2) and nitrogen oxides (NO_x) are only included in so far as they contribute to particulate levels through the formation of sulphate and nitrate aerosols (secondary particulates). Relationships linking effects directly to SO_2 or NO_x are not used. The species of VOC that are included are benzene, ethylene and formaldehyde.

All other impact indicators are covered by including further pollutants including carbon dioxide, methane and nitrous oxide (global warming), methane, non-methane VOC, benzene (photochemical ozone creation), and nitrogen oxides, sulphur dioxide (acidification and nitrification). The emission species and their main impacts are listed in Table 16.

Table 16: Pollutants and their *main* environmental impacts

Pollutant	*Impact on*
CO_2	global warming
CO	human health
CH_4	global warming, photochemical ozone creation
NMVOC	agriculture, human health, photochemical ozone creation
Particulates: $PM_{2.5}$, PM_{10}, $PM_{>10}$	human health
NO_x	human health, agriculture, building materials, acidification, nutrification
N_2O	global warming
SO_2	human health, agriculture, building materials, acidification
C_6H_6 (benzene)	human health, photochemical ozone creation
C_2H_4 (ethylene)	human health
HCHO (formaldehyde)	human health

In addition to the pollutant emissions listed above, any significant land use changes resulting from changes in transport demand as well as changes in primary energy demand are calculated in the LCEIM. With regards to *land use* this includes:

- land use conversion from undeveloped to cultivated,
- land use conversion from undeveloped to built up, and
- land use conversion from cultivated to built up.

With regards to *primary energy demand* this includes:

- crude lignite before extraction,

- crude hard coal before processing,
- crude natural gas,
- crude oil,
- uranium (ore),
- hydro energy (in terms of potential energy of water), and
- biomass.

Impact Indicators

Impact indicators are a means to describe environmental damage and to compare different pollutants with respect to a certain impact using different weighting factors. For example, the GWP (global warming potential) describes the greenhouse effect, while the POCP (photochemical ozone creation potential) refers to the formation of photochemical oxidants. These impact indicators can be determined using a set of weighting factors for different pollutants. Table 17 gives an overview of the impact indicators included in LCEIM.

Table 17: Impact indicators

Abbreviation	*Impact Description*
GWP_x	Global Warming Potential for different integration time horizons x=20, 100 and 500 years
AD	Abiotic Depletion (i.e. crude oil, natural gas, coal, etc.)
POCP	Photochemical Ozone Creation Potential
HCA	Human Toxicological Classification (Air)
AP	Acidification Potential
NP	Nutrification Potential

Monetary Valuation

The use of energy causes damage to a wide range of receptors, including human health, natural ecosystems and the built environment. Such damages are referred to as external costs, as they are not reflected in the market price of energy.

The methodology of determining external costs is based on an evaluation of marginal effects. To estimate marginal effects, the "Impact Pathway Approach" developed within the EU project ExternE (EC, 2005) taking into account technology specific emission data for individual locations. The "Impact Pathway Approach" is based on a step-by-step analysis, starting with the release of burdens from the fuel cycle, and moving through their interactions with the environment to a physical measure of impact and, where possible, a monetary valuation of the resulting welfare losses.

Based on the concepts of welfare economics, monetary valuation of environmental impacts follows the approach of Willingness To Pay (WTP) for improved environmental quality or Willingness To Accept (WTA) for environmental damage (Krewitt et al., 1996a). This approach implies underlying premises including:

- the philosophy that the value is measured by the aggregation of human preferences,
- that WTP and/or WTA is an adequate measure of preference, and
- that the values of environmental quality can be substituted by other commodities.

The techniques of monetary valuation fall broadly into three categories:

- Valuation through the use of market prices:

  - can be used where the receptors are commodities traded in normal markets, like crops or timber.
- Indirect valuation via hedonic prices and the travel cost method:
  - typically used for valuing impacts to amenity and recreational sites, where a public good is affected, and therefore behaviour in a related market is observed.
- Contingent Valuation Method (CVM):
  - valuation of goods like natural ecosystems and biodiversity which are not related to any real market using hypothetical markets.

A comprehensive analysis requires the assessment of all stages of the fuel cycle, all significant impacts and extending the impact analysis in space and time to capture all relevant effects. For instance, taking into account long range transport, chemical conversion of pollutants becomes an important issue. In particular the consideration of sulphate and nitrate aerosols subsequently produced from the emissions of gaseous SO_2 and NO_x has a major implication on the assessment of human health effects. In practice, a fully comprehensive analysis is not possible due to the number of impacts which could potentially be included. Priorities for an analysis should be selected based on both literature review and expert judgement, with the objective of including the impacts with the largest damages. Based on previous studies, e.g. EC (1996), the population density as the main influence variable for human health effects seems to be the driving parameter for impact quantity.

As the methodology for monetary valuation – in particular dispersion modelling – is rather complex, each single step of this method is not followed directly within the UKTCM. Instead, a "Building Block" methodology is employed using aggregated parameterised values for different processes and technologies. The "Building Blocks" provide functionality between input parameters (such as emissions) and external costs. They also allow a transition from marginal to absolute effects. The derived external cost data are based on the following methodological steps:

- atmospheric transport and chemical transformation modelling,
- calculation of concentrations/depositions, and
- application of dose-response relationships.

Model Specification

This Section describes the computational steps in the model as well as the functional relationships and the attributes of the model variables.

3.1.3 Definitions

Table 18 gives an overview of the variables used within the Life Cycle Inventory Model; and Table 19 gives an overview of the variables used within the Environmental Impacts Assessment Model. Two digit abbreviations indicate input or output variables. Three digit abbreviations indicate internal model variables.

Table 18: Abbreviations of variables used within the Life Cycle Inventory Model

Abbreviation	*Variable Name*
AI	Additional infrastructure
ET	Total (life cycle) emissions = direct plus indirect emissions
ED	Direct emissions (at source, tailpipe)
EI	Indirect emissions (upstream, downstream)
EN	Direct emissions except VOC (non-VOC)
EV	Direct VOC emissions
GE	Electricity generating mix
KM	Vehicle mileages (kilometres)
LU	Land use of infrastructure
NN	Number of new vehicles
NS	Number of scrapped vehicles
NT	Total number of vehicles
PR	Primary energy requirements
QF	Quantity of fuels
AIT	Additional infrastructure by technology
EIF	Life cycle emissions of fuel/energy supply
EII	Life cycle emissions of material supply
FDT	Total fuel/energy demand
FIC	Energy demand of infrastructure construction
FIS	Energy demand of material supply
FVM	Energy demand of vehicle manufacture
FVS	Energy demand of vehicle scrappage
FVU	Energy demand of vehicle maintenance (use)
IDI	Material demand for infrastructure construction
IDM	Material demand for vehicle manufacture
IDT	Total material demand
IDU	Material demand for vehicle maintenance
LIC	Land use of infrastructure construction
NVU	Number of vehicles under maintenance
PFS	Primary energy requirements of fuel/energy supply
RVU	Maintenance rate of vehicles
VOC	VOC split of direct emissions
ZFS	Emission factors for fuel/energy supply
ZIC	Emission factors for infrastructure construction
ZIS	Emission factors for material supply
ZVM	Emission factors for vehicle manufacture
ZVS	Emission factors for vehicle scrappage
ZVU	Emission factors for vehicle maintenance (use)

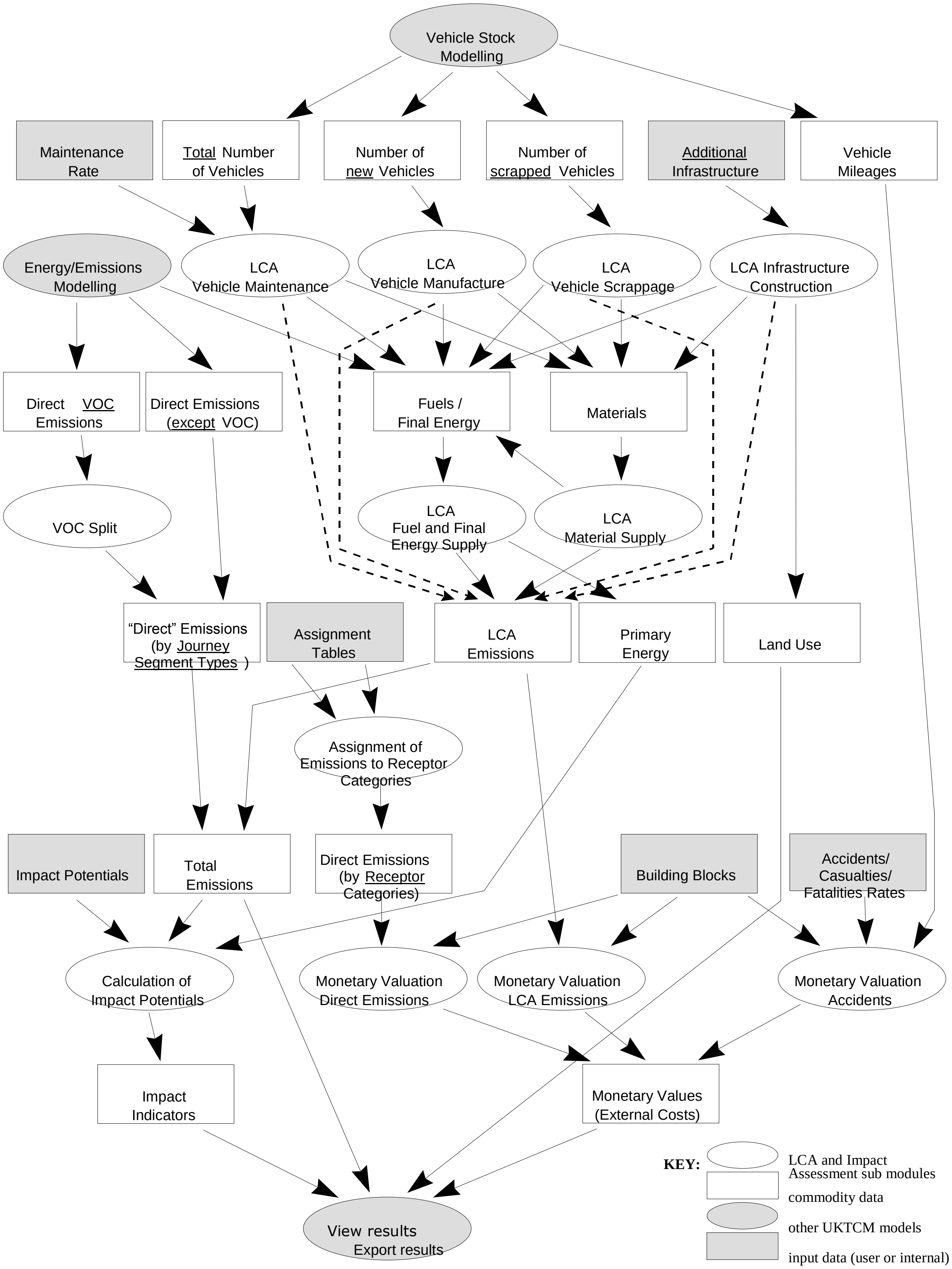
Table 19: Abbreviations of variables used within the Environmental Impacts Assessment Model

Abbreviation	*Variable Name*
ET	Total (life cycle) emissions = direct plus indirect emissions
ED	Direct emissions (at source, tailpipe)
EI	Indirect emissions (upstream, downstream)
II	Impact Indicators
KM	Vehicle mileages (kilometres)
PR	Primary energy requirements
RA	Rate of accidents
RF	Rate of fatalities
RM	Rate of minor casualties
RS	Rate of serious casualties
VL	Value of statistical life
XT	Total external costs
AJR	Assignment factors from journey segment types to receptor categories
IPO	Impact potentials
MVA	Monetary values for accidents
MVD	Monetary values ('Building Blocks') for direct emissions
MVI	Monetary values ('Building Blocks') of indirect emissions
MVM	Monetary values for minor casualties
MVS	Monetary values for serious casualties
XED	External costs of direct emissions
XEI	External costs of indirect emissions
XVA	External costs of vehicle accidents

3.1.4 Modelling flow within the LCEIM

Figure 29 shows the modelling flowchart for the LCEIM. In a first step, the demand for energy and materials is calculated from (a) the number of vehicles provided by the VSM and (b) from the fuel demand provided by the DEEM. For materials and energy the corresponding indirect (embedded) emissions and primary energy requirements are derived. Also, the emissions that are directly related to the manufacture, maintenance, and scrappage of vehicles as well as to the construction of infrastructure are added. For any additional infrastructure defined by the user the corresponding land use and emissions are computed. The number of accidents, casualties, and fatalities are calculated by means of corresponding impact rates related to the vehicle mileage travelled. Direct vehicle emissions from the DEEM (disaggregated by demand segment types) are converted into emissions disaggregated by receptor categories by means of assignment tables. In the next step these emissions as well as the total life cycle emissions, accidents, fatalities, and casualties are assessed in terms of monetary valuation of the related damages using the Building Blocks described earlier. Finally, the main output indicators (direct, indirect and total life cycle emissions, primary energy demand, land use, impact indicators, external costs) are passed to the view and export results module.

Figure 29: Detailed modelling flowchart of the LCEIM



3.1.5 Functional relationships

This Section outlines the functional dependencies between the modelling variables. For detailed specification of the functions themselves see the following Section. Refer to Table 20 for the LCEIM attribute names and subscript labels used in the relationships.

Table 20: LCEIM attribute names and subscript labels

Attribute labels	*Attribute name (disaggregation)*
S	Scenario
C	Country/region (only one region is used in UKTCM v1: the UK)
Y	Year (1995-2050)
M	Transport mode (road, rail, water, air)
K	Transport type (passenger, freight)
V	Vehicle type
W	Vehicle mass category or weight
T	Vehicle technology
J	Demand segment type
F	Fuel, final energy demand
E	Emission species
P	Primary energy
I	Material

<u>Life Cycle Inventory Model</u>

Direct emissions

$$ED_{S, C, Y, T, J, E} = f_E(EN_{S, C, Y, T, J, E}, EV_{S, C, Y, T, J}, VOC_{T, J, E})$$

Number of vehicles requiring maintenance

$$NVU_{S, C, Y, T} = f(NT_{S, C, Y, T}, RVU_{C, Y, T})$$

Additional infrastructure by technology

$$AIT_{S, C, Y, T} = f(AI_{S, C, Y, M}, KM_{S, C, Y, T})$$

Total material demand

$$IDT_{S, C, Y, T, I} = f(NN_{S, C, Y, T}, IDM_{C, Y, V, W, F, I}, NVU_{S, C, Y, T}, IDU_{C, Y, V, W, F, I}, AIT_{S, C, Y, T}, IDI_I)$$

Total fuel and energy demand

$$FDT_{S, C, Y, T, F} = f(QF_{S, C, Y, T, F}, NN_{S, C, Y, T}, FVM_{C, Y, V, W, F}, NVU_{S, C, Y, T}, FVU_{C, Y, V, W, F}, NS_{S, C, Y, T}, FVS_{C, Y, V, W, F}, AIT_{S, C, Y, T}, FIC_F, IDT_{S, C, Y, T, I}, FIS_{C, Y, F, I})$$

Indirect emissions, material Supply (without energy demand related emissions)

$$EII_{S, C, Y, T, E} = f(IDT_{S, C, Y, T, I}, ZIS_{C, Y, E, I})$$

Indirect emissions, fuel/energy supply

$EIF_{S, C, Y, T, E} = f(FDT_{S, C, Y, T, F}, ZFS_{C, Y, F, E})$

Total indirect emissions

$EI_{S, C, Y, T, E} = f(NN_{S, C, Y, T}, ZVM_{C, Y, V, W, F, E}, NVU_{S, C, Y, T}, ZVU_{C, Y, V, W, F, E}, NS_{S, C, Y, T}, ZVS_{C, Y, V, W, F, E}, AIT_{S, C, Y, T}, ZIC_{E}, EII_{S, C, Y, T, E}, EIF_{S, C, Y, T, E})$

Total life cycle emissions

$ET_{S, C, Y, T, E} = f(ED_{S, C, Y, T, J, E}, EI_{S, C, Y, T, E})$

Primary energy requirements

$PR_{S, C, Y, T, P} = f_{F}(FDT_{S, C, Y, T, F}, PFS_{C, Y, F, P}, GE_{S, C, Y})$

Land use of infrastructure

$LU_{S, C, Y, T} = f(AIT_{S, C, Y, T}, LIC)$

Environmental Impact Assessment Model

External costs of direct emissions

$XED_{S, C, Y, T} = f_{E}(ED_{S, C, Y, T, J, E}, AJR_{C, J}, MVD_{C, Y, J, E})$

External costs of indirect emissions

$XEI_{S, C, Y, T} = f_{E}(EI_{S, C, Y, T, E}, MVI_{C, Y, E})$

External costs of vehicle accidents

$XVA_{S, C, Y, T} = f(KM_{S, C, Y, T}, RA_{C, Y, V}, MVA, RF_{C, Y, V}, VL, RS_{C, Y, V}, MVS, RM_{C, Y, V}, MVM)$

Total external costs

$XT_{S, C, Y, T} = f(XED_{S, C, Y, T}, XEI_{S, C, Y, T}, XVA_{S, C, Y, T})$

Impact indicators

$II_{S, C, Y, T} = f_{E}(IPO_{E, P}, ET_{S, C, Y, T, E}, PR_{S, C, Y, T, P})$

3.1.6 Modelling equations

The following modelling equations specify the functional relationships outlined above; the subscripts of variable disaggregation have been left out here for the sake of clarity.

Life Cycle Inventory Model

Equation 33: Direct Emissions

$$ED_{NVOC} = EN$$
$$ED_{VOC} = EV \cdot VOC$$

Equation 34: Number of vehicles requiring maintenance

$$NVU = NT \cdot RVU$$

Equation 35: *Pro rata* distribution by technology of additional infrastructure

$$AIT = AI \cdot \frac{KM}{\sum_{T} KM}$$

Equation 36: Total material demand

$$IDT = (NN \cdot IDM) + (NVU \cdot IDU) + (AIT \cdot IDI)$$

Equation 37: Total fuel and energy demand

$$FDT = QF + (NN \cdot FVM) + (NVU \cdot FVU) + (NS \cdot FVS) + (AIT \cdot FIC) + (IDT \cdot FIS)$$

Equation 38: Life cycle emissions, material supply

$$ELI = \sum_{I} (IDT \cdot ZIS)$$

Equation 39: Life cycle emissions, fuel and energy supply

$$ELF = \sum_{F} (FDT \cdot ZFS)$$

Equation 40: Life cycle emissions

$$EI = (NN \cdot ZVM) + (NVU \cdot ZVU) + (NS \cdot ZVS) + (AIT \cdot ZIC) + ELI + ELF$$

Equation 41: Total emissions

$$ET = \sum_{J} ED + EI$$

Equation 42: Primary energy requirements

$$PR_{non-electricity} = \sum_{F} (FDT \cdot PFS)$$

$$PR_{electricity} = \sum_{F} \sum_{P} (FDT \cdot GE \cdot PFS)$$

Environmental Impact Assessment Model

Equation 43: Land use of infrastructure

$$LU = AIT \cdot LIC$$

Equation 44: External costs of direct emissions

$$XED = \sum_{J} \sum_{E} (ED \cdot AJR \cdot MVD)$$

Equation 45: External costs of indirect emissions

$$XEI = \sum_{E} (EI \cdot MVI)$$

Equation 46: External costs of vehicle accidents

$$XVA = KM \cdot \left((RA \cdot MVA) + (RF \cdot VL) + (RS \cdot MVS) + (RM \cdot MVM) \right)$$

Equation 47: Total external costs

$$XT = XED + XEI + XVA$$

Equation 48: Impact indicators

$$II = \sum_{E} IPO \cdot EC$$

$$II = \sum_{P} IPO \cdot PR$$

Key data sources

Given the uncertainty inherent in life cycle assessment, the differences in methods, assumptions and data used in these studies, default data were chosen for the LCEIM that represent 'best estimates', which can be changed by the user.

The default values of aggregated emission factors in life cycle inventory model stems from environmental life cycle inventory studies from the 1990s (Frischknecht et al., 1997; Maibach et al., 1995). These have been augmented as described in the main body of text, including a number of sources on fuel supply emissions and embedded emissions in material supply (Gover et al., 1996; Höpfner et al., 2007; International Iron and Steel Institute, 2002; Lane, 2006; Marheineke, 1996; Zamel and Li, 2006).

A number of European studies were used for the data requirements of the impact assessment model. "Building Block" data were derived from the EU projects *ExternE* (EC, 2005) and *ExternE Transport* (EC, 1996). Additional data for monetary valuation was derived from the EcoSense model (Krewitt et al., 1996b). Impact indicators were computed using values for impact potentials from IPCC (2007) and Heijungs. et al. (1993).

4 Conclusion

The UKTCM arguable makes the output of traditional complex models much more accessible to the decision-maker. By combining several models in a single system, the model enables a more holistic approach to decision-making, with a diverse range of criteria being handled simultaneously.

This guide shows how things are done – yet the real fun starts when the UKTCM is used to develop transport policy scenarios that explore the full range of technological, fiscal, regulatory and behavioural change policy interventions to meet UK climate change and energy security goals.

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Appendix A: Vehicle Stock Model Variables and Data Tables

A.1 VSM input and output variables

Table 21: Inputs from exogenous scenarios (context variables)

Variable	*Disaggregation*	*Sub Modules where variable is used*
GDP (or Base Year GDP plus annual GDP growth)	Scenario, Year	Car Ownership Module
Average Household Disposable Income	Scenario, Year	Car Ownership Module New Vehicle Choice Module
Household Size Distribution	Scenario, Year	Car Ownership Module New Vehicle Choice Module
Population Age Distribution	Scenario, Year	Car Ownership Module
Maximum Level of Car Ownership	Scenario, Car Ownership Level for the Base Year	Car Ownership Module
Population Distribution	Year, Location	Car Ownership Module
Car Ownership Elasticity$	Scenario	Car Ownership Module
Discount/Interest Rate	Scenario	New Vehicle Choice Module
Fuel Prices (before tax)	Scenario, Year, Fuel	New Vehicle Choice Module
Vehicle Purchase Prices (before tax)	Scenario, Year, Vehicle type, Size, Technology	New Vehicle Choice Module
Household Location*	Scenario, Year, Urban/Non-urban	Car Ownership Module New Vehicle Choice Module
Characteristic Vehicle Service Life*	Scenario, Vehicle Type, Technology	New Vehicle Choice Module Vehicle Scrappage Module
Available Technologies*	Scenario, Year	Vehicle Scrappage Module New Vehicle Choice Module

* Could be affected by user, as a policy variable.

$ Needs to be calibrated

Table 22: Inputs from other UKTCM models

Variable	*Disaggregation*	*Sub modules where variable is used*
Annual Vehicle Kilometres (from TDM)	Scenario, Policy, Vehicle Type, Urban/Non-urban	New Vehicle Choice Module Vehicle Kilometre Disaggregation Module
Average Trip Lengths	Scenario, Policy	Aircraft Population Module
Annual Transport Demand (from TDM) in pass-km and tonne-km	Scenario, Policy, Vehicle Type, Urban/Non-urban	Car Ownership Module Other Vehicle Ownership Modules

Table 23: Main outputs to other UKTCM models

Variable	*Disaggregation*	*Receiving Model*
Number of Vehicles	Scenario, Policy, Year, Vehicle Type, Size, Technology, Vehicle Category (new, total, scrapped)	Life Cycle and Environmental Impacts Model
Annual Vehicle Kilometres	Scenario, Policy, Year, Vehicle Type, Size, Technology, Journey Segment Type	Direct Energy and Emissions Model

A.2 Vehicle technology parameters

One of the key data sets containing technology information is the database table *Technology*. This includes information about:

- Mode, passenger/freight, vehicle type, size, fuel type, engine technology and hybridisation, and vintage (EURO 6, 7, etc signify future vintages not necessarily any future EU emissions standards!);
- The first year of technology availability (e.g. 2005 for EURO IV gasoline cars) and the final year of technology availability (e.g. 2004 for EURO III gasoline cars), which is used to simulate technology vintaging;
- Specific fuel consumption (litres of fuel per vehicle-km, kWh per vehicle-km), calculated using the DEEM during calibration phase and only used for calculating estimated annual fuel costs which underpin price factors in the technology choice module. The real SFC figures are modelled dynamically using speed-emissions curves;
- Average purchase price (before tax) – this is a showroom price not an engineering cost;

The other key technology data set is the vehicle technology choice table called *Scen_TechChoice*, which contains:

- T_{entry};
- $T_{maturity}$, and;
- the calibrated (for historic technologies) and assumed (for future technologies) performance and preference factor P.

The *default* values for the 604 vehicle technologies included in UKTCM v1 are provided in Table 24.

As the UKTCM employs an open modelling framework the user can easily add further vehicle technologies or whole categories and also change the characteristics for the default categories.

Table 24: Key vehicle technology parameters

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, P, MOTO, Average moto, Gasoline (petrol), 2-Stroke Standard 1	1980	2000	4.23	5000	594001	1980	1981
Road, P, MOTO, Average moto, Gasoline (petrol), 2-Stroke Standard 2	2000	2010	3.50	5000	594001	2000	2001
Road, P, MOTO, Average moto, Gasoline (petrol), 2-Stroke Economic	2010		2.76	5000	594001	2010	2011
Road, P, MOTO, Average moto, Electricity, 2-Stroke Standard 1	1995	2010	9.58	7000	0	1995	2000
Road, P, MOTO, Average moto, Electricity, 2-Stroke Standard 2	2010	2020	8.38	6000	5940	2010	2015
Road, P, MOTO, Average moto, Electricity, 2-Stroke Economic	2020		7.18	5500	5940	2020	2025
Road, P, MOTO, Average moto, Gaseous Hydrogen, Fuel Cell	2015	2030	6.57	7000	0	2015	2020
Road, P, MOTO, Average moto, Gaseous Hydrogen, Fuel Cell	2030		5.26	6500	0	2030	2035
Road, P, CAR, Small, Gasoline (petrol), Conventional (no catalyst)	1980	1992	7.37	10000	1373	1980	1981
Road, P, CAR, Small, Gasoline (petrol), Euro 1 (incl. catalyst)	1992	1996	6.74	10000	534	1992	1993
Road, P, CAR, Small, Gasoline (petrol), Euro 2 (incl. catalyst)	1996	2000	7.05	10000	534	1996	1997
Road, P, CAR, Small, Gasoline (petrol), Euro 3 (incl. catalyst)	2000	2005	6.92	10000	534	2000	2001
Road, P, CAR, Small, Gasoline (petrol), Euro 4 (incl. catalyst)	2005	2010	6.51	10000	534	2005	2006
Road, P, CAR, Small, Gasoline (petrol), Euro 5 (2009-14)	2009	2015	6.37	10000	534	2009	2010
Road, P, CAR, Small, Gasoline (petrol), Euro 6 (2015-19)	2015	2020	6.18	10000	534	2015	2016
Road, P, CAR, Small, Gasoline (petrol), Euro 7 (2020-24)	2020	2025	6.03	10000	534	2020	2021
Road, P, CAR, Small, Gasoline (petrol), Euro 8 (2025-29)	2025	2030	5.88	10000	534	2025	2026
Road, P, CAR, Small, Gasoline (petrol), Euro 9 (2030-34)	2030	2035	5.74	10000	534	2030	2031
Road, P, CAR, Small, Gasoline (petrol), Euro 10 (2035-39)	2035	2040	5.59	10000	534	2035	2036
Road, P, CAR, Small, Gasoline (petrol), Euro 11 (2040-44)	2040	2045	5.46	10000	534	2040	2041
Road, P, CAR, Small, Gasoline (petrol), Euro 12 (2045-50)	2045		5.32	10000	534	2045	2046
Road, P, CAR, Small, Gasoline (petrol), Euro 5 (2009-14), PHEV	2009	2015	4.44	12000	0	2009	2014
Road, P, CAR, Small, Gasoline (petrol), Euro 6 (2015-19), PHEV	2015	2020	4.32	11500	1	2015	2019
Road, P, CAR, Small, Gasoline (petrol), Euro 7 (2020-24), PHEV	2020	2025	4.20	11000	5	2020	2024
Road, P, CAR, Small, Gasoline (petrol), Euro 8 (2025-29), PHEV	2025	2030	4.14	10500	53	2025	2026
Road, P, CAR, Small, Gasoline (petrol), Euro 9 (2030-34), PHEV	2030	2035	4.02	10000	53	2030	2031
Road, P, CAR, Small, Gasoline (petrol), Euro 10 (2035-39), PHEV	2035	2040	3.90	10000	53	2035	2036
Road, P, CAR, Small, Gasoline (petrol), Euro 11 (2040-44), PHEV	2040	2045	3.84	10000	53	2040	2041
Road, P, CAR, Small, Gasoline (petrol), Euro 12 (2045-50), PHEV	2045		3.72	10000	53	2045	2046
Road, P, CAR, Small, Diesel (DERV), Euro 3 (incl. catalyst)	2000	2005	4.74	12000	267	2000	2001
Road, P, CAR, Small, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	4.37	12000	400	2005	2006
Road, P, CAR, Small, Diesel (DERV), Euro 5 (2009-14)	2009	2015	4.29	12000	534	2009	2010
Road, P, CAR, Small, Diesel (DERV), Euro 6 (2015-19)	2015	2020	4.16	12000	534	2015	2016
Road, P, CAR, Small, Diesel (DERV), Euro 7 (2020-24)	2020	2025	4.06	12000	534	2020	2021
Road, P, CAR, Small, Diesel (DERV), Euro 8 (2025-29)	2025	2030	3.96	12000	534	2025	2026

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, P, CAR, Small, Diesel (DERV), Euro 9 (2030-34)	2030	2035	3.86	12000	534	2030	2031
Road, P, CAR, Small, Diesel (DERV), Euro 10 (2035-39)	2035	2040	3.76	12000	534	2035	2036
Road, P, CAR, Small, Diesel (DERV), Euro 11 (2040-44)	2040	2045	3.67	12000	534	2040	2041
Road, P, CAR, Small, Diesel (DERV), Euro 12 (2045-50)	2045		3.58	12000	534	2045	2046
Road, P, CAR, Small, Biomethanol, Fuel Cell	2030		4.92	13000	0	2030	2035
Road, P, CAR, Small, Biomethanol, Fuel Cell	2015	2030	6.08	15000	0	2015	2020
Road, P, CAR, Small, Electricity, Standard 1	1990	2005	17.77	13000	3	1990	1995
Road, P, CAR, Small, Electricity, Standard 2	2005	2020	15.26	12000	13	2005	2019
Road, P, CAR, Small, Electricity, Standard 3	2020		12.72	11000	27	2020	2021
Road, P, CAR, Small, Gaseous Hydrogen, Fuel Cell	2030		8.69	13000	0	2030	2035
Road, P, CAR, Small, Gaseous Hydrogen, Fuel Cell	2020	2030	10.74	15000	0	2020	2025
Road, P, CAR, Medium, Gasoline (petrol), Conventional (no catalyst)	1980	1992	8.31	15000	1183	1980	1981
Road, P, CAR, Medium, Gasoline (petrol), Euro 1 (incl. catalyst)	1992	1996	7.81	15000	484	1992	1993
Road, P, CAR, Medium, Gasoline (petrol), Euro 2 (incl. catalyst)	1996	2000	8.21	15000	484	1996	1997
Road, P, CAR, Medium, Gasoline (petrol), Euro 3 (incl. catalyst)	2000	2005	8.06	15000	484	2000	2001
Road, P, CAR, Medium, Gasoline (petrol), Euro 4 (incl. catalyst)	2005	2010	7.43	15000	484	2005	2006
Road, P, CAR, Medium, Gasoline (petrol), Euro 5 (2009-14)	2009	2015	7.28	15000	484	2009	2010
Road, P, CAR, Medium, Gasoline (petrol), Euro 6 (2015-19)	2015	2020	7.07	15000	484	2015	2016
Road, P, CAR, Medium, Gasoline (petrol), Euro 7 (2020-24)	2020	2025	6.89	15000	484	2020	2021
Road, P, CAR, Medium, Gasoline (petrol), Euro 8 (2025-29)	2025	2030	6.72	15000	484	2025	2026
Road, P, CAR, Medium, Gasoline (petrol), Euro 9 (2030-34)	2030	2035	6.55	15000	484	2030	2031
Road, P, CAR, Medium, Gasoline (petrol), Euro 10 (2035-39)	2035	2040	6.39	15000	484	2035	2036
Road, P, CAR, Medium, Gasoline (petrol), Euro 11 (2040-44)	2040	2045	6.23	15000	484	2040	2041
Road, P, CAR, Medium, Gasoline (petrol), Euro 12 (2045-50)	2045		6.08	15000	484	2045	2046
Road, P, CAR, Medium, Gasoline (petrol), Euro 4 (incl. catalyst), HEV	2005	2010	4.50	16500	2	2005	2006
Road, P, CAR, Medium, Gasoline (petrol), Euro 5 (2009-14), HEV	2009	2015	4.41	16500	3	2009	2010
Road, P, CAR, Medium, Gasoline (petrol), Euro 6 (2015-19), HEV	2015	2020	4.28	16000	6	2015	2016
Road, P, CAR, Medium, Gasoline (petrol), Euro 7 (2020-24), HEV	2020	2025	4.17	16000	12	2020	2021
Road, P, CAR, Medium, Gasoline (petrol), Euro 8 (2025-29), HEV	2025	2030	4.07	15500	24	2025	2026
Road, P, CAR, Medium, Gasoline (petrol), Euro 9 (2030-34), HEV	2030	2035	3.97	15500	48	2030	2031
Road, P, CAR, Medium, Gasoline (petrol), Euro 10 (2035-39), HEV	2035	2040	3.87	15000	48	2035	2036
Road, P, CAR, Medium, Gasoline (petrol), Euro 11 (2040-44), HEV	2040	2045	3.78	15000	48	2040	2041
Road, P, CAR, Medium, Gasoline (petrol), Euro 12 (2045-50), HEV	2045		3.68	15000	48	2045	2046
Road, P, CAR, Medium, Gasoline (petrol), Euro 5 (2009-14), PHEV	2009	2015	5.06	18000	0	2009	2014
Road, P, CAR, Medium, Gasoline (petrol), Euro 6 (2015-19), PHEV	2015	2020	4.92	17250	6	2015	2019
Road, P, CAR, Medium, Gasoline (petrol), Euro 7 (2020-24), PHEV	2020	2025	4.78	16500	12	2020	2024
Road, P, CAR, Medium, Gasoline (petrol), Euro 8 (2025-29), PHEV	2025	2030	4.64	15750	24	2025	2029
Road, P, CAR, Medium, Gasoline (petrol), Euro 9 (2030-34), PHEV	2030	2035	4.57	15000	48	2030	2031
Road, P, CAR, Medium, Gasoline (petrol), Euro 10 (2035-39), PHEV	2035	2040	4.43	15000	48	2035	2036

Technology Description	First Year of Availability	Final Year of Availability	SFC (l/100km or kWh/100 km)	Average Purchase Price (GBP 2007)	P factor	T_{Start}	$T_{Maturity}$
Road, P, CAR, Medium, Gasoline (petrol), Euro 11 (2040-44), PHEV	2040	2045	4.36	15000	48	2040	2041
Road, P, CAR, Medium, Gasoline (petrol), Euro 12 (2045-50), PHEV	2045		4.23	15000	48	2045	2046
Road, P, CAR, Medium, Diesel (DERV), Conventional (no catalyst)	1980	1992	4.94	17500	163	1980	1981
Road, P, CAR, Medium, Diesel (DERV), Euro 1 (incl. catalyst)	1992	1996	5.14	17500	73	1992	1993
Road, P, CAR, Medium, Diesel (DERV), Euro 2 (incl. catalyst)	1996	2000	5.10	17500	146	1996	1997
Road, P, CAR, Medium, Diesel (DERV), Euro 3 (incl. catalyst)	2000	2005	5.27	17500	300	2000	2001
Road, P, CAR, Medium, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	4.86	17500	484	2005	2006
Road, P, CAR, Medium, Diesel (DERV), Euro 5 (2009-14)	2009	2015	4.76	17500	484	2009	2010
Road, P, CAR, Medium, Diesel (DERV), Euro 6 (2015-19)	2015	2020	4.62	17500	484	2015	2016
Road, P, CAR, Medium, Diesel (DERV), Euro 7 (2020-24)	2020	2025	4.51	17500	484	2020	2021
Road, P, CAR, Medium, Diesel (DERV), Euro 8 (2025-29)	2025	2030	4.39	17500	484	2025	2026
Road, P, CAR, Medium, Diesel (DERV), Euro 9 (2030-34)	2030	2035	4.29	17500	484	2030	2031
Road, P, CAR, Medium, Diesel (DERV), Euro 10 (2035-39)	2035	2040	4.18	17500	484	2035	2036
Road, P, CAR, Medium, Diesel (DERV), Euro 11 (2040-44)	2040	2045	4.08	17500	484	2040	2041
Road, P, CAR, Medium, Diesel (DERV), Euro 12 (2045-50)	2045		3.98	17500	484	2045	2046
Road, P, CAR, Medium, Diesel (DERV), Euro 4 (incl. catalyst), HEV	2005	2010	2.94	17500	2	2005	2006
Road, P, CAR, Medium, Diesel (DERV), Euro 5 (2009-14), HEV	2009	2015	2.88	19000	3	2009	2010
Road, P, CAR, Medium, Diesel (DERV), Euro 6 (2015-19), HEV	2015	2020	2.80	19000	6	2015	2016
Road, P, CAR, Medium, Diesel (DERV), Euro 7 (2020-24), HEV	2020	2025	2.73	19000	12	2020	2021
Road, P, CAR, Medium, Diesel (DERV), Euro 8 (2025-29), HEV	2025	2030	2.66	19000	24	2025	2026
Road, P, CAR, Medium, Diesel (DERV), Euro 9 (2030-34), HEV	2030	2035	2.60	19000	48	2030	2031
Road, P, CAR, Medium, Diesel (DERV), Euro 10 (2035-39), HEV	2035	2040	2.53	19000	48	2035	2036
Road, P, CAR, Medium, Diesel (DERV), Euro 11 (2040-44), HEV	2040	2045	2.47	19000	48	2040	2041
Road, P, CAR, Medium, Diesel (DERV), Euro 12 (2045-50), HEV	2045		2.41	19000	48	2045	2046
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 2 (incl. catalyst)	1995	2000	12.23	17000	1	1995	1996
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 3 (incl. catalyst)	2000	2005	11.96	17000	2	2000	2002
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 4 (incl. catalyst)	2005	2010	11.36	17000	5	2005	2007
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 5 (2009-14)	2009	2015	11.07	17000	5	2009	2010
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 6 (2015-19)	2015	2020	10.79	17000	5	2015	2016
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 7 (2020-24)	2020	2025	10.50	17000	5	2020	2021
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 8 (2025-29)	2025	2030	10.22	16500	5	2025	2026
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 9 (2030-34)	2030	2035	9.93	16000	5	2030	2031
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 10 (2035-39)	2035	2040	9.65	15500	5	2035	2036
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 11 (2040-44)	2040	2045	9.37	15000	5	2040	2041
Road, P, CAR, Medium, Liquefied Petrol Gas, Euro 12 (2045-50)	2045		9.08	15000	5	2045	2046
Road, P, CAR, Medium, Biomethanol, Fuel Cell	2015	2030	8.10	18000	0	2015	2020
Road, P, CAR, Medium, Biomethanol, Fuel Cell	2030		4.30	15000	0	2030	2035
Road, P, CAR, Medium, Biomethanol, Fuel Cell	2020	2030	6.56	17500	0	2020	2025
Road, P, CAR, Medium, Biomethanol, Fuel Cell	2030		5.31	16000	0	2030	2035

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 4 (incl. catalyst)	2005	2010	7.74	20000	1	2005	2009
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 5 (2009-14)	2009	2015	7.58	17000	5	2009	2010
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 6 (2015-19)	2015	2020	7.36	16000	5	2015	2016
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 7 (2020-24)	2020	2025	7.18	16000	5	2020	2021
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 8 (2025-29)	2025	2030	7.00	16000	5	2025	2026
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 9 (2030-34)	2030	2035	6.83	15000	5	2030	2031
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 10 (2035-39)	2035	2040	6.66	15000	5	2035	2036
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 11 (2040-44)	2040	2045	6.49	15000	5	2040	2041
Road, P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 12 (2045-50)	2045		6.33	15000	5	2045	2046
Road, P, CAR, Medium, Biodiesel from oilseed crops (B100), Standard 1	1995	2010	4.73	18000	0	1995	2000
Road, P, CAR, Medium, Biodiesel from oilseed crops (B100), Standard 2	2010	2025	3.75	17000	24	2010	2014
Road, P, CAR, Medium, Biodiesel from oilseed crops (B100), Standard 3	2025		3.03	16000	48	2025	2030
Road, P, CAR, Medium, Compressed Natural Gas, Standard 1	1995	2010	144.06	18000	0	1995	2000
Road, P, CAR, Medium, Compressed Natural Gas, Standard 2	2010	2025	141.25	16000	0	2010	2014
Road, P, CAR, Medium, Compressed Natural Gas, Standard 3	2025		114.32	16000	0	2025	2030
Road, P, CAR, Medium, Gaseous Hydrogen, Fuel Cell	2030		15.54	16000	0	2030	2035
Road, P, CAR, Medium, Gaseous Hydrogen, Fuel Cell	2020	2030	17.90	18000	0	2020	2025
Road, P, CAR, Large, Gasoline (petrol), Conventional (no catalyst)	1980	1992	9.28	22000	877	1980	1981
Road, P, CAR, Large, Gasoline (petrol), Euro 1 (incl. catalyst)	1992	1996	9.68	22000	391	1992	1993
Road, P, CAR, Large, Gasoline (petrol), Euro 2 (incl. catalyst)	1996	2000	10.13	22000	391	1996	1997
Road, P, CAR, Large, Gasoline (petrol), Euro 3 (incl. catalyst)	2000	2005	9.94	22000	391	2000	2001
Road, P, CAR, Large, Gasoline (petrol), Euro 4 (incl. catalyst)	2005	2010	9.17	22000	391	2005	2006
Road, P, CAR, Large, Gasoline (petrol), Euro 5 (2009-14)	2009	2015	8.99	22000	391	2009	2010
Road, P, CAR, Large, Gasoline (petrol), Euro 6 (2015-19)	2015	2020	8.72	22000	391	2015	2016
Road, P, CAR, Large, Gasoline (petrol), Euro 7 (2020-24)	2020	2025	8.51	22000	391	2020	2021
Road, P, CAR, Large, Gasoline (petrol), Euro 8 (2025-29)	2025	2030	8.30	22000	391	2025	2026
Road, P, CAR, Large, Gasoline (petrol), Euro 9 (2030-34)	2030	2035	8.09	22000	391	2030	2031
Road, P, CAR, Large, Gasoline (petrol), Euro 10 (2035-39)	2035	2040	7.89	22000	391	2035	2036
Road, P, CAR, Large, Gasoline (petrol), Euro 11 (2040-44)	2040	2045	7.69	22000	391	2040	2041
Road, P, CAR, Large, Gasoline (petrol), Euro 12 (2045-50)	2045		7.50	22000	391	2045	2046
Road, P, CAR, Large, Gasoline (petrol), Euro 4 (incl. catalyst), HEV	2005	2010	5.56	25000	0	2005	2006
Road, P, CAR, Large, Gasoline (petrol), Euro 5 (2009-14), HEV	2009	2015	5.44	24000	5	2009	2014
Road, P, CAR, Large, Gasoline (petrol), Euro 6 (2015-19), HEV	2015	2020	5.28	23000	10	2015	2019
Road, P, CAR, Large, Gasoline (petrol), Euro 7 (2020-24), HEV	2020	2025	5.15	23000	20	2020	2023
Road, P, CAR, Large, Gasoline (petrol), Euro 8 (2025-29), HEV	2025	2030	5.02	23000	39	2025	2027
Road, P, CAR, Large, Gasoline (petrol), Euro 9 (2030-34), HEV	2030	2035	4.90	23000	39	2030	2031
Road, P, CAR, Large, Gasoline (petrol), Euro 10 (2035-39), HEV	2035	2040	4.78	23000	39	2035	2036
Road, P, CAR, Large, Gasoline (petrol), Euro 11 (2040-44), HEV	2040	2045	4.66	23000	39	2040	2041
Road, P, CAR, Large, Gasoline (petrol), Euro 12 (2045-50), HEV	2045		4.54	23000	39	2045	2046

Technology Description	First Year of Availability	Final Year of Availability	SFC (l/100km or kWh/100 km)	Average Purchase Price (GBP 2007)	P factor	T_{Start}	$T_{Maturity}$
Road, P, CAR, Large, Gasoline (petrol), Euro 5 (2009-14), PHEV	2009	2015	6.29	26400	0	2009	2014
Road, P, CAR, Large, Gasoline (petrol), Euro 6 (2015-19), PHEV	2015	2020	6.12	25300	4	2015	2019
Road, P, CAR, Large, Gasoline (petrol), Euro 7 (2020-24), PHEV	2020	2025	5.95	24200	10	2020	2024
Road, P, CAR, Large, Gasoline (petrol), Euro 8 (2025-29), PHEV	2025	2030	5.78	23100	20	2025	2029
Road, P, CAR, Large, Gasoline (petrol), Euro 9 (2030-34), PHEV	2030	2035	5.69	22000	39	2030	2031
Road, P, CAR, Large, Gasoline (petrol), Euro 10 (2035-39), PHEV	2035	2040	5.52	22000	39	2035	2036
Road, P, CAR, Large, Gasoline (petrol), Euro 11 (2040-44), PHEV	2040	2045	5.43	22000	39	2040	2041
Road, P, CAR, Large, Gasoline (petrol), Euro 12 (2045-50), PHEV	2045		5.26	22000	39	2045	2046
Road, P, CAR, Large, Diesel (DERV), Conventional (no catalyst)	1980	1992	6.29	25000	161	1980	1981
Road, P, CAR, Large, Diesel (DERV), Euro 1 (incl. catalyst)	1992	1996	6.55	25000	72	1992	1993
Road, P, CAR, Large, Diesel (DERV), Euro 2 (incl. catalyst)	1996	2000	6.37	25000	195	1996	1997
Road, P, CAR, Large, Diesel (DERV), Euro 3 (incl. catalyst)	2000	2005	6.77	25000	300	2000	2001
Road, P, CAR, Large, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	6.24	25000	391	2005	2006
Road, P, CAR, Large, Diesel (DERV), Euro 5 (2009-14)	2009	2015	6.12	25000	391	2009	2010
Road, P, CAR, Large, Diesel (DERV), Euro 6 (2015-19)	2015	2020	5.94	25000	391	2015	2016
Road, P, CAR, Large, Diesel (DERV), Euro 7 (2020-24)	2020	2025	5.79	25000	391	2020	2021
Road, P, CAR, Large, Diesel (DERV), Euro 8 (2025-29)	2025	2030	5.65	25000	391	2025	2026
Road, P, CAR, Large, Diesel (DERV), Euro 9 (2030-34)	2030	2035	5.51	25000	391	2030	2031
Road, P, CAR, Large, Diesel (DERV), Euro 10 (2035-39)	2035	2040	5.37	25000	391	2035	2036
Road, P, CAR, Large, Diesel (DERV), Euro 11 (2040-44)	2040	2045	5.24	25000	391	2040	2041
Road, P, CAR, Large, Diesel (DERV), Euro 12 (2045-50)	2045		5.11	25000	391	2045	2046
Road, P, CAR, Large, Diesel (DERV), Euro 4 (incl. catalyst), HEV	2005	2010	3.78	27500	0	2005	2006
Road, P, CAR, Large, Diesel (DERV), Euro 5 (2009-14), HEV	2009	2015	3.70	26000	0	2009	2010
Road, P, CAR, Large, Diesel (DERV), Euro 6 (2015-19), HEV	2015	2020	3.59	26000	20	2015	2016
Road, P, CAR, Large, Diesel (DERV), Euro 7 (2020-24), HEV	2020	2025	3.51	26000	39	2020	2021
Road, P, CAR, Large, Diesel (DERV), Euro 8 (2025-29), HEV	2025	2030	3.42	26000	39	2025	2026
Road, P, CAR, Large, Diesel (DERV), Euro 9 (2030-34), HEV	2030	2035	3.33	26000	39	2030	2031
Road, P, CAR, Large, Diesel (DERV), Euro 10 (2035-39), HEV	2035	2040	3.25	26000	39	2035	2036
Road, P, CAR, Large, Diesel (DERV), Euro 11 (2040-44), HEV	2040	2045	3.17	26000	39	2040	2041
Road, P, CAR, Large, Diesel (DERV), Euro 12 (2045-50), HEV	2045		3.09	26000	39	2045	2046
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 2 (incl. catalyst)	1995	2000	13.24	25000	0	1995	1997
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 3 (incl. catalyst)	2000	2005	13.06	25000	2	2000	2002
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 4 (incl. catalyst)	2005	2010	12.41	25000	4	2005	2007
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 5 (2009-14)	2009	2015	12.09	25000	4	2009	2010
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 6 (2015-19)	2015	2020	11.78	25000	4	2015	2016
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 7 (2020-24)	2020	2025	11.47	24000	4	2020	2021
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 8 (2025-29)	2025	2030	11.16	23000	4	2025	2026
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 9 (2030-34)	2030	2035	10.85	22500	4	2030	2031
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 10 (2035-39)	2035	2040	10.54	22000	4	2035	2036

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 11 (2040-44)	2040	2045	10.23	22000	4	2040	2041
Road, P, CAR, Large, Liquefied Petrol Gas, Euro 12 (2045-50)	2045		9.92	22000	4	2045	2046
Road, P, CAR, Large, Biomethanol, Fuel Cell	2030		6.64	25000	0	2030	2035
Road, P, CAR, Large, Biomethanol, Fuel Cell	2015	2030	8.20	30000	0	2015	2020
Road, P, CAR, Large, Biomethanol, Fuel Cell	2010	2020	10.13	20000	0	2010	2015
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 4 (incl. catalyst)	2005	2010	9.55	25000	0	2005	2009
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 5 (2009-14)	2009	2015	9.36	23000	4	2009	2014
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 6 (2015-19)	2015	2020	9.08	23000	4	2015	2016
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 7 (2020-24)	2020	2025	8.86	23000	4	2020	2021
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 8 (2025-29)	2025	2030	8.64	23000	4	2025	2026
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 9 (2030-34)	2030	2035	8.42	22000	4	2030	2031
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 10 (2035-39)	2035	2040	8.22	22000	4	2035	2036
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 11 (2040-44)	2040	2045	8.01	22000	4	2040	2041
Road, P, CAR, Large, Bioethanol-petrol blend (E85), Euro 12 (2045-50)	2045		7.81	22000	4	2045	2046
Road, P, CAR, Large, Biodiesel from oilseed crops (B100), Standard 1	1995	2010	6.98	27500	1	1995	2000
Road, P, CAR, Large, Biodiesel from oilseed crops (B100), Standard 2	2010	2025	5.95	26000	5	2010	2014
Road, P, CAR, Large, Biodiesel from oilseed crops (B100), Standard 3	2025		4.81	25000	13	2025	2030
Road, P, CAR, Large, Gaseous Hydrogen, Fuel Cell	2030		14.49	25000	0	2030	2035
Road, P, CAR, Large, Gaseous Hydrogen, Fuel Cell	2015	2030	17.90	30000	0	2015	2020
Road, P, CAR, Large, Liquefied Hydrogen, Euro 5 (2009-14)	2009	2015	38.28	30000	0	2009	2014
Road, P, CAR, Large, Liquefied Hydrogen, Euro 6 (2015-19)	2015	2020	36.37	27000	0	2015	2016
Road, P, CAR, Large, Liquefied Hydrogen, Euro 7 (2020-24)	2020	2025	34.45	25000	0	2020	2021
Road, P, CAR, Large, Liquefied Hydrogen, Euro 8 (2025-29)	2025	2030	32.54	24000	0	2025	2026
Road, P, CAR, Large, Liquefied Hydrogen, Euro 9 (2030-34)	2030	2040	30.62	24000	0	2030	2031
Road, P, CAR, Large, Liquefied Hydrogen, Euro 11 (2040-44)	2040		28.71	24000	0	2040	2041
Road, P, BUS, Mini, Gasoline (petrol), Standard 1	1990	2005	18.36	62752	20243	1990	1991
Road, P, BUS, Mini, Gasoline (petrol), Standard 2	2005	2020	17.44	62752	20243	2005	2006
Road, P, BUS, Mini, Gasoline (petrol), Standard 3	2020		16.18	62752	20243	2020	2021
Road, P, BUS, Mini, Diesel (DERV), Conventional (no catalyst)	1980	1993	32.18	62752	4118	1980	1981
Road, P, BUS, Mini, Diesel (DERV), Euro 1 (incl. catalyst)	1992	1996	32.10	62752	1370	1992	1993
Road, P, BUS, Mini, Diesel (DERV), Euro 2 (incl. catalyst)	1996	2000	32.10	62752	5488	1996	1997
Road, P, BUS, Mini, Diesel (DERV), Euro 3 (incl. catalyst)	2000	2005	29.00	62752	20243	2000	2001
Road, P, BUS, Mini, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	27.58	62752	20243	2005	2006
Road, P, BUS, Mini, Diesel (DERV), Euro 5 (2009-14)	2009	2015	27.03	62752	20243	2009	2010
Road, P, BUS, Mini, Diesel (DERV), Euro 6 (2015-19)	2015	2020	26.23	62752	20243	2015	2016
Road, P, BUS, Mini, Diesel (DERV), Euro 7 (2020-24)	2020	2025	25.58	62752	20243	2020	2021
Road, P, BUS, Mini, Diesel (DERV), Euro 8 (2025-29)	2025	2030	24.95	62752	20243	2025	2026
Road, P, BUS, Mini, Diesel (DERV), Euro 9 (2030-34)	2030	2035	24.33	62752	20243	2030	2031
Road, P, BUS, Mini, Diesel (DERV), Euro 10 (2035-39)	2035	2040	23.73	62752	20243	2035	2036

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, P, BUS, Mini, Diesel (DERV), Euro 11 (2040-44)	2040	2045	23.14	62752	20243	2040	2041
Road, P, BUS, Mini, Diesel (DERV), Euro 12 (2045-50)	2045		22.57	62752	20243	2045	2046
Road, P, BUS, Mini, Diesel (DERV), Euro 4 (incl. catalyst), HEV	2005	2010	17.20	75300	202	2005	2008
Road, P, BUS, Mini, Diesel (DERV), Euro 5 (2009-14), HEV	2009	2015	16.37	74550	1012	2009	2012
Road, P, BUS, Mini, Diesel (DERV), Euro 6 (2015-19), HEV	2015	2020	15.88	73807	2024	2015	2018
Road, P, BUS, Mini, Diesel (DERV), Euro 7 (2020-24), HEV	2020	2025	15.49	73072	2024	2020	2022
Road, P, BUS, Mini, Diesel (DERV), Euro 8 (2025-29), HEV	2025	2030	15.11	72345	2024	2025	2027
Road, P, BUS, Mini, Diesel (DERV), Euro 9 (2030-34), HEV	2030	2035	14.73	71624	2024	2030	2031
Road, P, BUS, Mini, Diesel (DERV), Euro 10 (2035-39), HEV	2035	2040	14.37	70911	2024	2035	2036
Road, P, BUS, Mini, Diesel (DERV), Euro 11 (2040-44), HEV	2040	2045	14.01	70204	2024	2040	2041
Road, P, BUS, Mini, Diesel (DERV), Euro 12 (2045-50), HEV	2045		13.67	69505	2024	2045	2046
Road, P, BUS, Mini, Liquefied Petrol Gas, Standard 1	1995	2005	61.90	66092	0	1995	2000
Road, P, BUS, Mini, Liquefied Petrol Gas, Standard 2	2005	2015	28.93	66092	202	2005	2010
Road, P, BUS, Mini, Liquefied Petrol Gas, Standard 3	2015		50.63	66092	202	2015	2020
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 4 (incl. catalyst)	2005	2010	16.85	67998	101	2005	2009
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 5 (2009-14)	2010	2015	16.85	67998	202	2010	2014
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 6 (2015-19)	2015	2020	16.85	67321	202	2015	2019
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 7 (2020-24)	2020	2025	16.85	66650	202	2020	2021
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 8 (2025-29)	2025	2030	16.85	65986	202	2025	2026
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 9 (2030-34)	2030	2035	16.85	65329	202	2030	2031
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 10 (2035-39)	2035	2040	16.85	64678	202	2035	2036
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 11 (2040-44)	2040	2045	16.85	64034	202	2040	2041
Road, P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 12 (2045-50)	2045		16.85	63396	202	2045	2046
Road, P, BUS, Mini, Biodiesel from oilseed crops (B100), Standard 1	1990	2005	33.09	62752	0	1990	1995
Road, P, BUS, Mini, Biodiesel from oilseed crops (B100), Standard 2	2005	2015	28.51	62752	101	2005	2010
Road, P, BUS, Mini, Biodiesel from oilseed crops (B100), Standard 3	2015		27.11	62752	202	2015	2020
Road, P, BUS, Mini, Compressed Natural Gas, Standard 1	1995	2005	72.00	66074	0	1995	2000
Road, P, BUS, Mini, Compressed Natural Gas, Standard 2	2005	2015	291.95	66074	0	2005	2010
Road, P, BUS, Mini, Compressed Natural Gas, Standard 3	2015		64.00	66074	0	2015	2020
Road, P, BUS, Mini, Gaseous Hydrogen, Fuel Cell	2010		85.93	97873	0	2010	2030
Road, P, BUS, Urban, Diesel (DERV), Conventional (no catalyst)	1980	1992	40.83	125504	50459	1980	1981
Road, P, BUS, Urban, Diesel (DERV), Euro 1 (incl. catalyst)	1992	1996	40.45	125504	16667	1992	1993
Road, P, BUS, Urban, Diesel (DERV), Euro 2 (incl. catalyst)	1996	2000	32.70	125504	67125	1996	1997
Road, P, BUS, Urban, Diesel (DERV), Euro 3 (incl. catalyst)	2000	2005	33.08	125504	67125	2000	2001
Road, P, BUS, Urban, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	32.42	125504	67125	2005	2006
Road, P, BUS, Urban, Diesel (DERV), Euro 5 (2009-14)	2009	2015	31.81	125504	67125	2009	2010
Road, P, BUS, Urban, Diesel (DERV), Euro 6 (2015-19)	2015	2020	30.87	125504	67125	2015	2016
Road, P, BUS, Urban, Diesel (DERV), Euro 7 (2020-24)	2020	2025	30.10	125504	67125	2020	2021
Road, P, BUS, Urban, Diesel (DERV), Euro 8 (2025-29)	2025	2030	29.36	125504	67125	2025	2026

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	T_{Start}	$T_{Maturity}$
Road, P, BUS, Urban, Diesel (DERV), Euro 9 (2030-34)	2030	2035	28.63	125504	67125	2030	2031
Road, P, BUS, Urban, Diesel (DERV), Euro 10 (2035-39)	2035	2040	27.92	125504	67125	2035	2036
Road, P, BUS, Urban, Diesel (DERV), Euro 11 (2040-44)	2040	2045	27.23	125504	67125	2040	2041
Road, P, BUS, Urban, Diesel (DERV), Euro 12 (2045-50)	2045		26.56	125504	67125	2045	2046
Road, P, BUS, Urban, Diesel (DERV), Euro 4 (incl. catalyst), HEV	2005	2010	19.63	145000	16781	2005	2008
Road, P, BUS, Urban, Diesel (DERV), Euro 5 (2009-14), HEV	2009	2015	19.26	143556	34	2009	2012
Road, P, BUS, Urban, Diesel (DERV), Euro 6 (2015-19), HEV	2015	2020	18.69	142126	336	2015	2017
Road, P, BUS, Urban, Diesel (DERV), Euro 7 (2020-24), HEV	2020	2025	18.23	140710	3356	2020	2021
Road, P, BUS, Urban, Diesel (DERV), Euro 8 (2025-29), HEV	2025	2030	17.78	139309	6713	2025	2026
Road, P, BUS, Urban, Diesel (DERV), Euro 9 (2030-34), HEV	2030	2035	17.34	137921	6713	2030	2031
Road, P, BUS, Urban, Diesel (DERV), Euro 10 (2035-39), HEV	2035	2040	16.91	136548	6713	2035	2036
Road, P, BUS, Urban, Diesel (DERV), Euro 11 (2040-44), HEV	2040	2045	16.49	135188	6713	2040	2041
Road, P, BUS, Urban, Diesel (DERV), Euro 12 (2045-50), HEV	2045		16.08	133841	6713	2045	2046
Road, P, BUS, Urban, Diesel (DERV), Euro 5 (2009-14), PHEV	2009	2015	19.37	150605	34	2009	2014
Road, P, BUS, Urban, Diesel (DERV), Euro 6 (2015-19), PHEV	2015	2020	18.71	144330	336	2015	2019
Road, P, BUS, Urban, Diesel (DERV), Euro 7 (2020-24), PHEV	2020	2025	18.37	138054	3356	2020	2024
Road, P, BUS, Urban, Diesel (DERV), Euro 8 (2025-29), PHEV	2025	2030	18.04	131779	6713	2025	2029
Road, P, BUS, Urban, Diesel (DERV), Euro 9 (2030-34), PHEV	2030	2035	17.37	125504	6713	2030	2031
Road, P, BUS, Urban, Diesel (DERV), Euro 10 (2035-39), PHEV	2035	2040	17.04	125504	6713	2035	2036
Road, P, BUS, Urban, Diesel (DERV), Euro 11 (2040-44), PHEV	2040	2045	16.70	125504	6713	2040	2041
Road, P, BUS, Urban, Diesel (DERV), Euro 12 (2045-50), PHEV	2045		16.37	125504	6713	2045	2046
Road, P, BUS, Urban, Liquefied Petrol Gas, Standard 1	1995	2005	65.00	132184	0	1995	2000
Road, P, BUS, Urban, Liquefied Petrol Gas, Standard 2	2005		59.21	132184	67	2005	2010
Road, P, BUS, Urban, Biomethanol, Fuel Cell	2020	2030	51.77	135996	0	2020	2025
Road, P, BUS, Urban, Biomethanol, Fuel Cell	2030		46.82	135996	0	2030	2035
Road, P, BUS, Urban, Biomethanol, Fuel Cell	2010	2020	57.24	135996	0	2010	2015
Road, P, BUS, Urban, Bioethanol-petrol blend (E85), Standard 1	2010	2020	56.90	135996	0	2010	2015
Road, P, BUS, Urban, Bioethanol-petrol blend (E85), Standard 2	2020	2030	51.86	135996	0	2020	2025
Road, P, BUS, Urban, Bioethanol-petrol blend (E85), Standard 3	2030		54.12	135996	0	2030	2035
Road, P, BUS, Urban, Biodiesel from oilseed crops (B100), Standard 1	1990	2005	40.50	132184	34	1990	1995
Road, P, BUS, Urban, Biodiesel from oilseed crops (B100), Standard 2	2005	2020	41.83	113686	67	2005	2010
Road, P, BUS, Urban, Biodiesel from oilseed crops (B100), Standard 3	2020		38.84	97777	67	2020	2025
Road, P, BUS, Urban, Compressed Natural Gas, Standard 1	1995	2005	160.00	132148	0	1995	2000
Road, P, BUS, Urban, Compressed Natural Gas, Standard 2	2005	2020	911.16	132148	0	2005	2010
Road, P, BUS, Urban, Compressed Natural Gas, Standard 3	2020		120.00	128239	0	2020	2025
Road, P, BUS, Urban, Electricity, Standard 1	1995	2010	185.48	150000	67	2005	2009
Road, P, BUS, Urban, Electricity, Standard 2	2010	2020	170.02	145000	67	2010	2019
Road, P, BUS, Urban, Electricity, Standard 3	2020		154.57	140000	67	2020	2021
Road, P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	2035	2040	72.47	141048	0	2035	2036

Technology Description	First Year of Availability	Final Year of Availability	SFC (l/100km or kWh/100 km)	Average Purchase Price (GBP 2007)	P factor	T_{Start}	$T_{Maturity}$
Road, P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	2020	2025	84.26	176939	0	2020	2021
Road, P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	2030	2035	76.21	152120	0	2030	2031
Road, P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	2015	2020	88.61	195746	0	2015	2016
Road, P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	2040		68.92	130782	0	2040	2041
Road, P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	2025	2030	80.13	164061	0	2025	2026
Road, P, BUS, Coach, Diesel (DERV), Conventional (no catalyst)	1980	1993	29.13	125504	6111	1980	1981
Road, P, BUS, Coach, Diesel (DERV), Euro 1 (incl. catalyst)	1992	1996	29.11	125504	2027	1992	1993
Road, P, BUS, Coach, Diesel (DERV), Euro 2 (incl. catalyst)	1996	2000	29.38	125504	8138	1996	1997
Road, P, BUS, Coach, Diesel (DERV), Euro 3 (incl. catalyst)	2000	2005	29.73	125504	8138	2000	2001
Road, P, BUS, Coach, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	29.16	125504	8138	2005	2006
Road, P, BUS, Coach, Diesel (DERV), Euro 5 (2009-14)	2009	2015	28.62	125504	8138	2009	2010
Road, P, BUS, Coach, Diesel (DERV), Euro 6 (2015-19)	2015	2020	27.77	125504	8138	2015	2016
Road, P, BUS, Coach, Diesel (DERV), Euro 7 (2020-24)	2020	2025	27.08	125504	8138	2020	2021
Road, P, BUS, Coach, Diesel (DERV), Euro 8 (2025-29)	2025	2030	26.41	125504	8138	2025	2026
Road, P, BUS, Coach, Diesel (DERV), Euro 9 (2030-34)	2030	2035	25.76	125504	8138	2030	2031
Road, P, BUS, Coach, Diesel (DERV), Euro 10 (2035-39)	2035	2040	25.12	125504	8138	2035	2036
Road, P, BUS, Coach, Diesel (DERV), Euro 11 (2040-44)	2040	2045	24.50	125504	8138	2040	2041
Road, P, BUS, Coach, Diesel (DERV), Euro 12 (2045-50)	2045		23.89	125504	8138	2045	2046
Road, P, BUS, Coach, Diesel (DERV), Euro 4 (incl. catalyst), HEV	2005	2010	30.66	138054	0	2005	2006
Road, P, BUS, Coach, Diesel (DERV), Euro 5 (2009-14), HEV	2009	2015	30.09	134637	1	2009	2010
Road, P, BUS, Coach, Diesel (DERV), Euro 6 (2015-19), HEV	2015	2020	29.20	131305	81	2015	2018
Road, P, BUS, Coach, Diesel (DERV), Euro 7 (2020-24), HEV	2020	2025	28.48	128055	814	2020	2022
Road, P, BUS, Coach, Diesel (DERV), Euro 8 (2025-29), HEV	2025	2030	27.77	124885	814	2025	2026
Road, P, BUS, Coach, Diesel (DERV), Euro 9 (2030-34), HEV	2030	2035	27.09	121794	814	2030	2031
Road, P, BUS, Coach, Diesel (DERV), Euro 10 (2035-39), HEV	2035	2040	26.42	118780	814	2035	2036
Road, P, BUS, Coach, Diesel (DERV), Euro 11 (2040-44), HEV	2040	2045	25.76	115840	814	2040	2041
Road, P, BUS, Coach, Diesel (DERV), Euro 12 (2045-50), HEV	2045		25.12	112973	814	2045	2046
Road, P, BUS, Coach, Liquefied Petrol Gas, Euro 5 (2009-14)	2009	2030	95.40	130000	8	2009	2014
Road, P, BUS, Coach, Liquefied Petrol Gas, Euro 9 (2030-34)	2030		30.00	127500	8	2030	2035
Road, P, BUS, Coach, Biomethanol, Fuel Cell	2010	2020	52.50	131779	0	2010	2015
Road, P, BUS, Coach, Biomethanol, Fuel Cell	2020	2030	47.48	130524	0	2020	2025
Road, P, BUS, Coach, Biomethanol, Fuel Cell	2030		42.94	129269	0	2030	2035
Road, P, BUS, Coach, Biodiesel from oilseed crops (B100), Standard 1	1990	2005	28.91	131779	8	1990	1995
Road, P, BUS, Coach, Biodiesel from oilseed crops (B100), Standard 2	2005	2020	30.11	129269	8	2005	2010
Road, P, BUS, Coach, Biodiesel from oilseed crops (B100), Standard 3	2020		27.95	126759	8	2020	2025
Road, P, BUS, Coach, Compressed Natural Gas, Standard 1	1995	2005	732.14	135000	0	1995	2000
Road, P, BUS, Coach, Compressed Natural Gas, Standard 2	2005	2020	655.72	130000	0	2005	2010
Road, P, BUS, Coach, Compressed Natural Gas, Standard 3	2020		100.00	127500	0	2020	2025
Road, P, BUS, Coach, Electricity, Standard 1	1995	2010	265.58	150000	0	1995	2000

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, P, BUS, Coach, Electricity, Standard 2	2009	2020	255.36	145000	0	2009	2014
Road, P, BUS, Coach, Electricity, Standard 3	2020		245.15	140000	0	2020	2025
Road, P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	2025	2030	80.13	164061	0	2025	2026
Road, P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	2030	2035	76.21	152120	0	2030	2031
Road, P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	2040		68.92	130782	0	2040	2041
Road, P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	2035	2040	72.47	141048	0	2035	2036
Road, P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	2015	2020	88.61	195746	0	2015	2019
Road, P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	2020	2025	84.26	176939	0	2020	2024
Rail, P, TRAIN, Light, Diesel (DERV), Standard 1	1980	2000	362.20	2500000	0	1980	1981
Rail, P, TRAIN, Light, Diesel (DERV), Standard 2	2000	2015	330.00	2500000	0	2000	2001
Rail, P, TRAIN, Light, Diesel (DERV), Standard 3	2015		313.50	2500000	0	2015	2016
Rail, P, TRAIN, Light, Electricity, Standard 1	1980	2000	411.60	2500000	1068	1980	1981
Rail, P, TRAIN, Light, Electricity, Standard 2	2000	2015	333.00	2500000	1068	2000	2001
Rail, P, TRAIN, Light, Electricity, Standard 3	2015		308.88	2500000	1068	2015	2016
Rail, P, TRAIN, Regional, Diesel (DERV), Standard 1	1980	2000	262.76	5000000	3785	1980	1981
Rail, P, TRAIN, Regional, Diesel (DERV), Standard 2	2000	2015	242.33	5000000	3785	2000	2001
Rail, P, TRAIN, Regional, Diesel (DERV), Standard 3	2015		226.33	5000000	3785	2015	2016
Rail, P, TRAIN, Regional, Electricity, Standard 1	1980	2000	1258.11	5000000	3014	1980	1981
Rail, P, TRAIN, Regional, Electricity, Standard 2	2000	2015	1017.00	5000000	3014	2000	2001
Rail, P, TRAIN, Regional, Electricity, Standard 3	2015		943.34	5000000	3014	2015	2016
Rail, P, TRAIN, National, Diesel (DERV), Standard 1	1980	2000	340.74	10000000	634	1980	1981
Rail, P, TRAIN, National, Diesel (DERV), Standard 2	2000	2015	316.08	10000000	634	2000	2001
Rail, P, TRAIN, National, Diesel (DERV), Standard 3	2015		295.21	10000000	634	2015	2016
Rail, P, TRAIN, National, Electricity, Standard 1	1980	2000	1391.67	10000000	317	1980	1981
Rail, P, TRAIN, National, Electricity, Standard 2	2000	2015	1134.00	10000000	317	2000	2001
Rail, P, TRAIN, National, Electricity, Standard 3	2015		1051.86	10000000	317	2015	2016
Rail, P, TRAIN, High Speed, Electricity, Standard 1	1990	2000	3300.00	20000000	317	1990	1991
Rail, P, TRAIN, High Speed, Electricity, Standard 2	2000	2015	3000.00	15000000	317	2000	2004
Rail, P, TRAIN, High Speed, Electricity, Standard 3	2015		2550.00	12500000	317	2015	2016
Air, P, PLANE, General Aviation, Aviation fuel (BP Jet A-1), Standard 1	1980		11.65	400000	30	1980	1981
Air, P, PLANE, Short Distance, Liquefied Hydrogen, Standard 3	2025	2035	1698.77	5000000	68	2025	2030
Air, P, PLANE, Short Distance, Liquefied Hydrogen, Euro 10 (2035-39)	2035	2045	1510.02	5000000	136	2035	2040
Air, P, PLANE, Short Distance, Liquefied Hydrogen, Euro 12 (2045-50)	2045		1415.65	5000000	136	2045	2050
Air, P, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Standard 1	1985	2005	560.02	4000000	272	1985	1986
Air, P, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Standard 2	2005	2015	449.85	4000000	272	2005	2006
Air, P, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Euro 6 (2015-19)	2015	2025	427.60	4000000	272	2015	2016
Air, P, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Euro 8 (2025-29)	2025	2035	406.69	4000000	272	2025	2026
Air, P, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Euro 10 (2035-39)	2035	2045	386.81	4000000	272	2035	2036
Air, P, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Euro 12 (2045-50)	2045		367.90	4000000	272	2045	2046

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Air, P, PLANE, Middle Distance, Liquefied Hydrogen, Standard 3	2025	2035	1868.48	100000000	69	2025	2030
Air, P, PLANE, Middle Distance, Liquefied Hydrogen, Euro 10 (2035-39)	2035	2045	1660.88	90438208	138	2035	2040
Air, P, PLANE, Middle Distance, Liquefied Hydrogen, Euro 12 (2045-50)	2045		1557.07	81790696	138	2045	2050
Air, P, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Standard 1	1985	2005	609.78	75000000	275	1985	1986
Air, P, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Standard 2	2005	2015	494.87	75000000	275	2005	2006
Air, P, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Euro 6 (2015-19)	2015	2025	470.32	75000000	275	2015	2016
Air, P, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Euro 8 (2025-29)	2025	2035	447.32	75000000	275	2025	2026
Air, P, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Euro 10 (2035-39)	2035	2045	425.45	75000000	275	2035	2036
Air, P, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Euro 12 (2045-50)	2045		404.65	75000000	275	2045	2046
Air, P, PLANE, Long Distance, Liquefied Hydrogen, Standard 3	2025	2035	3454.51	200000000	21	2025	2030
Air, P, PLANE, Long Distance, Liquefied Hydrogen, Euro 10 (2035-39)	2035	2045	3070.68	180876416	43	2035	2040
Air, P, PLANE, Long Distance, Liquefied Hydrogen, Euro 12 (2045-50)	2045		2878.76	163581392	43	2045	2050
Air, P, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Standard 1	1985	2005	1123.25	150000000	85	1985	1986
Air, P, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Standard 2	2005	2015	914.93	150000000	85	2005	2006
Air, P, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Euro 6 (2015-19)	2015	2025	869.54	150000000	85	2015	2016
Air, P, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Euro 8 (2025-29)	2025	2035	827.02	150000000	85	2025	2026
Air, P, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Euro 10 (2035-39)	2035	2045	786.59	150000000	85	2035	2036
Air, P, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Euro 12 (2045-50)	2045		748.13	150000000	85	2045	2046
Air, P, PLANE, Supersonic, Liquefied Hydrogen, Standard 3	2025	2035	6636.00	155000000	0	2025	2030
Air, P, PLANE, Supersonic, Liquefied Hydrogen, Euro 10 (2035-39)	2035	2045	6400.00	155000000	0	2035	2040
Air, P, PLANE, Supersonic, Liquefied Hydrogen, Euro 12 (2045-50)	2045		6200.00	155000000	0	2045	2050
Air, P, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Standard 1	1980	2005	1645.50	155000000	7	1980	1981
Air, P, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Standard 2	2005	2015	1645.50	155000000	1	2005	2006
Air, P, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Euro 6 (2015-19)	2015	2025	1645.50	155000000	1	2015	2016
Air, P, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Euro 8 (2025-29)	2025	2035	1645.50	155000000	1	2025	2026
Air, P, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Euro 10 (2035-39)	2035	2045	1645.50	155000000	1	2035	2036
Air, P, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Euro 12 (2045-50)	2045		1645.50	155000000	1	2045	2046
Water, F, SHIP, River, Diesel (DERV), Standard 1	1980	2010	1278.51	600000	340	1980	1981
Water, F, SHIP, River, Diesel (DERV), Standard 2	2010		1230.44	600000	340	2010	2011
Water, F, SHIP, Coastal, Diesel (DERV), Standard 1	1980	2010	1534.22	2000000	161	1980	1981
Water, F, SHIP, Coastal, Diesel (DERV), Standard 2	2010		1476.52	2000000	161	2010	2011
Water, F, SHIP, Maritime, Diesel (DERV), Standard 1	1980	2010	1314.60	20000000	100	1980	1981
Water, F, SHIP, Maritime, Diesel (DERV), Standard 2	2010		1182.40	20000000	100	2010	2011
Road, F, TRUCK, Light, Gasoline (petrol), Conventional (no catalyst)	1980	1995	14.15	22000	688913	1980	1981
Road, F, TRUCK, Light, Gasoline (petrol), Euro 1 (incl. catalyst)	1994	1998	12.50	22000	310680	1994	1995
Road, F, TRUCK, Light, Gasoline (petrol), Euro 2 (incl. catalyst)	1998	2001	12.68	22000	999592	1998	1999
Road, F, TRUCK, Light, Gasoline (petrol), Euro 3 (incl. catalyst)	2001	2005	12.94	22000	999592	2001	2002
Road, F, TRUCK, Light, Gasoline (petrol), Euro 4 (incl. catalyst)	2005	2010	12.59	22000	999592	2005	2006
Road, F, TRUCK, Light, Gasoline (petrol), Euro 5 (2009-14)	2009	2015	12.35	22000	999592	2009	2010

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, F, TRUCK, Light, Gasoline (petrol), Euro 6 (2015-19)	2015	2020	11.98	22000	999592	2015	2016
Road, F, TRUCK, Light, Gasoline (petrol), Euro 7 (2020-24)	2020	2025	11.69	22000	999592	2020	2021
Road, F, TRUCK, Light, Gasoline (petrol), Euro 8 (2025-29)	2025	2030	11.40	22000	999592	2025	2026
Road, F, TRUCK, Light, Gasoline (petrol), Euro 9 (2030-34)	2030	2035	11.11	22000	999592	2030	2031
Road, F, TRUCK, Light, Gasoline (petrol), Euro 10 (2035-39)	2035	2040	10.84	22000	999592	2035	2036
Road, F, TRUCK, Light, Gasoline (petrol), Euro 11 (2040-44)	2040	2045	10.57	22000	999592	2040	2041
Road, F, TRUCK, Light, Gasoline (petrol), Euro 12 (2045-50)	2045		10.31	22000	999592	2045	2046
Road, F, TRUCK, Light, Diesel (DERV), Conventional (no catalyst)	1980	1995	11.75	22000	860749	1980	1981
Road, F, TRUCK, Light, Diesel (DERV), Euro 1 (incl. catalyst)	1994	1998	11.75	22000	406454	1994	1995
Road, F, TRUCK, Light, Diesel (DERV), Euro 2 (incl. catalyst)	1998	2001	11.71	22000	1267203	1998	1999
Road, F, TRUCK, Light, Diesel (DERV), Euro 3 (incl. catalyst)	2001	2005	11.50	22000	1267203	2001	2002
Road, F, TRUCK, Light, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	11.30	22000	1267203	2005	2006
Road, F, TRUCK, Light, Diesel (DERV), Euro 5 (2009-14)	2009	2015	11.08	22000	1267203	2009	2010
Road, F, TRUCK, Light, Diesel (DERV), Euro 6 (2015-19)	2015	2020	10.75	22000	1267203	2015	2016
Road, F, TRUCK, Light, Diesel (DERV), Euro 7 (2020-24)	2020	2025	10.48	22000	1267203	2020	2021
Road, F, TRUCK, Light, Diesel (DERV), Euro 8 (2025-29)	2025	2030	10.22	22000	1267203	2025	2026
Road, F, TRUCK, Light, Diesel (DERV), Euro 9 (2030-34)	2030	2035	9.97	22000	1267203	2030	2031
Road, F, TRUCK, Light, Diesel (DERV), Euro 10 (2035-39)	2035	2040	9.72	22000	1267203	2035	2036
Road, F, TRUCK, Light, Diesel (DERV), Euro 11 (2040-44)	2040	2045	9.48	22000	1267203	2040	2041
Road, F, TRUCK, Light, Diesel (DERV), Euro 12 (2045-50)	2045		9.25	22000	1267203	2045	2046
Road, F, TRUCK, Light, Diesel (DERV), Euro 4 (incl. catalyst), HEV	2005	2010	6.33	27500	0	2005	2006
Road, F, TRUCK, Light, Diesel (DERV), Euro 5 (2009-14), HEV	2009	2015	6.20	27000	317	2009	2013
Road, F, TRUCK, Light, Diesel (DERV), Euro 6 (2015-19), HEV	2015	2020	6.02	26000	31700	2015	2018
Road, F, TRUCK, Light, Diesel (DERV), Euro 7 (2020-24), HEV	2020	2025	5.87	25000	126720	2020	2021
Road, F, TRUCK, Light, Diesel (DERV), Euro 8 (2025-29), HEV	2025	2030	5.73	24000	126720	2025	2026
Road, F, TRUCK, Light, Diesel (DERV), Euro 9 (2030-34), HEV	2030	2035	5.58	23000	126720	2030	2031
Road, F, TRUCK, Light, Diesel (DERV), Euro 10 (2035-39), HEV	2035	2040	5.45	22000	126720	2035	2036
Road, F, TRUCK, Light, Diesel (DERV), Euro 11 (2040-44), HEV	2040	2045	5.31	22000	126720	2040	2041
Road, F, TRUCK, Light, Diesel (DERV), Euro 12 (2045-50), HEV	2045		5.18	22000	126720	2045	2046
Road, F, TRUCK, Light, Diesel (DERV), Euro 5 (2009-14), PHEV	2009	2015	8.20	26400	317	2009	2014
Road, F, TRUCK, Light, Diesel (DERV), Euro 6 (2015-19), PHEV	2015	2020	7.99	25300	31700	2015	2019
Road, F, TRUCK, Light, Diesel (DERV), Euro 7 (2020-24), PHEV	2020	2025	7.77	24200	126720	2020	2024
Road, F, TRUCK, Light, Diesel (DERV), Euro 8 (2025-29), PHEV	2025	2030	7.56	23100	126720	2025	2026
Road, F, TRUCK, Light, Diesel (DERV), Euro 9 (2030-34), PHEV	2030	2035	7.34	22000	126720	2030	2031
Road, F, TRUCK, Light, Diesel (DERV), Euro 10 (2035-39), PHEV	2035	2040	7.34	22000	126720	2035	2036
Road, F, TRUCK, Light, Diesel (DERV), Euro 11 (2040-44), PHEV	2040	2045	7.12	22000	126720	2040	2041
Road, F, TRUCK, Light, Diesel (DERV), Euro 12 (2045-50), PHEV	2045		6.91	22000	126720	2045	2046
Road, F, TRUCK, Light, Liquefied Petrol Gas, Standard 1	1995	2006	17.16	25000	998	1995	1996
Road, F, TRUCK, Light, Liquefied Petrol Gas, Standard 2	2006	2015	16.55	25000	500	2006	2007

Technology Description	First Year of Availability	Final Year of Availability	SFC (l/100km or kWh/100 km)	Average Purchase Price (GBP 2007)	P factor	T_{Start}	$T_{Maturity}$
Road, F, TRUCK, Light, Liquefied Petrol Gas, Standard 3	2015		15.11	25000	0	2015	2016
Road, F, TRUCK, Light, Biomethanol, Fuel Cell	2010	2020	27.29	30000	0	2010	2015
Road, F, TRUCK, Light, Biomethanol, Fuel Cell	2020	2030	27.29	27500	0	2020	2025
Road, F, TRUCK, Light, Biomethanol, Fuel Cell	2030		35.24	25000	0	2030	2035
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 4 (incl. catalyst)	2005	2010	13.11	24200	0	2005	2009
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 5 (2009-14)	2010	2015	12.86	24200	1267	2010	2014
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 6 (2015-19)	2015	2020	12.48	23100	1267	2015	2016
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 7 (2020-24)	2020	2025	12.17	23100	1267	2020	2021
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 8 (2025-29)	2025	2030	11.87	22000	1267	2025	2026
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 9 (2030-34)	2030	2035	11.57	22000	1267	2030	2031
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 10 (2035-39)	2035	2040	11.29	22000	1267	2035	2036
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 11 (2040-44)	2040	2045	11.01	22000	1267	2040	2041
Road, F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 12 (2045-50)	2045		10.74	22000	1267	2045	2046
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 4 (incl. catalyst)	2005	2010	11.62	24000	13	2005	2009
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 5 (2009-14)	2009	2015	11.39	23500	127	2009	2014
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 6 (2015-19)	2015	2020	11.05	23000	1267	2015	2019
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 7 (2020-24)	2020	2025	10.78	23000	1267	2020	2021
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 8 (2025-29)	2025	2030	10.51	23000	1267	2025	2026
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 9 (2030-34)	2030	2035	10.25	23000	1267	2030	2031
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 10 (2035-39)	2035	2040	10.00	23000	1267	2035	2036
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 11 (2040-44)	2040	2045	9.75	23000	1267	2040	2041
Road, F, TRUCK, Light, Biodiesel from oilseed crops (B100), Euro 12 (2045-50)	2045		9.51	23000	1267	2045	2046
Road, F, TRUCK, Light, Compressed Natural Gas, Standard 1	1995	2005	110.99	25000	0	1995	2000
Road, F, TRUCK, Light, Compressed Natural Gas, Standard 2	2005	2020	113.52	25000	0	2005	2006
Road, F, TRUCK, Light, Compressed Natural Gas, Standard 3	2020		108.79	25000	0	2020	2021
Road, F, TRUCK, Light, Electricity, Standard 1	1995	2005	62.39	35000	0	1995	2000
Road, F, TRUCK, Light, Electricity, Standard 2	2005	2020	56.15	30000	12672	2005	2019
Road, F, TRUCK, Light, Electricity, Standard 3	2020		49.92	25000	12672	2020	2021
Road, F, TRUCK, Medium, Diesel (DERV), Conventional (no catalyst)	1980	1993	29.21	55000	104672	1980	1981
Road, F, TRUCK, Medium, Diesel (DERV), Euro 1 (incl. catalyst)	1992	1996	29.09	55000	49083	1992	1993
Road, F, TRUCK, Medium, Diesel (DERV), Euro 2 (incl. catalyst)	1996	2000	28.55	55000	153755	1996	1997
Road, F, TRUCK, Medium, Diesel (DERV), Euro 3 (incl. catalyst)	2000	2005	27.54	55000	153755	2000	2001
Road, F, TRUCK, Medium, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	26.42	55000	153755	2005	2006
Road, F, TRUCK, Medium, Diesel (DERV), Euro 5 (2009-14)	2009	2015	25.94	55000	153755	2009	2010
Road, F, TRUCK, Medium, Diesel (DERV), Euro 6 (2015-19)	2015	2020	25.17	55000	153755	2015	2016
Road, F, TRUCK, Medium, Diesel (DERV), Euro 7 (2020-24)	2020	2025	24.55	55000	153755	2020	2021
Road, F, TRUCK, Medium, Diesel (DERV), Euro 8 (2025-29)	2025	2030	23.94	55000	153755	2025	2026
Road, F, TRUCK, Medium, Diesel (DERV), Euro 9 (2030-34)	2030	2035	23.35	55000	153755	2030	2031
Road, F, TRUCK, Medium, Diesel (DERV), Euro 10 (2035-39)	2035	2040	22.77	55000	153755	2035	2036

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, F, TRUCK, Medium, Diesel (DERV), Euro 11 (2040-44)	2040	2045	22.21	55000	153755	2040	2041
Road, F, TRUCK, Medium, Diesel (DERV), Euro 12 (2045-50)	2045		21.66	55000	153755	2045	2046
Road, F, TRUCK, Medium, Diesel (DERV), Euro 5 (2009-14), HEV	2009		15.00	66000	15376	2009	2014
Road, F, TRUCK, Medium, Biomethanol, Fuel Cell	2035	2040	33.81	66224	0	2035	2036
Road, F, TRUCK, Medium, Biomethanol, Fuel Cell	2025	2030	37.38	73226	0	2025	2026
Road, F, TRUCK, Medium, Biomethanol, Fuel Cell	2040	2045	32.15	62979	0	2040	2041
Road, F, TRUCK, Medium, Biomethanol, Fuel Cell	2015	2020	41.34	77000	0	2015	2019
Road, F, TRUCK, Medium, Biomethanol, Fuel Cell	2020	2025	39.31	77000	0	2020	2021
Road, F, TRUCK, Medium, Biomethanol, Fuel Cell	2045		30.58	59892	0	2045	2046
Road, F, TRUCK, Medium, Biomethanol, Fuel Cell	2030	2035	35.55	69637	0	2030	2031
Road, F, TRUCK, Medium, Biodiesel from oilseed crops (B100), Euro 4 (incl. catalyst)	2005	2010	27.44	57000	15	2005	2009
Road, F, TRUCK, Medium, Biodiesel from oilseed crops (B100), Euro 5 (2009-14)	2010	2020	26.81	57000	154	2010	2015
Road, F, TRUCK, Medium, Biodiesel from oilseed crops (B100), Euro 7 (2020-24)	2020	2030	25.50	56000	1538	2020	2025
Road, F, TRUCK, Medium, Biodiesel from oilseed crops (B100), Euro 9 (2030-34)	2030		24.25	55000	1538	2030	2035
Road, F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	2030	2035	81.38	69637	0	2030	2031
Road, F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	2045		70.00	59892	0	2045	2046
Road, F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	2020	2025	89.99	77000	0	2020	2024
Road, F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	2025	2030	85.58	73226	0	2025	2026
Road, F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	2040	2045	73.60	62979	0	2040	2041
Road, F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	2035	2040	77.40	66224	0	2035	2036
Road, F, TRUCK, Medium, Liquefied Hydrogen, Euro 4 (incl. catalyst)	2010		95.82	66000	0	2010	2015
Road, F, TRUCK, Heavy, Diesel (DERV), Conventional (no catalyst)	1980	1993	42.72	100000	162767	1980	1981
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 1 (incl. catalyst)	1992	1996	42.52	100000	76430	1992	1993
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 2 (incl. catalyst)	1996	2000	41.74	100000	239197	1996	1997
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 3 (incl. catalyst)	2000	2005	40.25	100000	239197	2000	2001
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 4 (incl. catalyst)	2005	2010	38.36	100000	239197	2005	2006
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 5 (2009-14)	2009	2015	37.66	100000	239197	2009	2010
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 6 (2015-19)	2015	2020	36.54	100000	239197	2015	2016
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 7 (2020-24)	2020	2025	35.64	100000	239197	2020	2021
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 8 (2025-29)	2025	2030	34.76	100000	239197	2025	2026
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 9 (2030-34)	2030	2035	33.90	100000	239197	2030	2031
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 10 (2035-39)	2035	2040	33.06	100000	239197	2035	2036
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 11 (2040-44)	2040	2045	32.24	100000	239197	2040	2041
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 12 (2045-50)	2045		31.44	100000	239197	2045	2046
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 5 (2009-14), HEV	2009	2020	22.13	110000	2392	2009	2014
Road, F, TRUCK, Heavy, Diesel (DERV), Euro 7 (2020-24), HEV	2020		22.13	105000	23920	2020	2025
Road, F, TRUCK, Heavy, Biomethanol, Fuel Cell	2045		44.69	103558	0	2045	2046
Road, F, TRUCK, Heavy, Biomethanol, Fuel Cell	2040	2045	46.99	108895	0	2040	2041

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Road, F, TRUCK, Heavy, Biomethanol, Fuel Cell	2035	2040	49.41	114507	0	2035	2036
Road, F, TRUCK, Heavy, Biomethanol, Fuel Cell	2025	2030	54.64	126613	0	2025	2026
Road, F, TRUCK, Heavy, Biomethanol, Fuel Cell	2015	2020	60.42	140000	0	2015	2019
Road, F, TRUCK, Heavy, Biomethanol, Fuel Cell	2020	2025	57.46	133139	0	2020	2021
Road, F, TRUCK, Heavy, Biomethanol, Fuel Cell	2030	2035	51.96	120408	0	2030	2031
Road, F, TRUCK, Heavy, Biodiesel from oilseed crops (B100), Euro 4 (incl. catalyst)	2005	2010	42.12	105000	24	2005	2009
Road, F, TRUCK, Heavy, Biodiesel from oilseed crops (B100), Euro 5 (2009-14)	2010	2020	41.14	105000	239	2010	2015
Road, F, TRUCK, Heavy, Biodiesel from oilseed crops (B100), Euro 7 (2020-24)	2020	2030	39.13	102500	2392	2020	2025
Road, F, TRUCK, Heavy, Biodiesel from oilseed crops (B100), Euro 9 (2030-34)	2030		37.22	100000	2392	2030	2035
Road, F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	2040	2045	92.00	106328	2392	2040	2041
Road, F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	2020	2025	112.49	130000	0	2020	2024
Road, F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	2030	2035	101.73	117570	2392	2030	2031
Road, F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	2025	2030	106.97	123629	2392	2025	2029
Road, F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	2045		87.49	101117	2392	2045	2046
Road, F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	2035	2040	96.74	111808	2392	2035	2036
Road, F, TRUCK, Heavy, Liquefied Hydrogen, Euro 4 (incl. catalyst)	2010		140.05	110000	0	2010	2015
Rail, F, TRAIN, Regional, Diesel (DERV), Standard 1	1980	2000	374.60	10000000	962	1980	1981
Rail, F, TRAIN, Regional, Diesel (DERV), Standard 2	2000	2015	242.33	10000000	962	2000	2001
Rail, F, TRAIN, Regional, Diesel (DERV), Standard 3	2015		226.33	10000000	962	2015	2016
Rail, F, TRAIN, Regional, Electricity, Standard 1	1980	2000	1590.30	10000000	106	1980	1981
Rail, F, TRAIN, Regional, Electricity, Standard 2	2000	2015	1296.00	10000000	106	2000	2001
Rail, F, TRAIN, Regional, Electricity, Standard 3	2015		1202.13	10000000	106	2015	2016
Rail, F, TRAIN, National, Diesel (DERV), Standard 1	1980	2000	362.20	15000000	0	1980	1981
Rail, F, TRAIN, National, Diesel (DERV), Standard 2	2000	2015	330.00	15000000	0	2000	2001
Rail, F, TRAIN, National, Diesel (DERV), Standard 3	2015		313.50	15000000	0	2015	2016
Rail, F, TRAIN, National, Electricity, Standard 1	1980	2000	1590.00	15000000	317	1980	1981
Rail, F, TRAIN, National, Electricity, Standard 2	2000	2015	1440.00	15000000	317	2000	2001
Rail, F, TRAIN, National, Electricity, Standard 3	2015		1224.00	15000000	317	2015	2016
Air, F, PLANE, Short Distance, Liquefied Hydrogen, Standard 3	2025	2035	1886.61	5000000	5	2025	2030
Air, F, PLANE, Short Distance, Liquefied Hydrogen, Euro 10 (2035-39)	2035	2045	1676.98	5000000	11	2035	2040
Air, F, PLANE, Short Distance, Liquefied Hydrogen, Euro 12 (2045-50)	2045		1572.17	5000000	11	2045	2050
Air, F, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Standard 1	1985	2005	611.20	4000000	21	1985	1986
Air, F, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Standard 2	2005	2015	490.90	4000000	21	2005	2006
Air, F, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Euro 6 (2015-19)	2015	2025	466.62	4000000	21	2015	2016
Air, F, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Euro 8 (2025-29)	2025	2035	443.80	4000000	21	2025	2026
Air, F, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Euro 10 (2035-39)	2035	2045	422.11	4000000	21	2035	2036
Air, F, PLANE, Short Distance, Aviation fuel (BP Jet A-1), Euro 12 (2045-50)	2045		401.47	4000000	21	2045	2046
Air, F, PLANE, Middle Distance, Liquefied Hydrogen, Standard 3	2025	2035	1837.68	100000000	11	2025	2030
Air, F, PLANE, Middle Distance, Liquefied Hydrogen, Euro 10 (2035-39)	2035	2045	1633.50	100000000	21	2035	2040

Technology Description	*First Year of Availability*	*Final Year of Availability*	*SFC (l/100km or kWh/100 km)*	*Average Purchase Price (GBP 2007)*	*P factor*	*T_{Start}*	*$T_{Maturity}$*
Air, F, PLANE, Middle Distance, Liquefied Hydrogen, Euro 12 (2045-50)	2045		1531.40	100000000	21	2045	2050
Air, F, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Standard 1	1985	2005	599.71	75000000	42	1985	1986
Air, F, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Standard 2	2005	2015	486.72	75000000	42	2005	2006
Air, F, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Euro 6 (2015-19)	2015	2025	462.56	75000000	42	2015	2016
Air, F, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Euro 8 (2025-29)	2025	2035	439.95	75000000	42	2025	2026
Air, F, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Euro 10 (2035-39)	2035	2045	418.44	75000000	42	2035	2036
Air, F, PLANE, Middle Distance, Aviation fuel (BP Jet A-1), Euro 12 (2045-50)	2045		397.98	75000000	42	2045	2046
Air, F, PLANE, Long Distance, Liquefied Hydrogen, Standard 3	2025	2035	3450.45	200000000	4	2025	2030
Air, F, PLANE, Long Distance, Liquefied Hydrogen, Euro 10 (2035-39)	2035	2045	3067.07	180876416	7	2035	2040
Air, F, PLANE, Long Distance, Liquefied Hydrogen, Euro 12 (2045-50)	2045		2875.38	163581392	7	2045	2050
Air, F, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Standard 1	1985	2005	1121.80	150000000	14	1985	1986
Air, F, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Standard 2	2005	2015	913.87	150000000	14	2005	2006
Air, F, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Euro 6 (2015-19)	2015	2025	868.51	150000000	14	2015	2016
Air, F, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Euro 8 (2025-29)	2025	2035	826.05	150000000	14	2025	2026
Air, F, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Euro 10 (2035-39)	2035	2045	785.67	150000000	14	2035	2036
Air, F, PLANE, Long Distance, Aviation fuel (BP Jet A-1), Euro 12 (2045-50)	2045		747.26	150000000	14	2045	2046
Air, F, PLANE, Supersonic, Liquefied Hydrogen, Standard 3	2025	2035	6636.00	155000000	0	2025	2030
Air, F, PLANE, Supersonic, Liquefied Hydrogen, Euro 10 (2035-39)	2035	2045	6400.00	155000000	0	2035	2040
Air, F, PLANE, Supersonic, Liquefied Hydrogen, Euro 12 (2045-50)	2045		6200.00	155000000	0	2045	2050
Air, F, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Standard 2	2005	2015	1645.50	155000000	1	2005	2006
Air, F, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Euro 6 (2015-19)	2015	2025	1645.50	155000000	1	2015	2016
Air, F, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Euro 8 (2025-29)	2025	2035	1645.50	155000000	1	2025	2026
Air, F, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Euro 10 (2035-39)	2035	2045	1645.50	155000000	1	2035	2036
Air, F, PLANE, Supersonic, Aviation fuel (BP Jet A-1), Euro 12 (2045-50)	2045		1645.50	155000000	1	2045	2046

Legend: P=passenger; F=freight; SFC=specific fuel consumption; light trucks=vans.

Appendix B: Direct Energy and Emissions Model Data Tables

B.1 Speed profiles

Table 25: Speed profiles for all road vehicle types for the reference scenario

	Motorcycle			*Car*			*Bus*			*Trucks*		
Speed brackets	*U*	*R*	*M*	*U*	*R*	*M*	*U*	*R*	*M*	*U*	*R*	*M*
0-5	2	1	1	2	1	1	4	1	1	2	1	1
5-15	2	1	1	2	1	1	6	5	1	2	1	1
15-25	13	1	1	13	1	1	20	10	1	16	2	1
25-35	17	2	1	17	2	1	30	15	2	25	6	2
35-45	25	3	1	25	3	1	20	22	3	30	10	3
45-55	25	5	1	25	5	1	10	19	4	15	15	4
55-65	10	10	1	10	10	1	7	16	5	5	25	5
65-75	5	20	2	5	20	2	2	7	6	3	25	6
75-85	1	25	3	1	25	3	1	3	10	2	10	10
85-95	0	18	4	0	18	4	0	1	15	0	5	15
95-105	0	10	8	0	10	8	0	1	22	0	0	22
105-115	0	4	22	0	4	22	0	0	15	0	0	15
115-125	0	0	24	0	0	24	0	0	8	0	0	8
125-135	0	0	18	0	0	18	0	0	5	0	0	5
135-145	0	0	10	0	0	10	0	0	2	0	0	2
145+	0	0	2	0	0	2	0	0	0	0	0	0
Sum	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Legend: U = urban, R = rural, M = motorway/dual carriageway

B.2 Direct energy use and emissions factors for the reference case

Table 26 shows the direct energy use and emissions factors for the reference case for all road vehicle technologies and by road type (urban | rural | motorway). This is the result of the DEEM model calibration for the reference case, based on the UKTCM specific energy use and emissions factor database and integration with existing UK road speed profiles for urban, rural and motorway driving.

Table 26: Fuel consumption, direct CO2 emissions and electricity use factors, for road transport technologies, by road type

	Specific fuel consumption (litres/100km)				*Direct CO2 emissions (gCO2/km)*				*Specific electricity consumption (kWh/100km)*			
Vehicle technology description	*combined*	*urban*	*rural*	*motorway*	*combined*	*urban*	*rural*	*motorway*	*combined*	*urban*	*rural*	*motorway*
P, MOTO, Average moto, Gasoline (petrol), 2-Stroke Standard 1	4.8	5.3	4.1	4.9	112	124	94	115				
P, MOTO, Average moto, Gasoline (petrol), 2-Stroke Standard 2	4.0	4.5	3.4	4.1	93	104	79	96				
P, MOTO, Average moto, Gasoline (petrol), 2-Stroke Economic	3.2	3.5	2.7	3.3	74	82	62	76				
P, MOTO, Average moto, Electricity, 2-Stroke Standard 1									9.6	8.7	9.9	13.9
P, MOTO, Average moto, Electricity, 2-Stroke Standard 2									8.4	7.6	8.7	12.2
P, MOTO, Average moto, Electricity, 2-Stroke Economic									7.2	6.5	7.4	10.5
P, MOTO, Average moto, Gaseous Hydrogen, Fuel Cell	7.6	7.6	7.6	7.6								
P, MOTO, Average moto, Gaseous Hydrogen, Fuel Cell	6.1	6.1	6.1	6.1								
P, CAR, Small, Gasoline (petrol), Conventional (no catalyst)	8.2	9.9	6.7	7.8	189	230	155	177				
P, CAR, Small, Gasoline (petrol), Euro 1 (incl. catalyst)	7.5	8.9	6.3	7.2	173	205	146	163				
P, CAR, Small, Gasoline (petrol), Euro 2 (incl. catalyst)	7.9	9.3	6.6	7.5	182	216	153	173				
P, CAR, Small, Gasoline (petrol), Euro 3 (incl. catalyst)	7.8	9.3	6.6	7.5	181	214	152	172				
P, CAR, Small, Gasoline (petrol), Euro 4 (incl. catalyst)	7.4	8.8	6.3	7.1	171	203	144	163				
P, CAR, Small, Gasoline (petrol), Euro 5 (2009-14)	7.3	8.6	6.1	6.9	168	199	142	160				
P, CAR, Small, Gasoline (petrol), Euro 6 (2015-19)	7.1	8.4	6.0	6.7	163	193	137	155				
P, CAR, Small, Gasoline (petrol), Euro 7 (2020-24)	6.9	8.2	5.8	6.6	159	189	134	151				
P, CAR, Small, Gasoline (petrol), Euro 8 (2025-29)	6.7	8.0	5.7	6.4	155	184	131	147				
P, CAR, Small, Gasoline (petrol), Euro 9 (2030-34)	6.6	7.8	5.5	6.2	151	179	127	144				
P, CAR, Small, Gasoline (petrol), Euro 10 (2035-39)	6.4	7.6	5.4	6.1	148	175	124	140				
P, CAR, Small, Gasoline (petrol), Euro 11 (2040-44)	6.2	7.4	5.3	5.9	144	171	121	137				
P, CAR, Small, Gasoline (petrol), Euro 12 (2045-50)	6.1	7.2	5.1	5.8	140	166	118	133				
P, CAR, Small, Gasoline (petrol), Euro 5 (2009-14), PHEV	5.1		4.9	5.5	117		112	127	8.6	8.6		
P, CAR, Small, Gasoline (petrol), Euro 6 (2015-19), PHEV	4.9		4.7	5.4	114		109	123	8.2	8.2		
P, CAR, Small, Gasoline (petrol), Euro 7 (2020-24), PHEV	4.8		4.6	5.2	111		106	120	7.8	7.8		
P, CAR, Small, Gasoline (petrol), Euro 8 (2025-29), PHEV	4.7		4.5	5.1	109		105	118	7.3	7.3		
P, CAR, Small, Gasoline (petrol), Euro 9 (2030-34), PHEV	4.6		4.4	5.0	106		102	115	6.9	6.9		
P, CAR, Small, Gasoline (petrol), Euro 10 (2035-39), PHEV	4.5		4.3	4.8	103		99	111	6.5	6.5		
P, CAR, Small, Gasoline (petrol), Euro 11 (2040-44), PHEV	4.4		4.2	4.8	101		97	110	6.0	6.0		
P, CAR, Small, Gasoline (petrol), Euro 12 (2045-50), PHEV	4.2		4.1	4.6	98		94	106	5.6	5.6		
P, CAR, Small, Diesel (DERV), Euro 3 (incl. catalyst)	5.4	6.1	4.6	5.6	139	158	119	143				
P, CAR, Small, Diesel (DERV), Euro 4 (incl. catalyst)	5.0	5.7	4.3	5.2	129	147	110	133				
P, CAR, Small, Diesel (DERV), Euro 5 (2009-14)	4.9	5.6	4.2	5.1	127	144	108	130				
P, CAR, Small, Diesel (DERV), Euro 6 (2015-19)	4.8	5.4	4.1	4.9	123	140	105	126				
P, CAR, Small, Diesel (DERV), Euro 7 (2020-24)	4.6	5.3	4.0	4.8	120	137	102	123				
P, CAR, Small, Diesel (DERV), Euro 8 (2025-29)	4.5	5.1	3.9	4.7	117	133	100	120				
P, CAR, Small, Diesel (DERV), Euro 9 (2030-34)	4.4	5.0	3.8	4.6	114	130	97	117				

	Specific fuel consumption (litres/100km)				*Direct CO2 emissions (gCO2/km)*				*Specific electricity consumption (kWh/100km)*			
Vehicle technology description	*combi ned*	*urban*	*rural*	*motor way*	*combi ned*	*urban*	*rural*	*motor way*	*combi ned*	*urban*	*rural*	*motor way*
P, CAR, Small, Diesel (DERV), Euro 10 (2035-39)	4.3	4.9	3.7	4.5	111	127	95	114				
P, CAR, Small, Diesel (DERV), Euro 11 (2040-44)	4.2	4.8	3.6	4.3	108	124	93	111				
P, CAR, Small, Diesel (DERV), Euro 12 (2045-50)	4.1	4.6	3.5	4.2	106	121	90	109				
P, CAR, Small, Biomethanol, Fuel Cell	6.9	6.9	6.9	6.9	77	77	77	77				
P, CAR, Small, Biomethanol, Fuel Cell	5.6	5.6	5.6	5.6	62	62	62	62				
P, CAR, Small, Electricity, Standard 1									17.8	15.3	17.4	24.4
P, CAR, Small, Electricity, Standard 2									15.3	13.1	14.9	20.9
P, CAR, Small, Electricity, Standard 3									12.7	10.9	12.4	17.4
P, CAR, Small, Gaseous Hydrogen, Fuel Cell	12.3	12.3	12.3	12.3								
P, CAR, Small, Gaseous Hydrogen, Fuel Cell	9.9	9.9	9.9	9.9								
P, CAR, Medium, Gasoline (petrol), Conventional (no catalyst)	9.3	11.5	7.6	8.2	215	266	175	193				
P, CAR, Medium, Gasoline (petrol), Euro 1 (incl. catalyst)	8.7	10.5	7.3	7.9	203	242	170	189				
P, CAR, Medium, Gasoline (petrol), Euro 2 (incl. catalyst)	9.2	11.0	7.7	8.5	213	254	179	198				
P, CAR, Medium, Gasoline (petrol), Euro 3 (incl. catalyst)	9.1	10.9	7.7	8.5	211	252	177	197				
P, CAR, Medium, Gasoline (petrol), Euro 4 (incl. catalyst)	8.5	10.1	7.1	7.9	196	234	165	183				
P, CAR, Medium, Gasoline (petrol), Euro 5 (2009-14)	8.3	9.9	7.0	7.7	192	230	162	179				
P, CAR, Medium, Gasoline (petrol), Euro 6 (2015-19)	8.1	9.6	6.8	7.5	187	223	157	174				
P, CAR, Medium, Gasoline (petrol), Euro 7 (2020-24)	7.9	9.4	6.6	7.3	182	217	153	170				
P, CAR, Medium, Gasoline (petrol), Euro 8 (2025-29)	7.7	9.2	6.5	7.1	177	212	149	166				
P, CAR, Medium, Gasoline (petrol), Euro 9 (2030-34)	7.5	9.0	6.3	7.0	173	207	146	161				
P, CAR, Medium, Gasoline (petrol), Euro 10 (2035-39)	7.3	8.7	6.2	6.8	169	202	142	157				
P, CAR, Medium, Gasoline (petrol), Euro 11 (2040-44)	7.1	8.5	6.0	6.6	165	197	138	154				
P, CAR, Medium, Gasoline (petrol), Euro 12 (2045-50)	6.9	8.3	5.9	6.5	161	192	135	150				
P, CAR, Medium, Gasoline (petrol), Euro 4 (incl. catalyst), HEV	5.1	6.1	4.3	4.8	119	142	100	111				
P, CAR, Medium, Gasoline (petrol), Euro 5 (2009-14), HEV	5.0	6.0	4.2	4.7	116	139	98	109				
P, CAR, Medium, Gasoline (petrol), Euro 6 (2015-19), HEV	4.9	5.8	4.1	4.5	113	135	95	105				
P, CAR, Medium, Gasoline (petrol), Euro 7 (2020-24), HEV	4.8	5.7	4.0	4.4	110	132	93	103				
P, CAR, Medium, Gasoline (petrol), Euro 8 (2025-29), HEV	4.7	5.6	3.9	4.3	107	128	90	100				
P, CAR, Medium, Gasoline (petrol), Euro 9 (2030-34), HEV	4.5	5.4	3.8	4.2	105	125	88	98				
P, CAR, Medium, Gasoline (petrol), Euro 10 (2035-39), HEV	4.4	5.3	3.7	4.1	102	122	86	95				
P, CAR, Medium, Gasoline (petrol), Euro 11 (2040-44), HEV	4.3	5.2	3.6	4.0	100	119	84	93				
P, CAR, Medium, Gasoline (petrol), Euro 12 (2045-50), HEV	4.2	5.0	3.5	3.9	97	116	82	91				
P, CAR, Medium, Gasoline (petrol), Euro 5 (2009-14), PHEV	5.8		5.6	6.2	134		129	143	15.1	15.1		
P, CAR, Medium, Gasoline (petrol), Euro 6 (2015-19), PHEV	5.6		5.4	6.0	130		126	139	14.6	14.6		
P, CAR, Medium, Gasoline (petrol), Euro 7 (2020-24), PHEV	5.5		5.3	5.8	126		122	135	14.1	14.1		
P, CAR, Medium, Gasoline (petrol), Euro 8 (2025-29), PHEV	5.3		5.1	5.7	123		119	132	13.6	13.6		
P, CAR, Medium, Gasoline (petrol), Euro 9 (2030-34), PHEV	5.2		5.1	5.6	121		117	130	13.1	13.1		
P, CAR, Medium, Gasoline (petrol), Euro 10 (2035-39), PHEV	5.1		4.9	5.4	117		113	126	12.6	12.6		
P, CAR, Medium, Gasoline (petrol), Euro 11 (2040-44), PHEV	5.0		4.8	5.3	115		112	124	12.1	12.1		
P, CAR, Medium, Gasoline (petrol), Euro 12 (2045-50), PHEV	4.8		4.7	5.2	112		108	120	11.6	11.6		

Vehicle technology description	Specific fuel consumption (litres/100km) combined	urban	rural	motorway	Direct CO2 emissions (gCO2/km) combined	urban	rural	motorway	Specific electricity consumption (kWh/100km) combined	urban	rural	motorway
P, CAR, Medium, Diesel (DERV), Conventional (no catalyst)	5.5	6.3	4.7	5.5	142	164	122	142				
P, CAR, Medium, Diesel (DERV), Euro 1 (incl. catalyst)	5.7	6.5	4.9	5.9	148	169	126	150				
P, CAR, Medium, Diesel (DERV), Euro 2 (incl. catalyst)	5.7	6.5	4.9	5.9	148	168	126	150				
P, CAR, Medium, Diesel (DERV), Euro 3 (incl. catalyst)	6.0	6.8	5.1	6.2	154	176	132	158				
P, CAR, Medium, Diesel (DERV), Euro 4 (incl. catalyst)	5.6	6.3	4.7	5.7	144	164	123	147				
P, CAR, Medium, Diesel (DERV), Euro 5 (2009-14)	5.4	6.2	4.6	5.6	141	160	120	144				
P, CAR, Medium, Diesel (DERV), Euro 6 (2015-19)	5.3	6.0	4.5	5.5	137	156	117	140				
P, CAR, Medium, Diesel (DERV), Euro 7 (2020-24)	5.2	5.8	4.4	5.3	133	152	114	137				
P, CAR, Medium, Diesel (DERV), Euro 8 (2025-29)	5.0	5.7	4.3	5.2	130	148	111	133				
P, CAR, Medium, Diesel (DERV), Euro 9 (2030-34)	4.9	5.6	4.2	5.1	127	144	108	130				
P, CAR, Medium, Diesel (DERV), Euro 10 (2035-39)	4.8	5.4	4.1	4.9	124	141	105	127				
P, CAR, Medium, Diesel (DERV), Euro 11 (2040-44)	4.7	5.3	4.0	4.8	121	137	103	124				
P, CAR, Medium, Diesel (DERV), Euro 12 (2045-50)	4.5	5.2	3.9	4.7	118	134	100	121				
P, CAR, Medium, Diesel (DERV), Euro 4 (incl. catalyst), HEV	3.4	3.8	2.9	3.5	87	99	74	89				
P, CAR, Medium, Diesel (DERV), Euro 5 (2009-14), HEV	3.3	3.7	2.8	3.4	85	97	73	87				
P, CAR, Medium, Diesel (DERV), Euro 6 (2015-19), HEV	3.2	3.6	2.7	3.3	83	94	71	85				
P, CAR, Medium, Diesel (DERV), Euro 7 (2020-24), HEV	3.1	3.5	2.7	3.2	81	92	69	83				
P, CAR, Medium, Diesel (DERV), Euro 8 (2025-29), HEV	3.0	3.5	2.6	3.2	79	90	67	81				
P, CAR, Medium, Diesel (DERV), Euro 9 (2030-34), HEV	3.0	3.4	2.5	3.1	77	87	65	79				
P, CAR, Medium, Diesel (DERV), Euro 10 (2035-39), HEV	2.9	3.3	2.5	3.0	75	85	64	77				
P, CAR, Medium, Diesel (DERV), Euro 11 (2040-44), HEV	2.8	3.2	2.4	2.9	73	83	62	75				
P, CAR, Medium, Diesel (DERV), Euro 12 (2045-50), HEV	2.8	3.1	2.3	2.9	71	81	61	73				
P, CAR, Medium, Liquefied Petrol Gas, Euro 2 (incl. catalyst)	13.7	16.1	11.5	13.0	166	196	139	156				
P, CAR, Medium, Liquefied Petrol Gas, Euro 3 (incl. catalyst)	13.5	16.0	11.4	12.9	165	195	139	156				
P, CAR, Medium, Liquefied Petrol Gas, Euro 4 (incl. catalyst)	13.0	15.4	10.9	12.4	153	181	129	145				
P, CAR, Medium, Liquefied Petrol Gas, Euro 5 (2009-14)	12.7	15.0	10.7	12.1	150	178	126	143				
P, CAR, Medium, Liquefied Petrol Gas, Euro 6 (2015-19)	12.3	14.6	10.4	11.7	146	173	123	138				
P, CAR, Medium, Liquefied Petrol Gas, Euro 7 (2020-24)	12.0	14.2	10.1	11.4	142	168	120	135				
P, CAR, Medium, Liquefied Petrol Gas, Euro 8 (2025-29)	11.7	13.8	9.8	11.1	138	164	117	132				
P, CAR, Medium, Liquefied Petrol Gas, Euro 9 (2030-34)	11.4	13.4	9.6	10.8	135	160	114	128				
P, CAR, Medium, Liquefied Petrol Gas, Euro 10 (2035-39)	11.0	13.1	9.3	10.5	132	156	111	125				
P, CAR, Medium, Liquefied Petrol Gas, Euro 11 (2040-44)	10.7	12.7	9.0	10.2	128	152	108	122				
P, CAR, Medium, Liquefied Petrol Gas, Euro 12 (2045-50)	10.4	12.3	8.7	9.9	125	148	105	119				
P, CAR, Medium, Biomethanol, Fuel Cell	9.3	9.3	9.3	9.3	102	102	102	102				
P, CAR, Medium, Biomethanol, Fuel Cell	7.5	7.5	7.5	7.5	83	83	83	83				
P, CAR, Medium, Biomethanol, Fuel Cell	4.9	4.9	4.9	4.9	54	54	54	54				
P, CAR, Medium, Biomethanol, Fuel Cell	6.1	6.1	6.1	6.1	67	67	67	67				
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 4	8.8	10.6	7.4	8.2	216	258	181	201				
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 5 (2009-14)	8.7	10.4	7.3	8.1	212	253	178	197				
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 6 (2015-19)	8.4	10.0	7.1	7.8	205	245	173	191				

Vehicle technology description	Specific fuel consumption (litres/100km)				Direct CO2 emissions (gCO2/km)				Specific electricity consumption (kWh/100km)			
	combined	urban	rural	motorway	combined	urban	rural	motorway	combined	urban	rural	motorway
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 7 (2020-24)	8.2	9.8	6.9	7.6	200	239	168	187				
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 8 (2025-29)	8.0	9.6	6.7	7.4	195	233	164	182				
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 9 (2030-34)	7.8	9.3	6.6	7.3	190	227	160	178				
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 10 (2035-39)	7.6	9.1	6.4	7.1	186	222	156	173				
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 11 (2040-44)	7.4	8.9	6.2	6.9	181	216	152	169				
P, CAR, Medium, Bioethanol-petrol blend (E85), Euro 12 (2045-50)	7.2	8.6	6.1	6.7	177	211	149	165				
P, CAR, Medium, Biodiesel (B100), Standard 1	5.3	6.0	4.5	5.5	147	168	126	150				
P, CAR, Medium, Biodiesel (B100), Standard 2	4.3	4.9	3.7	4.4	119	135	101	122				
P, CAR, Medium, Biodiesel (B100), Standard 3	3.5	3.9	3.0	3.6	96	109	82	98				
P, CAR, Medium, Compressed Natural Gas, Standard 1	162.5	194.9	136.8	147.9	192	229	161	179				
P, CAR, Medium, Compressed Natural Gas, Standard 3	130.7	156.1	110.0	121.5	153	183	129	143				
P, CAR, Medium, Gaseous Hydrogen, Fuel Cell	20.5	20.5	20.5	20.5								
P, CAR, Medium, Gaseous Hydrogen, Fuel Cell	17.8	17.8	17.8	17.8								
P, CAR, Large, Gasoline (petrol), Conventional (no catalyst)	10.3	12.8	8.4	9.2	237	296	193	203				
P, CAR, Large, Gasoline (petrol), Euro 1 (incl. catalyst)	10.8	12.8	9.1	10.1	250	295	211	236				
P, CAR, Large, Gasoline (petrol), Euro 2 (incl. catalyst)	11.4	13.4	9.6	10.7	263	310	223	251				
P, CAR, Large, Gasoline (petrol), Euro 3 (incl. catalyst)	11.3	13.3	9.6	10.6	261	308	221	249				
P, CAR, Large, Gasoline (petrol), Euro 4 (incl. catalyst)	10.5	12.4	8.9	9.9	243	286	206	232				
P, CAR, Large, Gasoline (petrol), Euro 5 (2009-14)	10.3	12.2	8.7	9.7	238	281	202	227				
P, CAR, Large, Gasoline (petrol), Euro 6 (2015-19)	10.0	11.8	8.5	9.4	231	273	196	221				
P, CAR, Large, Gasoline (petrol), Euro 7 (2020-24)	9.7	11.5	8.2	9.1	225	266	191	215				
P, CAR, Large, Gasoline (petrol), Euro 8 (2025-29)	9.5	11.2	8.0	8.9	220	259	186	210				
P, CAR, Large, Gasoline (petrol), Euro 9 (2030-34)	9.2	10.9	7.8	8.7	214	253	181	205				
P, CAR, Large, Gasoline (petrol), Euro 10 (2035-39)	9.0	10.7	7.6	8.5	209	247	177	200				
P, CAR, Large, Gasoline (petrol), Euro 11 (2040-44)	8.8	10.4	7.5	8.3	204	240	173	195				
P, CAR, Large, Gasoline (petrol), Euro 12 (2045-50)	8.6	10.2	7.3	8.1	199	235	168	190				
P, CAR, Large, Gasoline (petrol), Euro 4 (incl. catalyst), HEV	6.3	7.5	5.4	6.0	147	173	124	140				
P, CAR, Large, Gasoline (petrol), Euro 5 (2009-14), HEV	6.2	7.4	5.3	5.9	144	170	122	138				
P, CAR, Large, Gasoline (petrol), Euro 6 (2015-19), HEV	6.0	7.1	5.1	5.7	140	165	118	134				
P, CAR, Large, Gasoline (petrol), Euro 7 (2020-24), HEV	5.9	7.0	5.0	5.5	137	161	116	130				
P, CAR, Large, Gasoline (petrol), Euro 8 (2025-29), HEV	5.7	6.8	4.9	5.4	133	157	113	127				
P, CAR, Large, Gasoline (petrol), Euro 9 (2030-34), HEV	5.6	6.6	4.7	5.3	130	153	110	124				
P, CAR, Large, Gasoline (petrol), Euro 10 (2035-39), HEV	5.5	6.5	4.6	5.1	127	149	107	121				
P, CAR, Large, Gasoline (petrol), Euro 11 (2040-44), HEV	5.3	6.3	4.5	5.0	123	146	104	118				
P, CAR, Large, Gasoline (petrol), Euro 12 (2045-50), HEV	5.2	6.1	4.4	4.9	120	142	102	115				
P, CAR, Large, Gasoline (petrol), Euro 5 (2009-14), PHEV	7.2		7.0	7.7	167		161	182	23.0	23.0		
P, CAR, Large, Gasoline (petrol), Euro 6 (2015-19), PHEV	7.0		6.8	7.5	163		157	177	21.8	21.8		
P, CAR, Large, Gasoline (petrol), Euro 7 (2020-24), PHEV	6.8		6.6	7.3	158		152	172	21.2	21.2		
P, CAR, Large, Gasoline (petrol), Euro 8 (2025-29), PHEV	6.6		6.4	7.1	154		148	167	20.1	20.1		
P, CAR, Large, Gasoline (petrol), Euro 9 (2030-34), PHEV	6.5		6.3	7.0	151		146	164	19.5	19.5		

Vehicle technology description	Specific fuel consumption (litres/100km)				Direct CO2 emissions (gCO2/km)				Specific electricity consumption (kWh/100km)			
	combined	urban	rural	motorway	combined	urban	rural	motorway	combined	urban	rural	motorway
P, CAR, Large, Gasoline (petrol), Euro 10 (2035-39), PHEV	6.3		6.1	6.8	147		141	159	18.4	18.4		
P, CAR, Large, Gasoline (petrol), Euro 11 (2040-44), PHEV	6.2		6.0	6.7	144		139	157	17.8	17.8		
P, CAR, Large, Gasoline (petrol), Euro 12 (2045-50), PHEV	6.0		5.8	6.5	140		135	152	17.2	17.2		
P, CAR, Large, Diesel (DERV), Conventional (no catalyst)	7.0	8.3	6.0	6.5	182	214	156	167				
P, CAR, Large, Diesel (DERV), Euro 1 (incl. catalyst)	7.3	8.5	6.3	6.9	190	222	163	183				
P, CAR, Large, Diesel (DERV), Euro 2 (incl. catalyst)	7.1	8.3	6.1	6.7	186	217	159	179				
P, CAR, Large, Diesel (DERV), Euro 3 (incl. catalyst)	7.7	8.9	6.5	7.6	200	231	170	200				
P, CAR, Large, Diesel (DERV), Euro 4 (incl. catalyst)	7.1	8.3	6.1	7.1	186	215	158	186				
P, CAR, Large, Diesel (DERV), Euro 5 (2009-14)	7.0	8.1	5.9	6.9	182	210	155	182				
P, CAR, Large, Diesel (DERV), Euro 6 (2015-19)	6.8	7.9	5.8	6.7	177	204	150	177				
P, CAR, Large, Diesel (DERV), Euro 7 (2020-24)	6.6	7.7	5.6	6.6	172	199	146	172				
P, CAR, Large, Diesel (DERV), Euro 8 (2025-29)	6.5	7.5	5.5	6.4	168	194	143	168				
P, CAR, Large, Diesel (DERV), Euro 9 (2030-34)	6.3	7.3	5.3	6.2	164	189	139	164				
P, CAR, Large, Diesel (DERV), Euro 10 (2035-39)	6.1	7.1	5.2	6.1	160	185	136	160				
P, CAR, Large, Diesel (DERV), Euro 11 (2040-44)	6.0	6.9	5.1	5.9	156	180	133	156				
P, CAR, Large, Diesel (DERV), Euro 12 (2045-50)	5.8	6.8	5.0	5.8	152	176	129	152				
P, CAR, Large, Diesel (DERV), Euro 4 (incl. catalyst), HEV	4.3	5.0	3.7	4.3	113	130	96	112				
P, CAR, Large, Diesel (DERV), Euro 5 (2009-14), HEV	4.2	4.9	3.6	4.2	110	127	94	110				
P, CAR, Large, Diesel (DERV), Euro 6 (2015-19), HEV	4.1	4.8	3.5	4.1	107	124	91	107				
P, CAR, Large, Diesel (DERV), Euro 7 (2020-24), HEV	4.0	4.6	3.4	4.0	104	121	89	104				
P, CAR, Large, Diesel (DERV), Euro 8 (2025-29), HEV	3.9	4.5	3.3	3.9	102	118	87	102				
P, CAR, Large, Diesel (DERV), Euro 9 (2030-34), HEV	3.8	4.4	3.2	3.8	99	115	84	99				
P, CAR, Large, Diesel (DERV), Euro 10 (2035-39), HEV	3.7	4.3	3.2	3.7	97	112	82	97				
P, CAR, Large, Diesel (DERV), Euro 11 (2040-44), HEV	3.6	4.2	3.1	3.6	94	109	80	94				
P, CAR, Large, Diesel (DERV), Euro 12 (2045-50), HEV	3.5	4.1	3.0	3.5	92	106	78	92				
P, CAR, Large, Liquefied Petrol Gas, Euro 2 (incl. catalyst)	14.8	17.3	12.7	14.0	182	212	156	175				
P, CAR, Large, Liquefied Petrol Gas, Euro 3 (incl. catalyst)	14.8	17.1	12.6	14.7	182	210	155	182				
P, CAR, Large, Liquefied Petrol Gas, Euro 4 (incl. catalyst)	14.2	16.4	12.0	14.0	169	195	144	169				
P, CAR, Large, Liquefied Petrol Gas, Euro 5 (2009-14)	13.8	16.0	11.8	13.7	166	192	141	166				
P, CAR, Large, Liquefied Petrol Gas, Euro 6 (2015-19)	13.5	15.6	11.4	13.3	161	186	137	161				
P, CAR, Large, Liquefied Petrol Gas, Euro 7 (2020-24)	13.1	15.2	11.1	13.0	157	181	133	157				
P, CAR, Large, Liquefied Petrol Gas, Euro 8 (2025-29)	12.8	14.8	10.8	12.6	153	177	130	153				
P, CAR, Large, Liquefied Petrol Gas, Euro 9 (2030-34)	12.4	14.4	10.5	12.3	149	172	127	149				
P, CAR, Large, Liquefied Petrol Gas, Euro 10 (2035-39)	12.1	14.0	10.2	11.9	146	168	124	145				
P, CAR, Large, Liquefied Petrol Gas, Euro 11 (2040-44)	11.7	13.6	9.9	11.6	142	164	121	142				
P, CAR, Large, Liquefied Petrol Gas, Euro 12 (2045-50)	11.3	13.1	9.6	11.2	138	160	118	138				
P, CAR, Large, Biomethanol, Fuel Cell	11.6	11.6	11.6	11.6	128	128	128	128				
P, CAR, Large, Biomethanol, Fuel Cell	9.4	9.4	9.4	9.4	103	103	103	103				
P, CAR, Large, Biomethanol, Fuel Cell	7.6	7.6	7.6	7.6	84	84	84	84				
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 4 (incl. catalyst)	10.9	12.9	9.2	10.3	267	315	226	255				

	Specific fuel consumption (litres/100km)				*Direct CO2 emissions (gCO2/km)*				*Specific electricity consumption (kWh/100km)*			
Vehicle technology description	*combined*	*urban*	*rural*	*motorway*	*combined*	*urban*	*rural*	*motorway*	*combined*	*urban*	*rural*	*motorway*
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 5 (2009-14)	10.7	12.7	9.1	10.1	262	309	222	250				
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 6 (2015-19)	10.4	12.3	8.8	9.8	254	300	215	243				
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 7 (2020-24)	10.1	12.0	8.6	9.5	248	292	210	237				
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 8 (2025-29)	9.9	11.7	8.4	9.3	242	285	205	231				
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 9 (2030-34)	9.6	11.4	8.2	9.1	236	278	200	225				
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 10 (2035-39)	9.4	11.1	8.0	8.8	230	271	195	219				
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 11 (2040-44)	9.2	10.8	7.8	8.6	224	265	190	214				
P, CAR, Large, Bioethanol-petrol blend (E85), Euro 12 (2045-50)	8.9	10.6	7.6	8.4	219	258	185	209				
P, CAR, Large, Biodiesel (B100), Standard 1	7.9	9.2	6.7	7.4	219	255	188	211				
P, CAR, Large, Biodiesel (B100), Standard 2	6.8	7.9	5.8	6.7	189	219	161	189				
P, CAR, Large, Biodiesel (B100), Standard 3	5.5	6.4	4.7	5.5	153	177	130	153				
P, CAR, Large, Gaseous Hydrogen, Fuel Cell	20.5	20.5	20.5	20.5								
P, CAR, Large, Gaseous Hydrogen, Fuel Cell	16.6	16.6	16.6	16.6								
P, CAR, Large, Liquefied Hydrogen, Euro 5 (2009-14)	43.8	51.8	37.1	41.2								
P, CAR, Large, Liquefied Hydrogen, Euro 6 (2015-19)	41.6	49.2	35.2	39.1								
P, CAR, Large, Liquefied Hydrogen, Euro 7 (2020-24)	39.4	46.6	33.4	37.0								
P, CAR, Large, Liquefied Hydrogen, Euro 8 (2025-29)	37.2	44.0	31.5	35.0								
P, CAR, Large, Liquefied Hydrogen, Euro 9 (2030-34)	35.0	41.4	29.7	32.9								
P, CAR, Large, Liquefied Hydrogen, Euro 11 (2040-44)	32.8	38.8	27.8	30.9								
P, BUS, Mini, Gasoline (petrol), Standard 1	18.4	23.2	18.4	18.3	422	533	422	422				
P, BUS, Mini, Gasoline (petrol), Standard 2	17.4	22.0	17.4	17.4	401	506	401	401				
P, BUS, Mini, Gasoline (petrol), Standard 3	16.2	20.5	16.2	16.2	372	470	372	372				
P, BUS, Mini, Diesel (DERV), Conventional (no catalyst)	32.2	42.1	32.2	30.1	820	1064	820	775				
P, BUS, Mini, Diesel (DERV), Euro 1 (incl. catalyst)	32.1	41.8	32.1	30.0	818	1056	818	773				
P, BUS, Mini, Diesel (DERV), Euro 2 (incl. catalyst)	32.1	41.8	32.1	30.0	818	1056	818	773				
P, BUS, Mini, Diesel (DERV), Euro 3 (incl. catalyst)	29.0	37.8	29.0	27.1	739	954	739	699				
P, BUS, Mini, Diesel (DERV), Euro 4 (incl. catalyst)	27.6	35.9	27.6	25.8	703	907	703	664				
P, BUS, Mini, Diesel (DERV), Euro 5 (2009-14)	27.0	35.2	27.0	25.3	689	889	689	651				
P, BUS, Mini, Diesel (DERV), Euro 6 (2015-19)	26.2	34.2	26.2	24.5	669	863	669	632				
P, BUS, Mini, Diesel (DERV), Euro 7 (2020-24)	25.6	33.3	25.6	23.9	652	842	652	616				
P, BUS, Mini, Diesel (DERV), Euro 8 (2025-29)	24.9	32.5	24.9	23.3	636	821	636	601				
P, BUS, Mini, Diesel (DERV), Euro 9 (2030-34)	24.3	31.7	24.3	22.8	620	800	620	586				
P, BUS, Mini, Diesel (DERV), Euro 10 (2035-39)	23.7	30.9	23.7	22.2	605	781	605	572				
P, BUS, Mini, Diesel (DERV), Euro 11 (2040-44)	23.1	30.2	23.1	21.6	590	761	590	557				
P, BUS, Mini, Diesel (DERV), Euro 12 (2045-50)	22.6	29.4	22.6	21.1	575	742	575	544				
P, BUS, Mini, Diesel (DERV), Euro 4 (incl. catalyst), HEV	16.7	21.8	16.7	15.6	426	549	426	402				
P, BUS, Mini, Diesel (DERV), Euro 5 (2009-14), HEV	16.4	21.3	16.4	15.3	417	538	417	394				
P, BUS, Mini, Diesel (DERV), Euro 6 (2015-19), HEV	15.9	20.7	15.9	14.9	405	523	405	383				
P, BUS, Mini, Diesel (DERV), Euro 7 (2020-24), HEV	15.5	20.2	15.5	14.5	395	510	395	373				
P, BUS, Mini, Diesel (DERV), Euro 8 (2025-29), HEV	15.1	19.7	15.1	14.1	385	497	385	364				

Vehicle technology description	Specific fuel consumption (litres/100km)				Direct CO2 emissions (gCO2/km)				Specific electricity consumption (kWh/100km)			
	combined	urban	rural	motorway	combined	urban	rural	motorway	combined	urban	rural	motorway
P, BUS, Mini, Diesel (DERV), Euro 9 (2030-34), HEV	14.7	19.2	14.7	13.8	376	485	376	355				
P, BUS, Mini, Diesel (DERV), Euro 10 (2035-39), HEV	14.4	18.7	14.4	13.4	366	473	366	346				
P, BUS, Mini, Diesel (DERV), Euro 11 (2040-44), HEV	14.0	18.3	14.0	13.1	357	461	357	338				
P, BUS, Mini, Diesel (DERV), Euro 12 (2045-50), HEV	13.7	17.8	13.7	12.8	348	450	348	329				
P, BUS, Mini, Liquefied Petrol Gas, Standard 2	28.9	36.6	28.9	28.9	340	430	340	341				
P, BUS, Mini, Liquefied Petrol Gas, Standard 3	25.9	32.7	25.9	25.8	308	389	308	308				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 4 (incl. catalyst)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 5 (2009-14)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 6 (2015-19)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 7 (2020-24)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 8 (2025-29)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 9 (2030-34)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 10 (2035-39)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 11 (2040-44)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Bioethanol-petrol blend (E85), Euro 12 (2045-50)	16.8	21.3	16.8	16.8	409	517	409	409				
P, BUS, Mini, Biodiesel (B100), Standard 1	33.1	43.3	33.1	31.0	903	1171	903	853				
P, BUS, Mini, Biodiesel (B100), Standard 2	28.5	37.1	28.5	26.7	778	1003	778	735				
P, BUS, Mini, Biodiesel (B100), Standard 3	27.1	35.3	27.1	25.4	739	954	739	699				
P, BUS, Mini, Compressed Natural Gas, Standard 1	325.3	411.2	325.3	324.7	380	480	380	380				
P, BUS, Mini, Compressed Natural Gas, Standard 3	277.7	351.0	277.7	277.2	341	431	341	341				
P, BUS, Mini, Gaseous Hydrogen, Fuel Cell	85.9	85.9	85.9	85.9								
P, BUS, Urban, Diesel (DERV), Conventional (no catalyst)	25.5	25.5	19.8	19.4	661	661	514	501				
P, BUS, Urban, Diesel (DERV), Euro 1 (incl. catalyst)	25.2	25.2	19.8	19.3	655	655	512	499				
P, BUS, Urban, Diesel (DERV), Euro 2 (incl. catalyst)	20.2	20.2	15.8	15.5	524	524	410	400				
P, BUS, Urban, Diesel (DERV), Euro 3 (incl. catalyst)	20.3	20.3	15.9	15.5	525	525	411	401				
P, BUS, Urban, Diesel (DERV), Euro 4 (incl. catalyst)	19.9	19.9	15.6	15.3	516	516	404	394				
P, BUS, Urban, Diesel (DERV), Euro 5 (2009-14)	19.6	19.6	15.3	15.0	508	508	398	388				
P, BUS, Urban, Diesel (DERV), Euro 6 (2015-19)	19.0	19.0	14.9	14.6	493	493	386	376				
P, BUS, Urban, Diesel (DERV), Euro 7 (2020-24)	18.5	18.5	14.5	14.2	481	481	376	367				
P, BUS, Urban, Diesel (DERV), Euro 8 (2025-29)	18.1	18.1	14.2	13.9	469	469	367	358				
P, BUS, Urban, Diesel (DERV), Euro 9 (2030-34)	17.6	17.6	13.8	13.5	457	457	358	349				
P, BUS, Urban, Diesel (DERV), Euro 10 (2035-39)	17.2	17.2	13.5	13.2	446	446	349	340				
P, BUS, Urban, Diesel (DERV), Euro 11 (2040-44)	16.8	16.8	13.1	12.9	435	435	340	332				
P, BUS, Urban, Diesel (DERV), Euro 12 (2045-50)	16.4	16.4	12.8	12.5	424	424	332	324				
P, BUS, Urban, Diesel (DERV), Euro 4 (incl. catalyst), HEV	12.0	12.0	9.4	9.2	312	312	245	238				
P, BUS, Urban, Diesel (DERV), Euro 5 (2009-14), HEV	11.9	11.9	9.3	9.1	308	308	241	235				
P, BUS, Urban, Diesel (DERV), Euro 6 (2015-19), HEV	11.5	11.5	9.0	8.8	298	298	234	228				
P, BUS, Urban, Diesel (DERV), Euro 7 (2020-24), HEV	11.2	11.2	8.8	8.6	291	291	228	222				
P, BUS, Urban, Diesel (DERV), Euro 8 (2025-29), HEV	10.9	10.9	8.6	8.4	284	284	222	217				
P, BUS, Urban, Diesel (DERV), Euro 9 (2030-34), HEV	10.7	10.7	8.4	8.2	277	277	217	211				

Vehicle technology description	Specific fuel consumption (litres/100km)				Direct CO2 emissions (gCO2/km)				Specific electricity consumption (kWh/100km)			
	combined	urban	rural	motorway	combined	urban	rural	motorway	combined	urban	rural	motorway
P, BUS, Urban, Diesel (DERV), Euro 10 (2035-39), HEV	10.4	10.4	8.2	8.0	270	270	211	206				
P, BUS, Urban, Diesel (DERV), Euro 11 (2040-44), HEV	10.2	10.2	8.0	7.8	263	263	206	201				
P, BUS, Urban, Diesel (DERV), Euro 12 (2045-50), HEV	9.9	9.9	7.8	7.6	257	257	201	196				
P, BUS, Urban, Diesel (DERV), Euro 5 (2009-14), PHEV	11.9		11.9	11.7	309		309	301	103.7	103.7		
P, BUS, Urban, Diesel (DERV), Euro 6 (2015-19), PHEV	11.5		11.5	11.3	299		299	291	99.6	99.6		
P, BUS, Urban, Diesel (DERV), Euro 7 (2020-24), PHEV	11.3		11.3	11.1	293		293	286	95.4	95.4		
P, BUS, Urban, Diesel (DERV), Euro 8 (2025-29), PHEV	11.1		11.1	10.9	288		288	281	91.3	91.3		
P, BUS, Urban, Diesel (DERV), Euro 9 (2030-34), PHEV	10.7		10.7	10.5	277		277	270	87.1	87.1		
P, BUS, Urban, Diesel (DERV), Euro 10 (2035-39), PHEV	10.5		10.5	10.3	272		272	265	83.0	83.0		
P, BUS, Urban, Diesel (DERV), Euro 11 (2040-44), PHEV	10.3		10.3	10.1	267		267	260	78.8	78.8		
P, BUS, Urban, Diesel (DERV), Euro 12 (2045-50), PHEV	10.1		10.1	9.9	261		261	255	74.7	74.7		
P, BUS, Urban, Liquefied Petrol Gas, Standard 1	47.0	47.0	36.6	35.8	658	658	512	499				
P, BUS, Urban, Liquefied Petrol Gas, Standard 2	36.4	36.4	28.5	27.9	482	482	377	368				
P, BUS, Urban, Biomethanol, Fuel Cell	30.8	30.8	30.8	30.8	339	339	339	339				
P, BUS, Urban, Biomethanol, Fuel Cell	27.9	27.9	27.9	27.9	306	306	306	306				
P, BUS, Urban, Biomethanol, Fuel Cell	25.2	25.2	25.2	25.2	277	277	277	277				
P, BUS, Urban, Bioethanol-petrol blend (E85), Standard 1	35.0	35.0	27.3	26.7	722	722	562	547				
P, BUS, Urban, Bioethanol-petrol blend (E85), Standard 2	31.9	31.9	25.0	24.5	647	647	507	494				
P, BUS, Urban, Bioethanol-petrol blend (E85), Standard 3	33.3	33.3	26.1	25.5	681	681	533	520				
P, BUS, Urban, Biodiesel (B100), Standard 1	25.1	25.1	19.5	19.1	696	696	541	528				
P, BUS, Urban, Biodiesel (B100), Standard 2	25.7	25.7	20.1	19.7	713	713	558	544				
P, BUS, Urban, Biodiesel (B100), Standard 3	23.9	23.9	18.7	18.3	663	663	519	506				
P, BUS, Urban, Compressed Natural Gas, Standard 1	628.3	628.3	488.9	478.7	642	642	500	487				
P, BUS, Urban, Compressed Natural Gas, Standard 3	520.9	520.9	407.9	399.3	533	533	417	406				
P, BUS, Urban, Electricity, Standard 1									185.5	185.5	184.4	245.1
P, BUS, Urban, Electricity, Standard 2									170.0	170.0	169.0	224.7
P, BUS, Urban, Electricity, Standard 3									154.6	154.6	153.7	204.3
P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	54.6	54.6	54.6	54.6								
P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	51.9	51.9	51.9	51.9								
P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	49.3	49.3	49.3	49.3								
P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	46.9	46.9	46.9	46.9								
P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	44.6	44.6	44.6	44.6								
P, BUS, Urban, Gaseous Hydrogen, Fuel Cell	42.4	42.4	42.4	42.4								
P, BUS, Coach, Diesel (DERV), Conventional (no catalyst)	18.2	26.5	19.7	18.2	469	687	509	469				
P, BUS, Coach, Diesel (DERV), Euro 1 (incl. catalyst)	18.2	26.4	19.6	18.2	469	683	509	469				
P, BUS, Coach, Diesel (DERV), Euro 2 (incl. catalyst)	18.2	26.4	19.7	18.2	469	684	509	469				
P, BUS, Coach, Diesel (DERV), Euro 3 (incl. catalyst)	18.2	26.5	19.7	18.2	470	685	510	470				
P, BUS, Coach, Diesel (DERV), Euro 4 (incl. catalyst)	17.9	26.0	19.4	17.9	462	673	501	462				
P, BUS, Coach, Diesel (DERV), Euro 5 (2009-14)	17.6	25.6	19.1	17.6	455	663	493	455				
P, BUS, Coach, Diesel (DERV), Euro 6 (2015-19)	17.1	24.8	18.5	17.1	441	643	479	441				

Vehicle technology description	Specific fuel consumption (litres/100km)				Direct CO2 emissions (gCO2/km)				Specific electricity consumption (kWh/100km)			
	combined	urban	rural	motorway	combined	urban	rural	motorway	combined	urban	rural	motorway
P, BUS, Coach, Diesel (DERV), Euro 7 (2020-24)	16.7	24.2	18.0	16.7	430	627	467	430				
P, BUS, Coach, Diesel (DERV), Euro 8 (2025-29)	16.3	23.6	17.6	16.3	420	612	455	420				
P, BUS, Coach, Diesel (DERV), Euro 9 (2030-34)	15.9	23.0	17.2	15.9	409	597	444	409				
P, BUS, Coach, Diesel (DERV), Euro 10 (2035-39)	15.5	22.5	16.7	15.5	399	582	433	399				
P, BUS, Coach, Diesel (DERV), Euro 11 (2040-44)	15.1	21.9	16.3	15.1	389	567	422	389				
P, BUS, Coach, Diesel (DERV), Euro 12 (2045-50)	14.7	21.4	15.9	14.7	380	553	412	380				
P, BUS, Coach, Diesel (DERV), Euro 4 (incl. catalyst), HEV	18.8	27.3	20.3	18.8	485	707	526	485				
P, BUS, Coach, Diesel (DERV), Euro 5 (2009-14), HEV	18.5	26.9	20.0	18.5	478	697	519	478				
P, BUS, Coach, Diesel (DERV), Euro 6 (2015-19), HEV	18.0	26.1	19.4	18.0	464	676	503	464				
P, BUS, Coach, Diesel (DERV), Euro 7 (2020-24), HEV	17.5	25.5	19.0	17.5	453	660	491	453				
P, BUS, Coach, Diesel (DERV), Euro 8 (2025-29), HEV	17.1	24.8	18.5	17.1	441	643	479	441				
P, BUS, Coach, Diesel (DERV), Euro 9 (2030-34), HEV	16.7	24.2	18.0	16.7	430	627	467	430				
P, BUS, Coach, Diesel (DERV), Euro 10 (2035-39), HEV	16.3	23.6	17.6	16.3	420	612	455	420				
P, BUS, Coach, Diesel (DERV), Euro 11 (2040-44), HEV	15.9	23.0	17.2	15.9	409	597	444	409				
P, BUS, Coach, Diesel (DERV), Euro 12 (2045-50), HEV	15.5	22.5	16.7	15.5	399	582	433	399				
P, BUS, Coach, Liquefied Petrol Gas, Euro 9 (2030-34)	29.2	42.4	31.6	29.2	346	505	376	346				
P, BUS, Coach, Biomethanol, Fuel Cell	25.2	25.2	25.2	25.2	277	277	277	277				
P, BUS, Coach, Biodiesel (B100), Standard 1	17.9	26.2	19.4	17.9	495	725	537	495				
P, BUS, Coach, Biodiesel (B100), Standard 2	18.5	26.9	20.0	18.5	510	744	554	510				
P, BUS, Coach, Biodiesel (B100), Standard 3	17.2	25.0	18.6	17.2	475	693	516	475				
P, BUS, Coach, Compressed Natural Gas, Standard 3	374.9	544.6	405.5	374.9	381	556	414	381				
P, BUS, Coach, Electricity, Standard 1									265.6	200.9	199.8	265.6
P, BUS, Coach, Electricity, Standard 2									255.4	193.2	192.1	255.4
P, BUS, Coach, Electricity, Standard 3									245.1	185.5	184.4	245.1
P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	54.6	54.6	54.6	54.6								
P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	51.9	51.9	51.9	51.9								
P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	49.3	49.3	49.3	49.3								
P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	46.9	46.9	46.9	46.9								
P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	44.6	44.6	44.6	44.6								
P, BUS, Coach, Gaseous Hydrogen, Fuel Cell	42.4	42.4	42.4	42.4								
F, TRUCK, Light, Gasoline (petrol), Conventional (no catalyst)	10.7	12.0	9.6	10.5	247	277	221	241				
F, TRUCK, Light, Gasoline (petrol), Euro 1 (incl. catalyst)	9.4	10.9	8.3	8.8	217	252	191	203				
F, TRUCK, Light, Gasoline (petrol), Euro 2 (incl. catalyst)	9.3	10.8	8.2	8.7	214	248	189	200				
F, TRUCK, Light, Gasoline (petrol), Euro 3 (incl. catalyst)	9.3	10.8	8.2	8.7	214	248	189	200				
F, TRUCK, Light, Gasoline (petrol), Euro 4 (incl. catalyst)	9.0	10.4	7.9	8.4	207	240	182	193				
F, TRUCK, Light, Gasoline (petrol), Euro 5 (2009-14)	8.8	10.2	7.8	8.2	203	235	179	189				
F, TRUCK, Light, Gasoline (petrol), Euro 6 (2015-19)	8.5	9.9	7.5	8.0	197	228	173	184				
F, TRUCK, Light, Gasoline (petrol), Euro 7 (2020-24)	8.3	9.6	7.3	7.8	192	222	169	179				
F, TRUCK, Light, Gasoline (petrol), Euro 8 (2025-29)	8.1	9.4	7.2	7.6	187	217	165	175				
F, TRUCK, Light, Gasoline (petrol), Euro 9 (2030-34)	7.9	9.2	7.0	7.4	183	211	161	170				

	Specific fuel consumption (litres/100km)				Direct CO2 emissions (gCO2/km)				Specific electricity consumption (kWh/100km)			
Vehicle technology description	*combi ned*	*urban*	*rural*	*motor way*	*combi ned*	*urban*	*rural*	*motor way*	*combi ned*	*urban*	*rural*	*motor way*
F, TRUCK, Light, Gasoline (petrol), Euro 10 (2035-39)	7.7	8.9	6.8	7.2	178	206	157	166				
F, TRUCK, Light, Gasoline (petrol), Euro 11 (2040-44)	7.5	8.7	6.6	7.0	174	201	153	162				
F, TRUCK, Light, Gasoline (petrol), Euro 12 (2045-50)	7.3	8.5	6.5	6.8	169	196	149	158				
F, TRUCK, Light, Diesel (DERV), Conventional (no catalyst)	8.9	9.5	7.8	9.9	231	247	203	256				
F, TRUCK, Light, Diesel (DERV), Euro 1 (incl. catalyst)	8.9	9.5	7.8	9.8	230	246	202	255				
F, TRUCK, Light, Diesel (DERV), Euro 2 (incl. catalyst)	8.6	9.2	7.5	9.5	222	238	196	247				
F, TRUCK, Light, Diesel (DERV), Euro 3 (incl. catalyst)	8.3	8.8	7.3	9.2	214	229	189	238				
F, TRUCK, Light, Diesel (DERV), Euro 4 (incl. catalyst)	8.0	8.6	7.1	8.9	209	223	184	232				
F, TRUCK, Light, Diesel (DERV), Euro 5 (2009-14)	7.9	8.4	6.9	8.8	205	219	180	227				
F, TRUCK, Light, Diesel (DERV), Euro 6 (2015-19)	7.7	8.2	6.7	8.5	199	213	175	221				
F, TRUCK, Light, Diesel (DERV), Euro 7 (2020-24)	7.5	8.0	6.6	8.3	194	207	171	215				
F, TRUCK, Light, Diesel (DERV), Euro 8 (2025-29)	7.3	7.8	6.4	8.1	189	202	166	210				
F, TRUCK, Light, Diesel (DERV), Euro 9 (2030-34)	7.1	7.6	6.3	7.9	184	197	162	205				
F, TRUCK, Light, Diesel (DERV), Euro 10 (2035-39)	6.9	7.4	6.1	7.7	180	192	158	200				
F, TRUCK, Light, Diesel (DERV), Euro 11 (2040-44)	6.8	7.2	5.9	7.5	175	188	154	195				
F, TRUCK, Light, Diesel (DERV), Euro 12 (2045-50)	6.6	7.0	5.8	7.3	171	183	150	190				
F, TRUCK, Light, Diesel (DERV), Euro 4 (incl. catalyst), HEV	4.5	4.8	4.0	5.0	117	125	103	130				
F, TRUCK, Light, Diesel (DERV), Euro 5 (2009-14), HEV	4.4	4.7	3.9	4.9	115	123	101	127				
F, TRUCK, Light, Diesel (DERV), Euro 6 (2015-19), HEV	4.3	4.6	3.8	4.8	111	119	98	124				
F, TRUCK, Light, Diesel (DERV), Euro 7 (2020-24), HEV	4.2	4.5	3.7	4.6	108	116	96	121				
F, TRUCK, Light, Diesel (DERV), Euro 8 (2025-29), HEV	4.1	4.4	3.6	4.5	106	113	93	118				
F, TRUCK, Light, Diesel (DERV), Euro 9 (2030-34), HEV	4.0	4.3	3.5	4.4	103	110	91	115				
F, TRUCK, Light, Diesel (DERV), Euro 10 (2035-39), HEV	3.9	4.1	3.4	4.3	101	108	89	112				
F, TRUCK, Light, Diesel (DERV), Euro 11 (2040-44), HEV	3.8	4.0	3.3	4.2	98	105	86	109				
F, TRUCK, Light, Diesel (DERV), Euro 12 (2045-50), HEV	3.7	3.9	3.2	4.1	96	102	84	106				
F, TRUCK, Light, Diesel (DERV), Euro 5 (2009-14), PHEV	5.8		5.4	6.8	152		140	176	42.3	42.3		
F, TRUCK, Light, Diesel (DERV), Euro 6 (2015-19), PHEV	5.7		5.2	6.6	148		136	172	41.2	41.2		
F, TRUCK, Light, Diesel (DERV), Euro 7 (2020-24), PHEV	5.5		5.1	6.4	144		132	167	40.1	40.1		
F, TRUCK, Light, Diesel (DERV), Euro 8 (2025-29), PHEV	5.4		5.0	6.3	140		129	162	39.0	39.0		
F, TRUCK, Light, Diesel (DERV), Euro 9 (2030-34), PHEV	5.2		4.8	6.1	136		125	158	37.9	37.9		
F, TRUCK, Light, Diesel (DERV), Euro 10 (2035-39), PHEV	5.2		4.8	6.1	136		125	158	37.9	37.9		
F, TRUCK, Light, Diesel (DERV), Euro 11 (2040-44), PHEV	5.1		4.7	5.9	132		121	153	36.8	36.8		
F, TRUCK, Light, Diesel (DERV), Euro 12 (2045-50), PHEV	4.9		4.5	5.7	128		118	149	35.7	35.7		
F, TRUCK, Light, Liquefied Petrol Gas, Standard 1	12.8	14.8	11.3	12.0	162	188	143	151				
F, TRUCK, Light, Liquefied Petrol Gas, Standard 2	11.8	13.6	10.4	11.0	154	178	136	143				
F, TRUCK, Light, Liquefied Petrol Gas, Standard 3	10.8	12.5	9.5	10.0	145	168	128	136				
F, TRUCK, Light, Biomethanol, Fuel Cell	19.4	22.5	17.1	18.1	207	240	182	193				
F, TRUCK, Light, Biomethanol, Fuel Cell	19.4	22.5	17.1	18.1	195	226	172	182				
F, TRUCK, Light, Biomethanol, Fuel Cell	25.1	25.1	25.1	25.1	276	276	276	276				
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 4 (incl.	9.3	10.8	8.2	8.7	227	263	200	212				

Vehicle technology description	Specific fuel consumption (litres/100km) combi ned	urban	rural	motor way	Direct CO2 emissions (gCO2/km) combi ned	urban	rural	motor way	Specific electricity consumption (kWh/100km) combi ned	urban	rural	motor way
catalyst)												
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 5 (2009-14)	9.2	10.6	8.1	8.5	223	258	197	208				
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 6 (2015-19)	8.9	10.3	7.8	8.3	216	251	191	202				
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 7 (2020-24)	8.7	10.0	7.6	8.1	211	245	186	197				
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 8 (2025-29)	8.5	9.8	7.4	7.9	206	238	181	192				
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 9 (2030-34)	8.2	9.5	7.3	7.7	201	233	177	187				
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 10 (2035-39)	8.0	9.3	7.1	7.5	196	227	173	183				
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 11 (2040-44)	7.8	9.1	6.9	7.3	191	221	168	178				
F, TRUCK, Light, Bioethanol-petrol blend (E85), Euro 12 (2045-50)	7.6	8.9	6.7	7.1	186	216	164	174				
F, TRUCK, Light, Biodiesel (B100), Euro 4 (incl. catalyst)	8.3	8.9	7.3	9.2	230	246	202	255				
F, TRUCK, Light, Biodiesel (B100), Euro 5 (2009-14)	8.1	8.7	7.1	9.0	225	241	198	250				
F, TRUCK, Light, Biodiesel (B100), Euro 6 (2015-19)	7.9	8.4	6.9	8.8	218	234	192	243				
F, TRUCK, Light, Biodiesel (B100), Euro 7 (2020-24)	7.7	8.2	6.8	8.5	213	228	188	237				
F, TRUCK, Light, Biodiesel (B100), Euro 8 (2025-29)	7.5	8.0	6.6	8.3	208	222	183	231				
F, TRUCK, Light, Biodiesel (B100), Euro 9 (2030-34)	7.3	7.8	6.4	8.1	203	217	178	225				
F, TRUCK, Light, Biodiesel (B100), Euro 10 (2035-39)	7.1	7.6	6.3	7.9	198	211	174	220				
F, TRUCK, Light, Biodiesel (B100), Euro 11 (2040-44)	6.9	7.4	6.1	7.7	193	206	170	214				
F, TRUCK, Light, Biodiesel (B100), Euro 12 (2045-50)	6.8	7.2	6.0	7.5	188	201	165	209				
F, TRUCK, Light, Compressed Natural Gas, Standard 1	83.8	97.0	73.8	78.2	136	158	120	127				
F, TRUCK, Light, Compressed Natural Gas, Standard 2	80.8	93.6	71.2	75.4	128	148	113	120				
F, TRUCK, Light, Compressed Natural Gas, Standard 3	77.5	89.7	68.3	72.3	120	139	105	112				
F, TRUCK, Light, Electricity, Standard 1									62.4	58.3	59.0	77.6
F, TRUCK, Light, Electricity, Standard 2									56.2	52.5	53.1	69.8
F, TRUCK, Light, Electricity, Standard 3									49.9	46.7	47.2	62.1
F, TRUCK, Medium, Diesel (DERV), Conventional (no catalyst)	28.6	31.8	25.1	29.4	739	821	650	761				
F, TRUCK, Medium, Diesel (DERV), Euro 1 (incl. catalyst)	28.5	31.6	25.0	29.3	736	817	648	760				
F, TRUCK, Medium, Diesel (DERV), Euro 2 (incl. catalyst)	28.0	31.2	24.7	28.9	725	805	638	749				
F, TRUCK, Medium, Diesel (DERV), Euro 3 (incl. catalyst)	27.2	30.3	24.0	28.1	704	781	620	727				
F, TRUCK, Medium, Diesel (DERV), Euro 4 (incl. catalyst)	26.3	29.3	23.2	27.1	681	755	599	703				
F, TRUCK, Medium, Diesel (DERV), Euro 5 (2009-14)	25.9	28.8	22.8	26.7	669	743	589	691				
F, TRUCK, Medium, Diesel (DERV), Euro 6 (2015-19)	25.1	27.9	22.1	25.9	650	721	572	671				
F, TRUCK, Medium, Diesel (DERV), Euro 7 (2020-24)	24.5	27.2	21.6	25.3	634	703	558	654				
F, TRUCK, Medium, Diesel (DERV), Euro 8 (2025-29)	23.9	26.6	21.0	24.6	618	686	544	638				
F, TRUCK, Medium, Diesel (DERV), Euro 9 (2030-34)	23.3	25.9	20.5	24.0	603	669	530	622				
F, TRUCK, Medium, Diesel (DERV), Euro 10 (2035-39)	22.7	25.3	20.0	23.4	588	652	517	607				
F, TRUCK, Medium, Diesel (DERV), Euro 11 (2040-44)	22.2	24.6	19.5	22.8	573	636	504	592				
F, TRUCK, Medium, Diesel (DERV), Euro 12 (2045-50)	21.6	24.0	19.0	22.3	559	620	492	577				
F, TRUCK, Medium, Diesel (DERV), Euro 5 (2009-14), HEV	15.0	16.6	13.2	15.4	387	430	341	400				
F, TRUCK, Medium, Biomethanol, Fuel Cell	45.8	45.8	45.8	45.8	502	502	502	502				
F, TRUCK, Medium, Biomethanol, Fuel Cell	43.5	43.5	43.5	43.5	477	477	477	477				

	Specific fuel consumption (litres/100km)				Direct CO2 emissions (gCO2/km)				Specific electricity consumption (kWh/100km)			
Vehicle technology description	*combined*	*urban*	*rural*	*motorway*	*combined*	*urban*	*rural*	*motorway*	*combined*	*urban*	*rural*	*motorway*
F, TRUCK, Medium, Biomethanol, Fuel Cell	41.4	41.4	41.4	41.4	454	454	454	454				
F, TRUCK, Medium, Biomethanol, Fuel Cell	39.4	39.4	39.4	39.4	431	431	431	431				
F, TRUCK, Medium, Biomethanol, Fuel Cell	37.4	37.4	37.4	37.4	410	410	410	410				
F, TRUCK, Medium, Biomethanol, Fuel Cell	35.6	35.6	35.6	35.6	390	390	390	390				
F, TRUCK, Medium, Biomethanol, Fuel Cell	33.9	33.9	33.9	33.9	371	371	371	371				
F, TRUCK, Medium, Biodiesel (B100), Euro 4 (incl. catalyst)	27.3	30.4	24.0	28.2	756	839	665	780				
F, TRUCK, Medium, Biodiesel (B100), Euro 5 (2009-14)	26.8	29.7	23.5	27.6	740	821	651	764				
F, TRUCK, Medium, Biodiesel (B100), Euro 7 (2020-24)	25.5	28.3	22.4	26.2	704	781	620	727				
F, TRUCK, Medium, Biodiesel (B100), Euro 9 (2030-34)	24.2	26.9	21.3	25.0	670	743	589	691				
F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	89.8	89.8	89.8	89.8								
F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	85.4	85.4	85.4	85.4								
F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	81.2	81.2	81.2	81.2								
F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	77.3	77.3	77.3	77.3								
F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	73.5	73.5	73.5	73.5								
F, TRUCK, Medium, Gaseous Hydrogen, Fuel Cell	69.9	69.9	69.9	69.9								
F, TRUCK, Medium, Liquefied Hydrogen, Euro 4 (incl. catalyst)	95.7	106.3	84.1	98.6								
F, TRUCK, Heavy, Diesel (DERV), Conventional (no catalyst)	41.8	48.7	36.2	39.7	1085	1262	939	1034				
F, TRUCK, Heavy, Diesel (DERV), Euro 1 (incl. catalyst)	41.6	48.4	36.1	39.6	1081	1256	937	1032				
F, TRUCK, Heavy, Diesel (DERV), Euro 2 (incl. catalyst)	41.0	47.7	35.5	39.0	1065	1238	923	1017				
F, TRUCK, Heavy, Diesel (DERV), Euro 3 (incl. catalyst)	39.8	46.3	34.5	37.9	1034	1202	896	987				
F, TRUCK, Heavy, Diesel (DERV), Euro 4 (incl. catalyst)	38.2	44.5	33.1	36.4	993	1154	860	948				
F, TRUCK, Heavy, Diesel (DERV), Euro 5 (2009-14)	37.6	43.8	32.6	35.8	976	1135	846	932				
F, TRUCK, Heavy, Diesel (DERV), Euro 6 (2015-19)	36.5	42.5	31.6	34.7	947	1101	821	905				
F, TRUCK, Heavy, Diesel (DERV), Euro 7 (2020-24)	35.6	41.4	30.8	33.8	924	1074	801	882				
F, TRUCK, Heavy, Diesel (DERV), Euro 8 (2025-29)	34.7	40.4	30.1	33.0	901	1047	781	860				
F, TRUCK, Heavy, Diesel (DERV), Euro 9 (2030-34)	33.8	39.4	29.3	32.2	879	1021	762	839				
F, TRUCK, Heavy, Diesel (DERV), Euro 10 (2035-39)	33.0	38.4	28.6	31.4	857	996	743	818				
F, TRUCK, Heavy, Diesel (DERV), Euro 11 (2040-44)	32.2	37.5	27.9	30.6	836	972	724	798				
F, TRUCK, Heavy, Diesel (DERV), Euro 12 (2045-50)	31.4	36.5	27.2	29.9	815	947	706	778				
F, TRUCK, Heavy, Diesel (DERV), Euro 5 (2009-14), HEV	22.1	25.7	19.1	21.0	574	667	497	548				
F, TRUCK, Heavy, Diesel (DERV), Euro 7 (2020-24), HEV	22.1	25.7	19.1	21.0	574	667	497	548				
F, TRUCK, Heavy, Biomethanol, Fuel Cell	66.9	66.9	66.9	66.9	735	735	735	735				
F, TRUCK, Heavy, Biomethanol, Fuel Cell	63.6	63.6	63.6	63.6	699	699	699	699				
F, TRUCK, Heavy, Biomethanol, Fuel Cell	60.5	60.5	60.5	60.5	665	665	665	665				
F, TRUCK, Heavy, Biomethanol, Fuel Cell	57.6	57.6	57.6	57.6	632	632	632	632				
F, TRUCK, Heavy, Biomethanol, Fuel Cell	54.7	54.7	54.7	54.7	601	601	601	601				
F, TRUCK, Heavy, Biomethanol, Fuel Cell	52.1	52.1	52.1	52.1	572	572	572	572				
F, TRUCK, Heavy, Biomethanol, Fuel Cell	49.5	49.5	49.5	49.5	544	544	544	544				
F, TRUCK, Heavy, Biodiesel (B100), Euro 4 (incl. catalyst)	42.0	48.8	36.4	39.9	1166	1355	1010	1113				
F, TRUCK, Heavy, Biodiesel (B100), Euro 5 (2009-14)	41.1	47.8	35.6	39.1	1141	1326	989	1090				

	Specific fuel consumption (litres/100km)				Direct CO2 emissions (gCO2/km)				Specific electricity consumption (kWh/100km)			
Vehicle technology description	*combi ned*	*urban*	*rural*	*motor way*	*combi ned*	*urban*	*rural*	*motor way*	*combi ned*	*urban*	*rural*	*motor way*
F, TRUCK, Heavy, Biodiesel (B100), Euro 7 (2020-24)	39.1	45.5	33.9	37.2	1085	1261	941	1036				
F, TRUCK, Heavy, Biodiesel (B100), Euro 9 (2030-34)	37.2	43.2	32.2	35.4	1032	1200	895	986				
F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	112.3	112.3	112.3	112.3								
F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	106.8	106.8	106.8	106.8								
F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	101.6	101.6	101.6	101.6								
F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	96.6	96.6	96.6	96.6								
F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	91.8	91.8	91.8	91.8								
F, TRUCK, Heavy, Gaseous Hydrogen, Fuel Cell	87.3	87.3	87.3	87.3								
F, TRUCK, Heavy, Liquefied Hydrogen, Euro 4 (incl. catalyst)	139.8	162.7	121.2	133.0								

Appendix C: Life Cycle and Environmental Impacts Model – further specifications

C.1 Variable definitions

This section describes the LCEIM variables in terms of input, output and internal variables of the UKTCM component models for a computation of life cycle effects and environmental impacts. The tables are structured as follows:

- input variables taken from scenarios (context variables),
- input variables taken from the user (policy variables)
- input variables taken from other UKTCM sub-models (input model variables),
- internal variables used only within the LCEIM (internal model variables),
- output variables needed by other UKTCM models (output model variables), and
- output variables.

Each table contains:

- the name and abbreviation of each variable;
- the attributes of each variable;
- the indirect dependencies of the variables (in this context, indirect dependencies describe dependencies of a variable that are not related to the variable itself but to other parameters which affect this variable – in other words these are pass-through dependencies), and;
- the interface with other components of the UKTCM.

C.1.1Life Cycle Inventory Model

Table 27: Input variables for life cycle model from exogenous scenarios

Name	*Abbrev*	*Variable Attributes*	*Indirect Dependencies*	*Interface*
Electricity generating mix	GE	S, C, Y	none	none

Table 28: Input variables for life cycle model from policy simulation module

Name	*Abbrev*	*Variable Attributes*	*Indirect Dependencies*	*Interface*
Additional infrastructure	AI	S, C, Y, M	none	user

Table 29: Input variables for life cycle model from other UKTCM models

Name	*Abbrev*	*Variable Attributes*	*Indirect Depend.*	*Interface*
Total number of vehicles	NT	S, C, Y, T	none	VSM
Number of new vehicles	NN	S, C, Y, T	none	VSM
Number of scrapped vehicles	NS	S, C, Y, T	none	VSM
Mileages	KM	S, C, Y, T	none	VSM
Quantity of fuels	QF	S, C, Y, T, F	none	VEEM
Direct emissions (except VOC)	EN	S, C, Y, T, J, E	none	VEEM
Direct VOC emissions	EV	S, C, Y, T, J	none	VEEM

Table 30: Internal variables of the life cycle inventory model

Name	*Abbrev*	*Variable Attributes*	*Indirect Depend.*	*Interface*
VOC split of direct emissions	VOC	T, J, E	S, C, Y	none
Emission factors for vehicle manufacture	ZVM	C, Y, V, W, F, E	S	none
Energy demand of vehicle manufacture	FVM	C, Y, V, W, F	S	none
Material demand for vehicle manufacture	IDM	C, Y, V, W, F, I	S	none
Vehicle maintenance frequency	RVU	C, Y, T	S	none
Number of vehicles under maintenance	NVU	S, C, Y, T	none	none
Emission factors for vehicle maintenance	ZVU	C, Y, V, W, F, E	S	none
Energy demand of vehicle maintenance	FVU	C, Y, V, W, F	S	none
Material demand for vehicle maintenance	IDU	C, Y, V, W, F, I	S	none
Emission factors for vehicle scrappage	ZVS	C, Y, V, W, F, E	S	none
Energy demand of vehicle scrappage	FVS	C, Y, V, W, F	S	none
Additional infrastructure by technology	AIT	S, C, Y, T	none	none
Emission factors for infrastructure construction	ZIC	E	S, C, Y, T	none
Energy demand of infrastructure construction	FIC	F	S, C, Y, T	none
Material demand for infrastructure construction	IDI	I	S, C, Y, T	none
Land use of infrastructure construction	LIC		S, C, Y, T	none
Life cycle emissions of material supply	EII	S, C, Y, T, E	None	none
Emission factors for material supply	ZIS	C, Y, E, I	S	none
Total material demand	IDT	S, C, Y, T, I	None	none
Energy demand of material supply	FIS	C, Y, F, I	S, T	none
Life cycle emissions of fuel/energy supply	EIF	S, C, Y, T, E	none	none
Emission factors for fuel/energy supply	ZFS	C, Y, F, E	S, T	none
Total fuel/energy demand	FDT	S, C, Y, T, F	none	none
Primary energy requirements of	PFS	C, Y, F, P	S, T	none

fuels/final energy				

Table 31: Output variables of the life cycle model required by other UKTCM sub models

Name	*Abbrev*	*Variable Attributes*	*Indirect Dependencies*	*Interface*
Direct emissions	ED	S, C, Y, T, J, E	none	EIM
Life cycle emissions	EI	S, C, Y, T, E	none	EIM
Primary energy requirements	PR	S, C, Y, T, P	none	EIM

Table 32: Key output variables of the life cycle inventory model

Name	*Abbrev*	*Variable Attributes*	*Indirect Depend.*	*Interface*
Direct emissions	ED	S, C, Y, T, J, E	none	user
Life cycle emissions	EI	S, C, Y, T, E	none	user
Total emissions	ET	S, C, Y, T, E	none	user
Primary energy requirements	PR	S, C, Y, T, P	none	user
Land use of infrastructure	LU	S, C, Y, T	none	user

C.1.2 Environmental Impact Assessment Model

There are no input variables for impact assessment taken from scenarios (context variables).

Table 33: Input variables for impact assessment from the policy module

Name	*Abbrev*	*Variable Attributes*	*Indirect Dependencies*	*Interface*
Value of Statistical Life	VL		none	user
Rate of accidents	RA	C, Y, V	none	user
Rate of fatalities	RF	C, Y, V	none	user
Rate of serious casualties	RS	C, Y, V	none	user
Rate of minor casualties	RM	C, Y, V	none	user

Table 34: Input variables for impact assessment taken from other UKTCM Models

Name	*Abbrev*	*Variable Attributes*	*Indirect Dependencies*	*Interface*
Mileages	KM	S, C, Y, T	none	VSM
„Direct" emissions	ED	S, C, Y, T, J, E	none	LCM
Life cycle emissions	EI	S, C, Y, T, E	none	LCM
Total emissions	ET	S, C, Y, T, E	none	LCM
Primary energy requirements	PR	S, C, Y, T, P	none	LCM

Table 35: Internal variables used only within the impact assessment sub model

Name	*Abbrev*	*Variable Attributes*	*Indirect Dependencies*	*Interface*
Assignment factors from demand segment types to receptor categories	AJR	C, J	S, Y, T	none
Monetary values (Building Blocks) of direct emissions	MVD	C, Y, J, E	S, T	none
Monetary values (Building Blocks) of indirect emissions	MVI	C, Y, E	S, T	none
Monetary values for accidents	MVA		S, C, Y, T	none
Monetary values for serious casualties	MVS		S, C, Y, T	none
Monetary values for minor casualties	MVM		S, C, Y, T	none
External costs of direct emissions	XED	S, C, Y, T	none	none
External costs of indirect emissions	XEI	S, C, Y, T	none	none
External costs of vehicle accidents	XVA	S, C, Y, T	none	none
Impact potentials	IPO	E, P	S, C, Y, T	none

Table 36: Key output variables of the impact assessment model

Name	*Abbrev*	*Variable Attributes*	*Indirect Dependencies*	*Interface*
Total external costs	XT	S, C, Y, T	none	user
Impact indicators	II	S, C, Y, T	none	user