Specialist Professional and Technical Services (SPaTS) Framework
Lot 1

Task 1-798
TSTR0009 Updating Marginal External Costs of Road Freight

Technical Report

December 2019

ATKINS JACOBS

Member of the SNC-Lavalin Group

Notice

This document has 136 pages including the cover.

Document history

Rev	Purpose description	Originated	Checked	Reviewed	Authorised	Date
1.0	Initial draft for the client's review	KC	MD	AD	AD	18.10.2019
2.0	Revised draft for the client's review	MD	KC	AD	AD	28.11.2019
3.0	Revised final version	MD	KC	AD	AD	02.12.2019

Table of Contents

List of tables

List of figures

Appendices tables

1 Introduction

Marginal External Costs (MECs) are primarily used to inform and optimise pricing schemes and modal change support schemes. They reflect the external costs of an additional vehicle (or vehicle kilometre) added to the transport system. In the case of MEC of road freight in the UK, they reflect the impact of an additional unit of Heavy Goods Vehicle (HGV) traffic entering the UK road network.

MECs are the key input to mode shift revenue support (MSRS) grants provided by the Department for Transport (DfT) to encourage a shift from transporting freight by road to rail or water. Based on MECs, the Mode Shift Benefit Values are calculated to determine the allocation of mode shift grants. The objective of this research project (hereinafter: the project) is to update selected MECs from HGVs, for both articulated and rigid goods vehicles. The scope of this project covers the Infrastructure, Accidents, Noise and 'Other' external costs. The MEC Other category includes:

- Up and down stream processes,
- Soil and water pollution
- Nature and landscape
- Driver frustration/stress
- Fear of accidents
- Community severance
- Visual intrusions

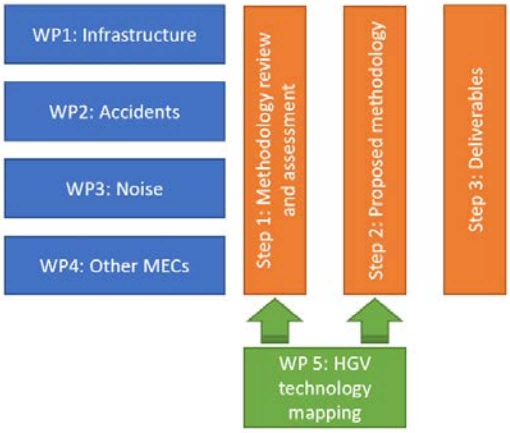


Figure 1: MECs calculation approach

The project methodology was structured around five key work packages, reflecting the MEC categories considered, and providing HGV focused technology input. The first step in the process was to conduct the MEC methodology review, highlighting the evolution of MEC methodologies and provide recommendations on the most suitable methods for MECs calculations, including the options and value added in developing new methodologies.

The next step was the development of the proposed methodology. Technical guidelines for the updated MEC methodology provide a comprehensive description of data sources, calculation procedures, indexation methods and sensitivity scenarios. In the final step, the MECs calculation model was developed as a practical implementation of the methodologies. An indexation databook, linked with the model, provides comprehensive data sets used for MECs calculations.

The scope and structure of the report is as follows:

- Sections 3 to 5 describe the methodological approaches developed for MEC Accidents, Infrastructure and Noise.
- Sections 6-8 present the methodology established for MEC Others, split into three distinct categories:
  - MEC Behaviour combines the sub-categories driver frustration/stress, fear of accidents, community severance (section 6)
  - MEC Environment covers the sub-categories soil and water pollution, nature and landscape and visual intrusions (section 7)
  - MEC Up and Downstream processes accounts for the indirect effects associated with the energy and fuel production sectors (section 8)
- Section 9 summarises the recommendations for all MEC categories.

2 General approach

2.1 Methodology selection

Over the last 20 years, numerous research projects addressed MEC calculation methodologies, including several EU funded initiatives which provided a comprehensive estimate of average and marginal external costs for all transport modes. This study was based on the review of these best practices complemented by additional subject-specific documents. The following criteria were defined to develop the MEC-specific methodologies:

- **Suitability of the methodology approach.** To estimate the marginal external costs of transport two general approaches are widely used: a bottom-up and top-down approach. The bottom-up approach calculates the impacts of an individual vehicle, which are subsequently translated to overall impacts (per vehicle category) by multiplying them by the total number of vehicles (or vehicle kilometres). The overall impacts are multiplied with relevant shadow prices to estimate the total external costs.
    - The top-down approach is used to a) benchmark the results of the bottom-up calculations, b) overcome data scarcities and lack of available impact pathways. In this approach, the starting point is to calculate the total impact of road traffic and translate it into total external costs by using relevant shadow prices. Subsequently, the total costs are allocated to different vehicle types based on appropriate weighting factors (cost drivers).
    - The bottom-up method allows to consider specific traffic, vehicle and infrastructure conditions and commonly follows the impact pathway methodology. This approach is widely recommended for pricing purposes as more precise and accurate, with a potential for better differentiation and disaggregation. On the other hand, the bottom-up approach is costly, time consuming and highly dependent on data availability and quality. In this project, feasibility of development of the bottom-up methodology was evaluated for all MECs against other criteria discussed below.
- **Data availability.** An assessment of data availability was conducted to determine which methodologies are feasible to implement within the scope of this project. Both the overarching data on HGV traffic, fleet structure and performance, and MECs-specific data sets were identified and used as the cut-off criteria to sift the methodology options.
- **Granularity and accuracy of the output values.** MEC methodologies were reviewed in the context of the granularity and accuracy of the outcomes. The fit-for-purpose approach was adopted to identify methods which provide disaggregation levels and accuracy which meets the project objectives. We made sure that the methodologies we recommend will provide outputs that are compliant with Transport Analysis Guidance (TAG) disaggregation levels and can be used in conjunction with TAG datasets.
- **Deliverability**. The methodologies which provide the best value for money and are feasible to be developed in the timeframe of the project were chosen for each MEC.

2.2 Methodology assumptions

Initially, four MEC categories were considered:

- Infrastructure,
- Accidents,
- Noise
- ‘Other’ external costs, including
    - Up and down stream processes,
    - Soil and water pollution
    - Nature and landscape
    - Driver frustration/stress
    - Fear of accidents
    - Community severance

- Visual intrusions

In the course of the project, ‘Other’ category of external costs was divided into three separate MEC types:

- Environment, which addresses environmental costs such as soil and water pollution, nature and landscape, and visual intrusion
- Behaviour, which considers driver frustration and stress, fear of accidents, and community severance
- Up and downstream processes

These three categories were subsequently considered together with Infrastructure, Accidents and Noise to develop six distinguished methodologies.

In order to ensure consistency between MEC values, two overarching assumptions were defined to guide methodology development for each MEC category.

- **Consistent disaggregation levels** were defined for all MECs, which include 2 vehicle types, 3 road types and 4 area types. Also, a differentiation between congestion free flow and congested traffic conditions were considered and included in the methodology to calculate intermediate MEC values. The disaggregation levels and their representation in TAG classification is presented in Table 1. The final MEC-N values presented in the report were aggregated across congestion levels. Intermediate MEC-N values are available in the calculation model accompanying the report.

Table 1: Disaggregation levels for MEC values

MEC disaggregation level	TAG codes
Vehicle type	
Rigid vehicles (rigids)	NA
Articulated vehicles (artics)	NA
Road type	
Motorways	Road type 1
A Roads	Road types 2-5
Other Roads	Road types 6-7
Area types	
London	Area types 1-3
Inner and Outer Conurbations	Area types 4-5
Other Urban	Area types 6-9
Rural	Area type 10
Congestion levels	
Free flow	Congestion bands 1-3
Congested	Congestion bands 4-5

- **Consistent price years** and forecast years for all MEC values were defined. The base values were calculated in 2020 prices for seven forecast years (2020, 2025, 2030, 2035, 2040, 2045, 2050). MEC values were also computed for additional combinations of price years and forecast years to provide required input for the DfT’s Mode Shift grant scheme (see Table 2).

Table 2: Price and impact year assumptions for MEC calculations

Price year	2020	2020	2025	2030	2035	2040	2045
Impact year	2020	2025	2030	2035	2040	2045	2050

3 Accidents

3.1 Introduction

Although several studies reviewing the Marginal Cost of Accidents (MEC-A) have been conducted, no new methodological approach has emerged within these studies. The external costs of accidents in TAG, and also values applied for the mode shift grants, are calculated based on marginal cost approach presented in the study by Sansom et al. (2001).

When a user of freight vehicle enters the traffic flow, they are exposed to an average accident risk. The user simultaneously exposes and affects the accident risk for all other road users. Marginal accident cost is the economic value assigned to the entrance of an additional road user. Material damage, administrative costs, medical costs production losses, pain, grief and suffering are all important ‘costs' that can be incurred from accidents. The insurance system enables road users to internalise the risk that they expose themselves to in their decision to travel. Any other cost that the road user does not internalise, forms the external cost. Therefore, the marginal external accident costs refer to the change in accident costs of other users due to the entrance of the additional road user; the external marginal accident costs also represent the remaining costs after internalisations. In essence it is the extra cost imposed by a vehicle (in this case freight) on all other road users and the general public.

Using the marginal cost approach, an additional road user raises the accident rate per vehicle kilometre for all existing transport users and the impact of additional traffic on accident risk rates is known as the risk elasticity. The other existing approach is the fully allocate cost approach, which simply takes the social cost of accidents and does not consider the way in which accident rate vary with additional traffic.

Following the review of the literature, the bottom up approach (i.e. marginal cost approach) used in the Sansom et al. (2001) study remains most appropriate method for calculating MEC-A for road freight as it provides accident costs dependent on traffic volumes. Therefore, it was agreed that the same methodology would be used for updating MEC-A. This section outlines the methodology used to update the MEC-A for road freight and can be used to accompany the model developed to calculate these values.

3.2 Current approach

The external costs of accidents in TAG, and also values applied for the mode shift grants, are calculated based on the study by Sansom et al. 2001. For this study, the Institute for Transport Studies, University of Leeds, in association with AEA Technology Environment, was appointed by the Department of the Environment, Transport and the Regions in 2000 to undertake the study of “Surface Transport Costs and Charges”.

This study looked at two distinct approaches in calculating an external cost:

1. **Marginal cost approach.** This approach calculates the social cost of an additional vehicle kilometre. This also captures how the additional traffic has an impact on accident risk.
2. **Fully allocated costs approach.** This approach seeks to calculate social costs for each vehicle class imposed by road users as a whole on the rest of society.

Following this study, the marginal cost approach was adopted to be incorporated into the guidance. The study provided high and low estimates of the marginal external accident costs per kilometre for a range of vehicle types in 1998 prices and values.

The impact of additional traffic on accident risk rates is known as the risk elasticity. The marginal cost approach uses these risk elasticities to calculate the social cost of an accident for an additional vehicle kilometre.

To calculate the marginal external cost, the risk elasticities of 0.25 in urban areas, 0.5 for inter-urban contexts were multiplied by unit cost values and risk rates to get the marginal external cost by vehicle type, road type and area type.

Casualty cost (which is one element of the unit cost values) figures were sourced from Highways Economics Note1: DETR, 1999). The economic cost of casualty was adjusted by:

- Reducing the material damages by 40% to reflect the proportion that would be covered by insurance payments.
- Adding an uplift of 40% to the casualty cost to account for the individual's willingness to pay for risk reduction. This is an estimate of the value that friends and family place on reduced risks.

As a sensitivity test, Sansom et al. used:

- Low marginal cost estimate- by omitting the value held by friends & family and using a risk elasticity equal to zero.
- High marginal cost estimate - by using a non-zero risk elasticity. The risk elasticities used for HGV (sourced from Jansson and Lindberg, 1998) were 0.25 in urban areas and 0.5 for inter-urban contexts.

Table 3 and Table 4 present the values estimated by the study.

Table 3: MEC Accidents – currently used values by road types (pence/vkm) (1998 prices)

Pence/vkm (1998 prices)	Motorway	Trunk	Other
Low estimate	0.030	0.870	1.110
High estimate	0.150	1.500	1.840
Mean	0.090	1.185	1.475

Table 4: MEC Accidents – currently used values by HGV types (pence/vkm) (1998 prices)

Pence/vkm (1998 prices)	HGV rigids	HGV artics
Low estimate	1.390	0.990
High estimate	1.960	1.400
Peak (low cost est.)	1.400	0.990
Off-Peak (low cost est.)	1.390	0.990
Outer conurbation area type peak (low cost est.)	1.680	1.680
Outer conurbation area type off-peak (low cost est.)	1.680	1.680

Sansom et al. 2001 provided values for 28 area type and road type permutations across eleven area types and three road types. The mean of the low and high values was calculated to work out the MEC-A for HGVs. These figures are uplifted to current values using GDP per capita. The applied uplift accounts for the increase in people's willingness to pay. Summary of the current approach is presented below:

- Value are underpinned by Sansom et al. 2001 study, which given the time lapse needs revisiting.
- The figures are based on 1998 data and evidence.
- Risk elasticity were based on much older study and are expected to have changed.
- The unit costs were adjusted to account for the amount covered by insurance. This amount is likely to have changed.
- There is no disaggregation of MEC-A values by Rigid and Artic type, or by region and road type. The only difference in the values is a result of the relative weights.
- Whilst the values are desegregated by road type (Motorways, A roads and Other Roads), there is no disaggregation by region between London, Inner and Conurbations and Other Urban.

3.3 Best practice methodologies review

A number of studies have been undertaken in the recent years to assess the marginal cost of accidents. As part of the literature review, the following studies were reviewed:

Table 5: MEC Accidents – best practice methodologies

List of studies reviewed	Overview	Approach & parameters used
Weinreich, et al. Discussion paper No.98-06: External Costs of Road, Rail and Air transport – a bottom-up approach.	Calculate external costs of passenger road, rail and air traffic trip direction Frankfurt - Milan	Cost allocation approach
Sansom et al. (2001). Surface Transport Costs and Charges: Final Report. For the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds, Leeds, July 2001.	External costs of accidents in TAG are based on Sansom et al.'s study. This study provides figures derived from both approaches: marginal cost and fully allocated cost	Both approaches used the risk elasticities of 0.25 in urban areas 0.5 for inter-urban contexts
Lindberg, G. (2001). External Accident Cost of Heavy Goods Vehicles. Swedish National Road and Transport Research Institute, Borlange 2001.	Provides the econometric formula for the MEC-A and step-by-step calculation of inputs and parameters based on Swedish statistics. Calculates risk elasticity and internalization rate based on vkm and vehicle weight.	Marginal cost approach Risk elasticity -0.84 calculated based on HGV distance, but used -0.8 in calculations Internalisation factor calculated 0.03-0.62 based on vehicle weight
Danish Ministry of Transport (2004). External Costs of Transport: 1st Report – Review of European Studies.	Reviews major studies that calculate MEC-A and based on them recommends a preferred methodology for updating the MEC-A for Denmark.	Marginal cost approach Recommends not to apply EU average estimates to individual countries Use risk elasticity of -0.4 even if outdated Corrects current methodology to fully reflect the recommendations of High-level Group (1999(/Nash and Sansom (1999)
Delft (2004). Marginal costs of infrastructure use – towards a simplified approach: Final report.	Summarises approaches and critically analyses points of discussion.	Analysis of discussion points Views risk elasticity as the most theoretically acceptable but uses cost allocation approach for the simplified calculation methodology
Delft (2008). Handbook on estimations of external costs in the transport sector: Produced within the study Internalization Measures and Policies for all external Cost of Transport (IMPACT) Version1.1.	Summarises approaches and critically analyses points of discussion.	Has list of marginal accident costs for different countries, per road type and based on different studies
CE-Delft; INFRAS & Fraunhofer (2011). External Cost of Transport in Europe. Update study for 2008.	Provide a handbook that can contribute to EU and national transport policy development, with differentiated reliable country specific figures (the UK is included).	Cost allocations approach (total and average costs) Output is average costs per pkm and tkm by mode Average freight transport cost of accidents is 49.7 euros/1000 tkm*a
Ricardo-AEA (for EC) (2014). Update of the Handbook on External Costs of Transport, London: Ricardo-AEA.	Provides a detailed review on current approaches and studies on MECs. Identifies input sources for calculations. Also compares MEC-A using different parameters – suggests country specific values should be calculated for risk elasticity	Marginal cost approach following same formulas as Lindberg (2001)
CE-Delft (2015). External and infrastructure costs of HGVs in the Eu28 in 2013: Update	Aims to estimate the total external and infrastructure	Cost allocation approach

List of studies reviewed	Overview	Approach & parameters used
of the total cost figures from 'Are trucks taking their toll?'	costs of HGVs in the EU28 in 2013 and compare with results from CE Delft (2009).	Presents accident costs for HGVs in the EU28 in 2013 not broken down by country
CE-Delft (2016). Infrastructure and external cost coverage of road freight transport on EU28 motorways.	Examines to what extent the infrastructure and external costs of road freight transport on EU28 motorways in 2013 are covered by revenues from taxes related to vkm on those motorways.	Uses cost allocation approach Does not provide actual costs only coverage ratios and not presented on per country basis

Several studies were selected for a detailed assessment as they underpin all the recent works and remain the most widely used approaches:

- Sansom et al. 2001 to revisit other approaches considered in the study.
- Lindberg G. 2001
- Delft 2008

3.3.1 Cost allocation approach

Sansom et al. (2001) applied a fully allocated costs approach to quantify the external cost of accident. This approach calculated the social costs of an accident for each vehicle class imposed by road users on the rest of society. It covers the overall costs attributed to user groups on the basis of responsibilities of the accident. The approach involved calculating the accident rates per vehicle kilometre based on Road Accident Statistics, Great Britain (DETR, 1999)

The unit cost value comprises of the external component of net material costs plus the values held by friends and family. For accidents that involved more than one vehicle, it was assumed that the responsibility was equally shared between parties involved in the accident. For accidents where a vulnerable road user (i.e. pedestrians and cyclists) was involved, no costs were allocated to the vulnerable road users.

3.3.2 Marginal cost approach

Lindberg 2001 follows a similar bottom-up approach as Sansom et al. (2001) by capturing the impact of additional traffic on accident risk rates. When an additional vehicle joins the traffic, the driver exposes himself/herself to the average accident risk, the historical value of which can be assessed by relating the number of accidents involving a given vehicle class to the traffic flow. Furthermore, an additional vehicle may change the accident risk of the other transport users. This effect is captured by the risk elasticity, for which various econometric estimates exist.

The MEC-A is calculated by including the risk elasticity multiplied by accident costs elements and the accident risk. The formulaic representation of this is shown below:

$$MC_i^v = r_i^v (a + b + c)(1 + E_i^v) - \theta^v r_i^v (a + b)$$

$$r_i^v = \frac{x_i^v}{Q_i^v}$$

$$E_i^v = \frac{\partial r_i^v}{\partial Q_i^v} \frac{Q_i^v}{r_i^v}$$

r=risk

v=vehicle type

i=road type

X=personal damage cases

Q= vehicle km

E= risk elasticity quantifying how much 1% increase in traffic increases the accident risk in %

Θ= share of accident costs that is internal

(a+b+c)= average accident costs

The average cost of accident comprises of:

- Expected cost of death and injury due to an accident for the person exposed to risk. This is based on Willingness to Pay for safety which is estimated in the Value for Statistical Life (VSL) (a)
- Expected cost for the relatives and friends of the person exposed to risks (based on the VSL) (b)
- Accident cost for the rest of society (output loss, material costs, police and medical costs) (c) – around 10% of VSL

3.3.3 Comparative assessment approaches

Delft (2008) provides a detailed literature review of the studies that have looked at external accident costs.

In light of the amending Directive 1999/62/EC on charging heavy duty vehicles for the use of infrastructure, the Delft (2008) study aims to provide comprehensive overview of approaches for estimation and internalisation of external costs.

The two overarching approaches (as summarised in Figure 2 and Figure 3) are:

1. Bottom-up approach (marginal cost approach)
2. Top-down (cost allocation approach)

The study showed that the bottom-up approach leads to lower values than top-down as only part of the total accident costs is considered. Additionally, the values of marginal external costs resulting from both, top down and the bottom up approaches are sensitive to values of internalisation. Delft (2008) states "that if the focus is on infrastructure pricing, the marginal cost approach based on bottom-up approach is in the foreground" (like UNITE, 2000; GRACE 2006). Meaning that it is theoretically preferred. But if the focus is on types of accident externalities, the top down approach is more appropriate. Figure 2 and Figure 3 summarises the top down and bottom up approaches.

Figure 2: MEC Accidents - bottom-up approach

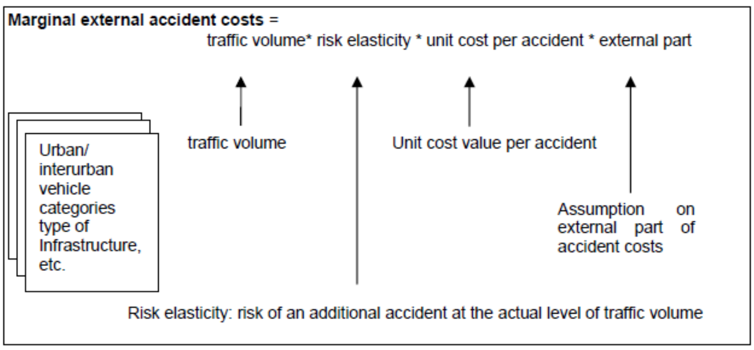
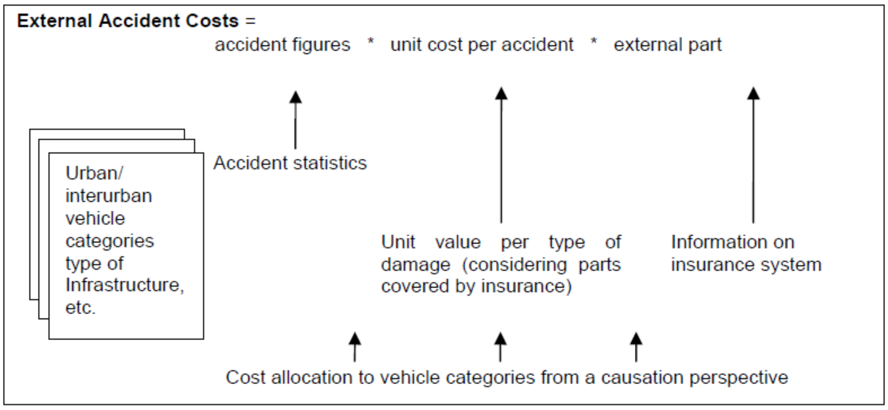


Figure 3: MEC Accidents - top-down approach



Although this study suggests the marginal approach is theoretically preferable, it uses a cost allocation approach for the simplified calculation methodology. This study outlines the following steps for a cost allocation approach:

1. Determine the valuation of traffic fatalities and injuries. Apply costs to casualties to get the total cost of accidents (based on VSL).
2. Collection of statistics on causers of accidents by vehicle type. If no information is available, one could use a benchmark figure of 25% of the accidents are caused by HGVs.
3. Valuation of fatalities and injuries per vkm.
4. Collection of statistics on victims of road accidents (e.g. gender, age, location, driver, passenger, pedestrian other, etc).
5. Determination of 'correctional factors' for specific cost drivers. In other words, the contribution of a specific cost driver to the total. Using correctional factors, average costs can be specified to different cost drivers.

Table below presents the marginal external cost for Accidents estimated by various studies:

Table 6: MEC Accidents – values used in the key studies reviewed

Study	Urban	Motorways	Other non-urban roads	Units
Sansom et al. (2001)	0.090	1.185	1.475	Marginal costs for External accident costs (pence/vkm) (1998 prices). Mean values and Irrespective of vehicle type
2014 Handbook (Ricardo-AEA for EC)	0.3	0.9	0.5	Marginal accident costs for HGV per road type €ct/vkm (2010)
Delft 2008	6.64	0.19	1.68	Marginal accident costs for HGV per road type €ct/vkm (2000)
MIRA (2010), Table 136, Flanders	3.85	1.44	4.53	Marginal accident costs for HGV per road type €ct/vkm (2010) Also present in 2014 Handbook (Table 11)

3.4 Methodology selection

Following the review of the literature, number of approaches have been identified and evaluated to select the most appropriate methodology for MEC-A calculations.

Table 7: MEC Accidents – methodology options

Approach	Scope	Advantages	Disadvantages	Data requirements
Update values using existing approach	In scope	Improvement on existing values, easiest of all options	Most risk elasticities from the studies are older than 5 years.	Updated accident rate Updated value of Statistical life Elasticities from a more recent study (2014 Handbook) Internalisation rate from a more recent study
Update values using existing approach with Risk elasticities Re-estimated (Recommended)	Out of Scope	Improvement on existing values, captures the most recent trends in accidents	Time and data intensive. Introduce additional level of modelling	Requires re-estimation of risk elasticities.
Update values using existing approach with Risk elasticities and internalisation re-estimated	Out of Scope	Improvement on existing values, captures the most recent trends in accidents and the cost incurred by the individual and insurers better accounted.	Time and data intensive. Introduce additional level of modelling	
Use cost allocation	Out of scope	Application is easier and data availability is better. Can take into account other cost drivers (e.g. driver/victim age and gender)	Cost allocation based on responsibility requires data which is usually not available.	Accident costs considering national accident statistics and insurance systems Total vehicle km

Following the review of the various methodologies, it was concluded that:

1. The bottom up approach used in the Sansom et al. remains more appropriate as it provides accident costs dependent on traffic volumes
2. The risk elasticities used by Sansom, whilst not largely changed as shown in the 2014 Handbook, require re-estimation based on the latest UK based traffic and accident data.
3. The level of internalisation used in the Sansom et al 2001 study needs updating to reflect the changes observed in the latest insurance system.
4. It is prudent to update to the average cost of the accident to use the latest estimates from Value of Statistical life (VSL).
5. The data required to deliver the recommended methodology are available and consist of:
    a. Historic and forecast of traffic volume and composition data (vehicle km per vehicle type and road type) (Source: RAS20003, RAS20006, RAS20007 and NTM)
    b. Accident and causality figures caused by HGVs and involving HGVs (Source: RAS30019, RAS20003, RAS20006, RAS20007)
    c. Updated risk elasticity: traffic volume and accident frequency from literature
    d. Updated internalization percentage from literature
    e. Cost of accident (TAG A4.1.3)
    f. Insurance compensation paid per accident.

3.5 Adopted methodology outline

Following a comprehensive review of all the studies and the methodologies as highlighted above, Marginal External Cost-Accident (MEC-A) for this study was calculated by taking the risk elasticity multiplied by accident costs and the accident risk rate. The formulaic representation of this is shown below:

$$MC_i^v = r_i^v(a + b + c)(1 + E_i^v) - \theta^v \, r_i^v(a + b) \quad (1)$$

$$r_i^v = \frac{x_i^v}{Q_i^v} \quad (2)$$

$$E_i^v = \frac{\partial r_i^v}{\partial Q_i^v}\frac{Q_i^v}{r_i^v} \quad (3)$$

The model parameters are discussed in the following section.

3.6 Data specification

Specification of data used is summarized in the table below:

Table 8: MEC Accidents – Parameter estimates used in the model

Variable / factor	Name	Description / Value	Source
a+b	*a is the expected cost of death and injury due to an accident for the person exposed to risk per severity type;* *b is the expected cost for the relatives and friends of the person exposed to risks*	Based on Willingness to Pay for safety which is estimated in the Value for Statistical Life (VSL)	2018 Data Book Unit A 4.1.4 May 2019 Data Book A4.1.1
c	*Accident cost for the rest of society*	Accident related costs	2018 Data Book Unit A 3.1.4 May 2019 Data Book A4.1.3
v	*Vehicle type*	HGV	N/A
r	*Risk of accidents*	Number of casualties (only for accidents where HGVs were involved) per HGV vehicle kilometer. Calculated per severity type, road type and area type.	Number of casualties obtained from Road Safety Data and vehicle kilometer from NTM for 2015
X	*Casualties*	Casualties in accidents where HGVs were involved	Road Safety Data 2015
Q	*Vehicle km*	Per road type and Area for Rigids and Artics	NTM 2015
i	*Road type*	Motorways, Urban and Rural	
θ	*Share of accident costs that is internal*	0.25	Link et al. 2017
E	*Risk elasticity*	0.25	2014 Handbook (Ricardo-AEA for EC)

3.7 Model assumptions

This section discuses key assumptions relating to the calculations for each of the component included in MEC-A:

- Risk elasticity
- Cost allocation of casualties
- Internalisation and insurance deductions
- Costs to society
- Rigid and Artic split

3.7.1 Risk elasticity

The impact of additional traffic on accident risk rates is known as the risk elasticity. Sansom et al (2001). used a risk elasticity of 0.25 for HGV in urban areas and 0.50 for inter-urban contexts and 0 for a low-cost sensitivity estimate. The original source of these elasticity is from Jansson and Lindberg (1998).

Estimating the risk elasticity is often a big challenge due to data requirements. The risk elasticity strongly influences the marginal cost estimates. A number of studies suggest different values for risk elasticity, some are based on road types, vehicle type and time of the day, while others are irrespective of such categories. The 2014 European Commission Handbook (Ricardo-AEA for European Commission) recommends a conservative risk elasticity of 0.25 should be used as the findings of other researchers are based in different countries and cannot be generalised to the UK.

As part of the recommendations provided to DfT, an update to risk elasticity was recommended. However, given the relative weighting of MEC-A compared to other MECs it was deemed proportionate to not update the elasticity. Therefore, this study uses a conservative risk elasticity estimate of 0.25 irrespective of the vehicle or road type and it is assumed to remain fixed throughout all the modelled years.

Furthermore, it is assumed that the risk rate to remain constant overtime. This is because the although the vehicle kilometer from NTM traffic is easily to updated, the relationship between accident and traffic volume for future years is hard to predict with certainty. Therefore, for the central case scenario, it was proportionate to assume a fixed risk rate of accidents over time.

To account for improvement in road safety overtime, further sensitivity tests have been conducted to assess the impact of changing the risk rate on marginal external costs for accidents.

3.7.2 Cost allocation of casualties

The disaggregation of the total accident cost between HGV and other road users is an important consideration. As set out in Sansom et al.'s approach "When an additional road user raises the accident rate per vehicle kilometre for all existing transport users, the full value per accident is relevant because this additional risk is external to the additional road user. The full value is also applicable when the costs are imposed on vulnerable road users" (Sansom et al.,2001, p39). What this means is that all costs of accidents where an HGV was involved are allocated fully to HGVs.

3.7.3 Internalisation and insurance deductions

The level of external costs does not only depend on the level of accidents, but also on the insurance system (which determines the share of internal costs). An element of the costs of road accidents is internalised through the process of insurance, assessed through the claims made by accident victims against drivers at fault. However, not all accident costs are covered by insurance. Therefore, in theory the external cost of road accidents is the difference between the total cost of all such accidents and the payment by road users for accident related insurance. But in practice no information exists and the payments made by insurance companies bare no relationship with the willingness to pay based values of statistical life or injury.

Link et al. (2007) derive the estimates for internal cost shares (fatalities only) from the CARE database (data from 2002-2003). The average values are: 0.73 for cars, 0.25 for HGVs and LDVs together, and 0.18 for buses. In the absence of better information, we use 0.25 for the level of internalisation to net them off against accident costs.

3.7.4 Costs to society

Certain elements of accident costs are met by the public sector or other transport users and are not covered by insurance costs. These include police and ambulance costs, hospital costs, output loss and delays to other transport users. For this study, accident related costs (including police costs, damage to property and Insurance & admin) from the Data Book 4.1.3 have been used for this update.

3.7.5 Rigid and Artic split

The values for MEC-A calculated by Sansom et al. and subsequently the current presented in the Data Book are not disaggregated by HGV type. A weighted average value is produced at the end based on vehicle kilometre.

3.7.6 Other assumptions

The following additional assumptions have been made for the calculations:

- For the base year 2015, NTM 2015 kilometre and Road Safety Data 2015 (for number of casualties) were used,
- For forecast years, GDP per capita growth was applied

3.8 Calculation procedures

The following steps were taken to calculate MEC-A of road freight per road and area type:

1. Calculate the HGV vehicle kilometers per road type and area type based on DfT's NTM 2015 data
2. Calculate the casualties resulting from an accident where an HGV was involved based on DfT's Road Safety data 2015.
3. Disaggregate the casualty data by road and area type (this was done by mapping the accident locations to GIS onto LSOA and DI area classifications and road type).
4. Calculate the risk rates (casualties/vkm) per casualty severity, area type and road type based on steps 1 and 3.
5. Calculate the MEC-A using the formula above for each road type and area type and divide it per 100 to get pence per vkm.
6. Inflate the costs to 2020 prices using the GDP deflator.
7. Forecast future year values by multiplying the results by GDP per capita growth between the forecast year and base year.

3.9 MEC Accident values

The results for the different road types and area types in 2020 price year are presented in Table 9.

Table 9: MEC Accidents – values in pence/vkm, Artics, Rigids 2020 prices, base scenario

	Artics							Rigids						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inner and Outer Conurbations														
Motorways	0.49	0.51	0.55	0.60	0.66	0.72	0.79	0.49	0.51	0.55	0.60	0.66	0.72	0.79
A Roads	2.13	2.24	2.42	2.62	2.87	3.16	3.47	2.13	2.24	2.42	2.62	2.87	3.16	3.47
Other Roads	4.05	4.26	4.59	4.99	5.45	6.00	6.58	4.05	4.26	4.59	4.99	5.45	6.00	6.58
London														
Motorways	0.55	0.58	0.63	0.68	0.74	0.82	0.90	0.55	0.58	0.63	0.68	0.74	0.82	0.90
A Roads	4.44	4.67	5.03	5.46	5.97	6.57	7.21	4.44	4.67	5.03	5.46	5.97	6.57	7.21
Other Roads	9.86	10.37	11.18	12.13	13.26	14.59	16.02	9.86	10.37	11.18	12.13	13.26	14.59	16.02
Other Urban														
A Roads	3.17	3.33	3.59	3.90	4.26	4.69	5.15	3.17	3.33	3.59	3.90	4.26	4.69	5.15
Other Roads	5.05	5.31	5.73	6.21	6.79	7.47	8.21	5.05	5.31	5.73	6.21	6.79	7.47	8.21
Rural														
Motorways	0.46	0.48	0.52	0.56	0.61	0.68	0.74	0.46	0.48	0.52	0.56	0.61	0.68	0.74
A Roads	2.09	2.20	2.37	2.57	2.81	3.09	3.39	2.09	2.20	2.37	2.57	2.81	3.09	3.39
Other Roads	2.71	2.85	3.07	3.33	3.64	4.01	4.40	2.71	2.85	3.07	3.33	3.64	4.01	4.40

The freight MEC-A values for different road and area types for 2025 calculated using the updated marginal cost approach is presented on Figure 4 (2025 impacts) and in Table 9. In general, 'Motorways' have the lowest marginal external cost, followed by 'A Roads' and 'Other Roads'. The lowest and highest MEC-A value was identified for 'Motorways' in Rural areas and 'Other Roads' in London, respectively. There is no available data to differentiate between impacts of artics and rigids, so they were analysed as one category.

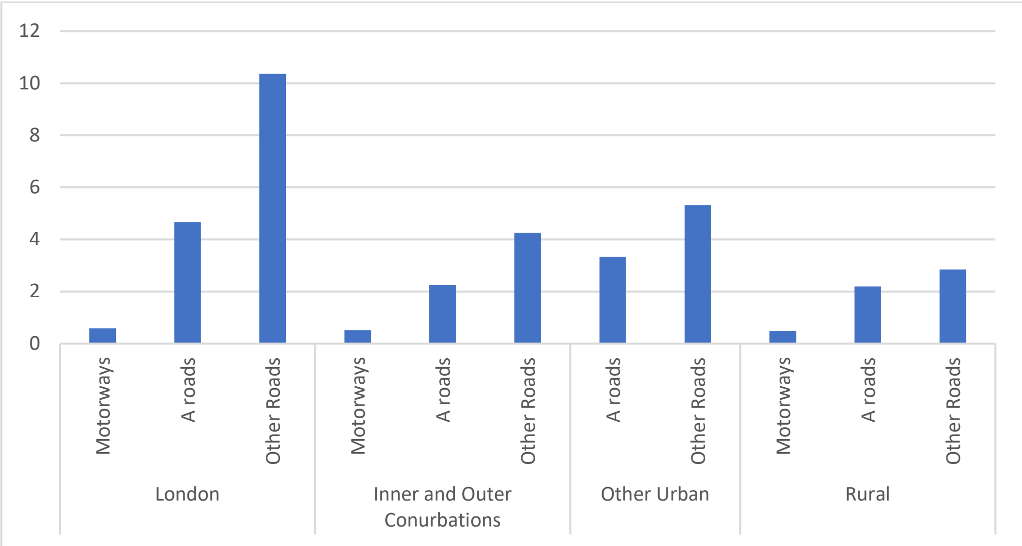


Figure 4: MEC-A values, pence per vkm, 2025 impact, 2020 prices, rigid and articulated HGVs

MEC-A values calculated using the updated methodology tend to be lower than values computed based on the previous method, both for rigid and articulated HGVs (see Figure 5). This is because HGV traffic volumes, in general, have not increased significantly in last 20 years, except for 'Motorways', and the casualty rate, for which HGVs are involved in personal injuries, reduced by 52.6% between 2000 and 2017. The only significant increase of MEC-A values was observed for Other roads in London area, where the new values are more than 100% higher than the previous ones.

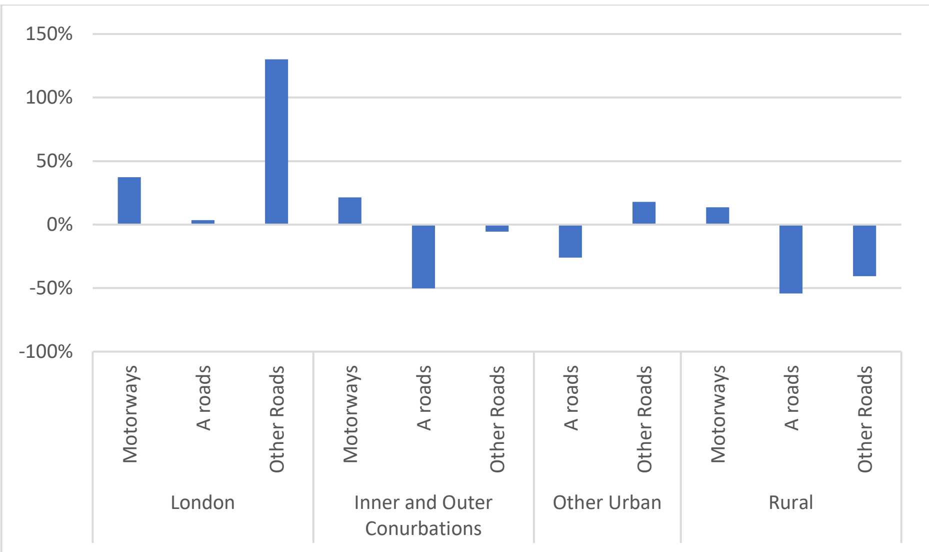


Figure 5: Difference between the MEC-A values computed using the new and the previous methodology, rigid and articulated HGVs, 2025 impact, 2020 prices, previous values = 100%

3.10 Sensitivity scenarios

There is limited historic data for road traffic accidents where HGVs were involved. Therefore DfT's data on vehicles involved in reported personal injury road accident by vehicle type was used to depict the accidents trend.

From 1999 to 2015, the reduction in proportion of accidents where HGVs were involved dropped by 5% annually. It is likely that the number of road accidents will reduce between 2015, which is our model's base year, and 2020, due to vehicle technology development and legislation, among other road safety improvements. For HGVs in specific, the following developments are expected to reduce road accidents:

- Lane Departure Warning System (LDW) - In 2015 the EU mandated the installation of LDW on all commercial heavy vehicles. Given the typical HGV life it is expected that by 2024 most HGVs will have LDW. Based on Germany published research a 70% market penetration rate of LDW systems would reduce crashes by 2.9%.
- Automatic Emergency Breaking (AEB) – Also in 2015 the EU legislation has mandated AEB systems on newly registered HGVs. Independent safety bodies have estimated that AEB have led to a 38% reduction in rear-end crashes.

For future years the following developments are expected to reduce HGV related road accidents:

- Advanced Driver Drowsiness Detection Systems - Advanced DDD systems such as the Denson facial detection system are currently in trial phase and likely to be commercially available in the mid-2020s.
- TfL Direct Vision Standard and Safety Permit for HGVs - Forms part of the Mayor and TfL's Vision Zero approach to eliminating all deaths and serious injuries from London's roads by 2041.
- The development of increasingly connected and autonomous vehicles (CAVs).

For our 'Base Scenario' we assume no additional reductions will occur between 2015 and 2020. Based on historical trends and considerations of the technologies and legislations for between years 2015 to 2020 we estimate a 25% reduction of accidents as our 'Medium Scenario'. This is viewed as a scenario with a moderate safety improvement. For a 'High Scenario', we assume an ambitious further improvement of 5% every five years, resulting in an overall 25% improvement in accident rates between 2025 and 2050

3.10.1 Medium scenario

Table 10 presents the MEC-Accidents values for the Medium Scenario.

Table 10: MEC Accidents – Medium Scenario pence/vkm,2020 prices (Rigids & Artics)

	London			Inner and Outer Conurbations			Other Urban		Rural		
	Motorways	**A Roads**	**Other Roads**	**Motorways**	**A Roads**	**Other Roads**	**A Roads**	**Other Roads**	**Motorways**	**A Roads**	**Other Roads**
2020	0.414	3.330	7.397	0.366	1.600	3.040	2.379	3.789	0.342	1.568	2.031
2025	0.435	3.501	7.776	0.384	1.683	3.196	2.501	3.984	0.360	1.648	2.135
2030	0.469	3.774	8.383	0.414	1.814	3.446	2.696	4.294	0.388	1.776	2.302
2035	0.509	4.096	9.099	0.450	1.969	3.740	2.926	4.661	0.421	1.928	2.498
2040	0.557	4.477	9.945	0.492	2.152	4.088	3.198	5.094	0.460	2.107	2.731
2045	0.612	4.927	10.943	0.541	2.368	4.498	3.519	5.606	0.506	2.319	3.005
2050	0.672	5.409	12.014	0.594	2.599	4.938	3.864	6.154	0.556	2.546	3.299

3.10.2 High scenario

Table 11 presents the MEC-Accidents values for the High Scenario.

Table 11: MEC Accidents – High Scenario pence/vkm,2020 prices (Rigids & Artics)

	London			Inner and Outer Conurbations			Other Urban		Rural		
	Motorways	A Roads	Other Roads	Motorways	A Roads	Motorways	A Roads	Other Roads	Motorways	A Roads	Motorways
2020	0.414	3.330	7.397	0.366	1.600	3.040	2.379	3.789	0.342	1.568	2.031
2025	0.326	2.626	5.832	0.288	1.262	2.397	1.876	2.988	0.270	1.236	1.601
2030	0.352	2.831	6.287	0.311	1.360	2.584	2.022	3.221	0.291	1.332	1.726
2035	0.382	3.072	6.824	0.337	1.476	2.805	2.195	3.496	0.316	1.446	1.874
2040	0.417	3.358	7.458	0.369	1.614	3.066	2.399	3.821	0.345	1.581	2.048
2045	0.459	3.695	8.208	0.406	1.776	3.374	2.639	4.204	0.380	1.739	2.254
2050	0.504	4.057	9.010	0.445	1.950	3.704	2.898	4.616	0.417	1.909	2.474

3.11 Indexation and updates

Currently, in developing the ‘Base Scenario’ for MEC-A’s, the forecast for future year values are calculated by multiplying the base year results by GDP per capita growth between the forecast year and base year. It is important to note, the use of NTM traffic volume was viewed unsuitable in estimating future MEC-A values. This is because without updating the accident numbers, the risk rate would reduce over time with increasing traffic volume and therefore the MEC-A values would be undervalued.

For the ‘Medium Scenario’ a reduction of 25% in accident numbers is applied to 2015 values. For the ‘High Scenario’, a 5% annual reduction in accident numbers is applied from 2015 onwards. In addition, the forecasts for future years for both sensitivity scenarios includes the growth of GDP per capita. This is consistent with the base scenario.

For any future updates to the MEC-A’s values, it is recommended that the most recent traffic volume, accident and economic data are incorporated. The table below (Table 12) reports the key parameters that will need updating and the recommended frequency of updates. The update intervals are meant only as a guide and in light of new research, for instance on internalisation and risk elasticity parameters, the MEC-A values should also be updated to incorporate findings from any major new research.

Table 12: MEC Accidents – model parameters and updating intervals

Parameter	Recommended update frequency
Traffic volumes	Should be updated every 5 years based on the NTM.
Number of accidents	Should be updated every 5 years based on Road Safety Data.
Value of Statistical life	Should be updated every 5 years based on TAG.
GDP per Capita	Should be updated every 5 years based on TAG.

3.12 Limitations and recommendations

The analysis represented in this report updates the methodology used by Sansom et al. (2001). It is important to note that the results are very sensitive to the values of accident risk, risk elasticity and degree of internalisation.

Future research opportunities for more robust results were identified and are listed below.

- Re-estimating the risk elasticity. The risk elasticities used by Sansom et al. were sourced from the European PETS project (Jansson and Lindberg, 1998), whist it has not largely changed as shown in the 2014 Handbook, it requires re-estimation based on the latest UK based traffic and accident data.

- The level of internalisation used in the Sansom et al. (2001) study needs updating to reflect the changes observed in the latest insurance system.
- Disaggregate accident data by artics and rigids and congestion band.

4 Infrastructure

4.1 Introduction

Firstly, this section provides an organised review of MEC-Infrastructure (MEC-I) methodologies used in the UK and worldwide, highlighting the evolution of approaches and summarizing the objectives served by each approach. Following the review, the development of the proposed methodology is presented complemented by technical guidelines for the updated MEC-Infrastructure methodology that provide a comprehensive description of data sources, calculation procedures, indexation methods and sensitivity scenarios.

The first sections provide the Department with an assessment of the MEC-I methodologies in the context of MSRS (Mode Shift Revenue Support) objectives and recommends the most suitable methods for MEC calculation.

MECs are intended to provide a simple, proportionate means of capturing these impacts. Incorporating them with the private cost of freight transport presents a truer total cost of transporting freight by road.

MEC-Infrastructure costs relate to direct expenditure for renewal of sections of the road network, routine maintenance of road infrastructure and road operations. They also include the financing cost of capital investment.

The infrastructure costs can be allocated into either fixed or variable costs:

1. **Fixed costs** refer to costs that are constant with regardless of traffic volume or relate to additional investment which enhances the functionality or lifetime of the asset over and above the investment required to maintain the asset. Examples of fixed costs are road upgrade and road widening schemes.
2. **Variable costs** refer to costs that vary with traffic volumes. Examples of variable costs are maintenance and operational costs – note that some elements of these costs are considered fixed and do not vary with traffic volumes.

Variable road maintenance costs are typically used as a proxy to calculate the Marginal External Infrastructure Costs (MEC-I). This is based on the assumption that road maintenance costs in a given year provide a reasonable indication of the damage to roads caused by vehicles, such as HGVs, using the roads in that year. Periodic renewal expenditure is not typically included as it is considered to be a proxy for depreciation of the asset over time, which may not be influenced by variation in road traffic volume.

A key issue in literature reviewed is the definition of which cost categories can be considered variable and which are fixed, as well as the percentages of fixed to variable (Sansom et al 2001, Delft 2016). There is significant variation across the various MEC-I studies. The accuracy of category allocation is normally dependent on the level of disaggregation of cost data – some fixed cost categories may be included as variable costs due to absence of detail. This has an overall impact on the marginal cost, as the inclusion of fixed costs such as capacity enhancements will falsely increase the resulting marginal cost.

Variable costs can be overestimated if maintenance expenditure is included that is not due to traffic volumes, for example weather degradation of road surface. Variable costs can also be underestimated if annual road maintenance expenditure is significantly below required levels to maintain functionality of the asset.

4.1.1 Current approach

The current MEC-I values presented in the Data Book use values estimated in the study ‘Surface Transport Costs and Charges: Great Britain 1998’ by Sansom et al. This study gave MEC-I values by vehicle-type, road-type and area-type using data collected in 1998.

The current methodology uses a top down cost allocation approach to assign specific variable costs to one of four cost drivers.

1. Passenger Car Unit (PCU) km
2. Average gross vehicle weight-km
3. Maximum gross vehicle weight km
4. Standard axle-km

Only a subset of infrastructure costs can be attributed to traffic volume and therefore were selected for inclusion in the marginal cost analysis. Maximum gross vehicle weight km was not used for any of the cost categories.

The specific allocations and the variable cost items considered in scope for the marginal cost analysis are presented in the following table (Table 13). The items marked in italics were not included in the marginal cost analysis used to derive the MEC-I values.

Table 13: MEC Infrastructure - variable cost items considered in scope for the marginal cost analysis

	PCU km	Average gwt km	Standard axle km	Included in MC
Long-life pavements			100%	Yes
Resurfacing			100%	Yes
Overlay			100%	Yes
Surface dressing	20%	80%		Yes
Patching and minor repairs		20%	80%	Yes
Drainage	100%			Yes
Road markings	10%	90%		Yes
Bridges and remedial earthworks				*No*
Footways, cycle tracks & kerbs				*No*
Fences and barriers				*No*
Verges, traffic signs and crossings				*No*
Sweeping and cleaning				*No*
Winter maintenance & misc.				*No*
Street lighting				*No*
Policing and traffic wardens				*No*

The cost allocation approach follows the standard methodology at the time of publishing the report, which was in 2001. The report allocates percentages to different costs categories by road category based on previous econometric studies or engineering judgement.

The methodological approach, using these costings, to estimating the MEC-I values in Sansom (2001) is summarised as follows.

1. Costs for 7 variable expenditure categories and 4 road types were estimated for 1998 (the latest available data for 2001 study).
2. The relationship with cost drivers were determined for each of the expenditure categories.
3. Road maintenance cost categories were allocated to cost drivers as per the table above.
4. The cost drivers for each vehicle category (most of which relate to heavy goods vehicles, but also including cars, PSVs) were estimated for the 4 road types.
5. Costs were then allocated to the 37 vehicle types by 4 road types.
6. The final infrastructure cost outputs, for the 5 vehicle types and 3 road types were then created by

weighting the disaggregate vehicle/road types according to relative vehicle km.

It was viewed by the authors that renewals expenditure had not been insufficient to maintain the quality of the overall road network in previous years, To account for this, renewals expenditure was adopted as a proxy for depreciation. as a lower bound. On the basis of the author's judgement, an upper bound was estimated by increasing infrastructure costs by 30% across all road types and expenditure categories[1].

MEC-I values in the Data Book have been adjusted from original study values by applying:

1. GDP deflator indexation to inflate values to 2010 prices
2. Indexation to produce annual values in real terms using the GDP per capita index series which reflects increases in individuals' willingness to pay over time.

The MEC-I 2010 values in the current Data Book (Dec 2018) are presented on Table 14 and Table 15.

Table 14: MEC Infrastructure for rigid HGVs, 2010

Pence per vehicle km, 2010 prices	Motorways	A Roads	Other Roads
London	0.9	4.8	20.1
Inner and Outer Conurbations	0.9	3.6	20.1
Other Urban	N/A	3.5	20.1
Rural	0.9	3.0	20.1

Table 15: MEC Infrastructure for articulated HGVs, 2010

Pence per vehicle km, 2010 prices	Motorways	A Roads	Other Roads
London	3.6	16.8	82.8
Inner and Outer Conurbations	3.6	12.7	82.8
Other Urban	N/A	12.5	82.8
Rural	3.6	10.9	82.8

All Costs in the table are presented in Market Prices. Costs are converted to the specified price base by multiplying by the GDP per capita index value in the price year and dividing by the GDP deflator per capita index value for the source year.

As can be observed in MEC-I values, the MEC values for Motorways and Other Roads do not vary across geographies. This limited geographical disaggregation of MEC values was identified as a limitation of the study and an area for further research.

4.2 Best practice methodologies review

This section of the report explores the main issues facing the calculation of the MEC-I, and the different approaches that have been taken around Europe, namely Sweden, Austria, Germany and Norway to estimate MEC-I.

As found by the AASHO Road Test in 1961, HGVs cause significantly more damage to the road surface than a standard passenger car. It was observed that the damage of the road increases by the fourth

[1] It should be noted that most of the reviewed academic studies, carried out since 2001, have considered maintenance costs only, with only a small number of studies taking renewal costs into account

power of the weight added to the axle, for example doubling the weight on the axle increases damage to the road surface by 16 times. This has led to increased interest around Europe where toll roads are common place and users pay towards the impact of driving on the road network.

There are two main approaches to determining the costs of an additional vehicle on the road, which are the marginal cost, and the average cost.

- The **Marginal Cost Methodology (MCM)** aims to calculate the cost of one extra vehicle on the road by determining the impact of that specific vehicle for a kilometre of road.
- The **Average Cost Methodology (ACM)** divides the total costs (which is maintenance costs for road infrastructure) for a specific mode of transport, in a defined area, by the total vehicle mileage. This does not account for the site-specific traits, for example being a heavily or sparsely congested road, weather conditions or the topography of the road (as road on an incline could be expected to be damaged more quickly than flat roads).

Within the Marginal Cost Methodology, the three main approaches are used:

- **Econometric approach.** The total cost is defined as the dependent variable which is to be explained by the independent variables (such as traffic volume and location-specific characteristics such as topography). The approach requires the construction of a total cost function, using econometric regression analysis on a traffic volume variable which represents the marginal infrastructure cost with respect to traffic volume. This requires very detailed information about the road network and all of the maintenance costs for each specific section of the road network. All vehicles on the road can either be reclassified as standard axle weights, or passenger car equivalents. This provides a total flow of weight for one measure of vehicle, which can then be increased to represent an HGV, or a passenger car as needed.
- **Engineering approach.** The engineering approach assumes that road renewal spend – which from the engineering point of view are necessary – is incurred where in practice underinvestment may occur. This approach looks at the life cycle of the road and uses case studies to predict when the assets will require maintenance and how much. This approach requires cross-sectional, annual measurements of road conditions for a time horizon long enough to create a renewals cycle. This makes the data requirements quite high, as you need a long history of road conditions. A limitation of this approach is that renewals in real life (with budget restraints) may not actually occur. Link (2006) finds that the engineering approach produces higher marginal costs, because the econometric analysis covers only observed costs over a historic data set whereas the engineering approach covers expenditure that may not have been incurred due to underinvestment. For this reason, the engineering approach is not recommended in this study as it may result in an over-estimate of MEC-I values.
- **Cost allocation approach (cost accounting).** The current approach, as detailed in Sansom et al (2001) is the cost allocation approach. This involves categorizing all costs into fixed or variable costs. Academic literature (predominantly from Europe) informs which expenditure categories can be considered variable and therefore those within the scope of MEC-I estimation. The variable costs are then allocated to the equivalent traffic flow and scaled up or down for each vehicle type.

The table below (Table 16) provides an overview of the methodological approach and commentary about the main findings of MEC-I studies reviewed for the purpose of this study.

Table 16: MEC Infrastructure – best practice methodologies

Paper	Comments and Data Requirements
Sansom et al. (2001)	Comments: National cost allocation approach Data requirements: • Disaggregated costs • National Transport Model (NTM) for 4 road types, and 37 vehicle types • Upper bound of 30% added to expenditure to cover possibility renewals are insufficient.
CE Delft (2016)	Comments: Cost allocation approach as per Sansom et al (2001), but as this study is looking at the total infrastructure cost, it also includes some fixed costs. The study also splits variable costs on vehicle kilometres and axle load. Fixed costs are allocated to passenger car equivalents values, or vehicle kilometres. The data requirements for the variable costs are the same as per Sansom et al. (2001).
Haraldsson *(2007)*	Comments: Econometric methodology Data requirements: • Observed maintenance and operation costs, split by pavement types, across several year period (Haraldsson has 14 years of data). • The econometric approach used in this study is discussed above.
Swardh and Jonsson (2014)	Comments: This study builds directly on the Haraldsson (2007) study, adding three more years of data, and more explanatory variables such as the number of bridges on each road, and speed limits of each section, and the number of maintenance delivery units (i.e. instances of maintenance). Separate models are created for road maintenance, winter road operation and other road operation. The limitation here is data, regarding the correct actual cost per each instance of maintenance, and multicollinearity issues. Marginal costs using this methodological approach are found to be approximately 20% of average costs.
Link (2004)	Comments: Econometric translog cost function used to determine the marginal costs. This study was highly data intensive and requires a thorough break down of past maintenance, including the material used, length and cost of the renewal, how many lanes the renewal had, and even the thickness of the layers concerned. This appears to be more data than will be available within this study, and furthermore Link ran over 200 iterations/cases of the model, which would not be feasible for this study.
AASHO Road Test (Highways Research Board 1961)	Comments: Engineering experiments which concluded the so-called fourth power rule reflecting the relationship between axle weight and road damages. This is the assumption that many axle weighted papers rely on, for example the Delft (2016) paper above.
Link (2003)	Comment: This paper is focused on the short-run marginal costs where capacity is considered fixed. Therefore, the costs to be analysed are maintenance, operation and renewals only. The paper gives an overview of what other countries have tried to do in calculating the marginal infrastructure cost, whilst also stating many issues with the approach or data availability. Austria, Switzerland and Germany have all attempted (at least in part) econometric analysis, but the resulting log-linear models have rather low R^2 values (25% to 65%). The Austrian approach concluded most of the parameters to be significant at the 5% or 10% confidence level, but only had 38 observations. Link raises concerns about the credibility of all three approaches based on problems of multicollinearity.
Eriksen (2000)	Comment: Eriksen agrees that all costs should be split into fixed and variable, and the variable costs are used to find the marginal costs. It is stated that we do not have much knowledge of the relationship between vehicle weight and the number of axles and road wear. The AASHO (1974) study is relied on, whereby road wear of each vehicle axle is the vehicle weight per axle raised to a power (fixed at 2.5 in Norwegian studies). Therefore, each vehicle can be transformed into passenger car units.

Paper	Comments and Data Requirements
Yarmukhamedov and Swardh (2016)	Comment: The study used an econometric cost function approach, using traffic volume, costs, and road attributes for the Swedish national road network. The observation unit used in this study is the road maintenance delivery unit (MDU), a geographical area covered by maintenance provider. This study was unable to find a statistically significant marginal cost for paved roads but did find one for gravel roads. One of the main issues is separating out reinvestment costs from other maintenance costs and identifying the costs of additional work orders undertaken from a base contract (i.e. there are more costs that are not being accounted for in the records).
Lindberg (2002)	Comment: This study focuses only on maintenance costs, and specifically pavement renewals (every 10-15 years). All other maintenance costs were considered out of scope for this study. For pavements, the asset lifetime depends on traffic volume, measured in standard axles. The marginal cost of HGVs is shown as the product of the average cost, and an elasticity representing the change in lifespan of the infrastructure due to more HGVs. This elasticity is -0.1 on high quality roads, and -0.8 on low quality roads with a high load for standard axles. Lindberg notes that creating an econometric cost function is too difficult for some cost category elements of infrastructure costs.

A literature review of current publications relating to marginal cost infrastructure cost estimation and methodologies was undertaken to provide context for the range of options and suitability of each option for updating the MEC-I values. The following sub-headings present a more detailed review of selected papers and their methodological approach to estimating MEC-I values.

4.2.1 Cost allocation approach

CE Delft (2016), Infrastructure and External Cost coverage of road freight transport on EU28 motorways study attempts to examine to what extent the infrastructure and external costs of road freight transport on EU28 motorways in 2013 are covered by revenue from taxes and charges related to the kilometres driven by these vehicles. This study focuses on the total infrastructure cost, rather than the marginal infrastructure cost. Therefore, it also contains reference to some fixed costs that are not typically used in calculating the marginal infrastructure cost per vehicle.

Approach used: allocation of total infrastructure costs to various vehicles based on equivalency factor method.

The study considers four types of infrastructure costs as follows:

1. Enhancement Costs – all new infrastructure or capacity enhancing infrastructure
2. Renewal Costs – all costs relating to the renewal of existing infrastructure, whereby the renewed area will have a lifespan of at least 1-2 years
3. Maintenance Costs – all relatively minor repairs, with an economic lifetime of less than 1-2 years
4. Operational Costs – organizational costs to make for an efficient use of the infrastructure.

Enhancement and renewal costs are estimated using Perpetual Inventory Method (PIM), such that the annual depreciation costs are the initial investments split over the lifetime of the asset, with an appropriate interest rate. The total enhancement or renewal cost is then the sum of the depreciation and the interest costs.

Operation and maintenance costs are directly based on expenditure. Operation costs are assumed to be 100% fixed, whereas maintenance costs are 30% variable and 70% fixed. The passenger car equivalency factor is then used to create an allocation of the total infrastructure costs to various vehicle categories. This applies a proportionality factor for each vehicle type based on literature evidence of which vehicles cause the most damage (Table 17).

Table 17: MEC Infrastructure – proportionality factors in CE Delft (2016) study

Cost Category	Proportionality Factor
Enhancement costs (Costs made to enhance the capacity of the road network)	• Passenger car equivalent kilometres (90%) • 4th power axle load kilometres (10%)
Renewal costs (Cost of renewal works for infrastructure with more than 1-2 years lifetime remaining)	• Passenger car equivalent (40%) • 4th power axle load kilometres (60%)
Variable maintenance costs ('Ordinary' maintenance costs, for minor repairs on infrastructure with less than 1-2 years lifetime remaining)	• 4th power axle load kilometres (100%)
Fixed maintenance costs	• Passenger car equivalent kilometres (50%) • Vehicle kilometres (35%) • Allocation to HGVs (15%)
Operation costs (Costs of the organization e.g. traffic systems)	• Vehicle kilometres (30%) • Passenger car equivalent kilometres (70%)

Data requirements: As this study was focusing on motorways across all EU28 countries, the data requirements were quite significant, but not very disaggregated. This approach requires operations and maintenance expenditures and breakdowns of investments in enhancements and renewals. A variable cost analysis would require data for 'ordinary' maintenance costs for relatively minor repairs with an economic lifetime of less than two years.

The analysis creates a breakdown across fixed and variable costs and allocates infrastructure costs based on an equivalency factor. Our understanding is that the necessary data is currently available to replicate this study in the UK.

Operations costs were assumed to be 100% fixed, while maintenance costs were assumed to be 70% variable, 30% fixed. Variable maintenance costs were allocated based on 4th power axle load kilometres (ESAL vehicle kms).

4.2.2 A cost function approach

Haraldsson (2007), Marginal costs for road maintenance and operation – a cost function approach study aimed to estimate a set of road maintenance and operation marginal costs using data at a low level of aggregation, and to test whether average costs are equal to marginal costs.

Haraldsson adopted a cost function approach (econometric analysis), focusing on the impact of some traffic measures on maintenance and operation costs, then keeping all things equal, used econometric analysis to calculate the additional cost of an extra vehicle kilometre equivalent single axle load (ESAL) km or similar (standard axle) is the marginal cost.

Data requirements: large data sets are required, with much of the data being compiled specifically for this study. This comprised observed maintenance and operation costs, vehicle kilometres, road categories, pavement types for the entire road network, across a 14-year period.

4.2.3 Econometric approach

Link (2004), An economic analysis of motorway renewal costs in Germany[2] study aimed to analyse the cost behavior of motorway renewal costs to derive an estimate of marginal infrastructure costs per vehicle kilometre of trucks.

[2] Link (2006), An economic analysis of motorway renewal costs in Germany. Transportation Research Part A, 40(1):19-34.

Approach used: Econometric analysis, using a translog cost function model. Details can be found on Table 18.

Data requirements: The translog model used in this approach contained a large array of data, such as labour prices, material and capital, the average annual daily traffic volume of trucks and passenger cars for each region and the type of material used for the renewal works. For maintenance, the study used a data set of detailed physical (non-monetary) descriptions of each renewal measure (length and type of measure, material used, thickness of layers concerned) for 1830 road sections, disaggregated by different road layers, over a 20-year period. Unit costs of each type of construction were used to express the physical description in monetary terms. Traffic data was collected using automated vehicle counting stations across 400 motorway sections. This study also used weather and temperature fluctuations based on 260 climate stations across the road network but found this to be statistically insignificant (details presented on Table 18: MEC Infrastructure – variables within Link (2004) studyTable 18).

Table 18: MEC Infrastructure – variables within Link (2004) study

Variables within study	Data Requirements
Dependent variable	• Data on larger renewal measures for 1837 motorway sections during the period 1980-1999
Independent variables Factor inputs Factor Prices Use data Type of renewal measures Road characteristics Maintenance information Climate	• Input quantities of labour, material and capital • Prices for labour, material and capital • Average daily traffic volume and mileages for counting stations for passenger cars and freight vehicles (400 sections) from 1990-1999 • Material used for the renewal measure (7 types of material) • Length of sections • Number of lanes • Age of sections • Past expenditure on larger renewals for 1837 motorway sections • Number of days where the temperature changed from below zero to above zero from 260 climate stations • Number of days with snowfall
Econometric analysis	• Specified translog model with 221 observations in dataset • Seemingly unrelated regression model using constrained Maximum Likelihood estimator

4.3 Methodology selection

We believe there are five credible methods for updating the MEC-I, which range from updating the current approach, to creating econometric analysis of the true marginal external costs to infrastructure. Table 19 below identifies these options, commenting on their feasibility.

Table 19: MEC Infrastructure – methodology options

	Options to Update MEC Values	Scope	Advantages	Disadvantages	Data Requirements
1	Cost allocation: Update traffic and cost values using existing approach (Sansom et al. 1998)	In scope	Improvement on existing values, easiest of all options, data readily is available	Calculates average costs as proxy for marginal costs Uses aggregated traffic and cost data to calculate MEC-I values for required TAG breakdown	Feasible with existing data

	Options to Update MEC Values	Scope	Advantages	Disadvantages	Data Requirements
2	Cost allocation: Update traffic and cost values with existing approach, with updated variable cost weightings	In scope	Improvement on existing approach, data appears to be available	Calculates average costs as proxy for marginal costs Uses aggregated traffic and cost data to calculate MEC-I values for required TAG breakdown	Feasible with existing data, may require additional datasets
3	Extended cost allocation method (recommended methodology) Develop a consistent database containing traffic and variable cost data at the Local Authority level. Calculate MEC values through aggregation of LA level data by road type, artic/ rigid and regional split. Use updated variable cost weightings or ESAL weight only	Out of scope	Disaggregated approach offers potential for better accuracy, taking into account variations at local authority level. Outputs of this approach would provide useful insights on variations in Freight MEC-I values across regions and road types	Calculates average costs as proxy for marginal costs. Heavier data requirements and more intensive data analysis	Feasible with data available to DfT but would require require more intensive data analysis and creation of bespoke dataset
4	Engineering approach	Out of scope	Relatively simple approach	Literature does not show this as a credible approach, does not use real life expenditure or infrastructure lifecycle, relies on assumptions, not advised in the literature	Feasible with existing data, but would require creating some overarching assumptions on infrastructure lifecycle costs, and other data such as the cost per intervention
5	Econometric approach	Out of scope	Most comprehensive approach, widely accepted as the best approach internationally	Heavy data requirements, long data analysis, may need to collect additional data not readily available. May result in lower values than average cost approaches.	To create the dataset, would need disaggregated data from several sources over multiple years. Unknown yet if the data as seen in other studies exists or can be sourced for the UK. See Table 17 for more information.

The literature suggests that an econometric study would be the best approach to take from the theoretical perspective, as the econometric approach uses the observed expenditure and traffic flows/volumes across a range of areas to create a true marginal cost. In principle, this would be the most methodologically ‘correct’ approach based on our review of the academic literature.

The econometric approach is subject to several data availability and practical implementation issues which limit the feasibility of its application to updating TAG MEC-I values. There is a risk that applying this approach using UK data may result in the study not being able to find a statistically significant marginal cost for certain road types – as was the case in the Yarmukhamedov and Swardh (2016) study. In this scenario, it would then be necessary to revert to a cost allocation approach in order to calculate MEC-I values.

The cost allocation approach creates an average cost, which is likely to be higher than the econometric approach which will produce a true marginal cost. In Swedish studies, the marginal cost was found to be approximately 20% of the average cost value (Swardh and Jonsson (2014)).

This is because the engineering approach assumes that all works deemed necessary according to a lifecycle plan are undertaken. In reality, not all maintenance and renewals can be funded and road condition is not kept constant. Therefore, the engineering approach would likely result in the highest MEC-I values.

Whilst the econometric approach is recommended, we believe that the data requirements and time to create such a detailed cost function model mean this approach is out of scope and beyond the timescales of this project. It is also subject to risk that the analysis will not result in the estimation of significant marginal cost values. This would require the study to revert to using a cost allocation methodology.

Summarizing, we recommend using the extended cost allocation method (option 3). This approach is methodologically more rigorous than the original method producing potentially more accurate results and providing insights to DfT about the regional distribution of MEC-I values. Also, the dataset produced would be a pre-requisite to carrying out the econometric approach, which DfT may consider pursuing in future for all vehicle types.

4.4 Adopted methodology outline

4.4.1 Overview

Annual vehicle traffic incurs damage on the road infrastructure which requires ongoing expenditure on renewal of sections of the road network, routine maintenance of road infrastructure and road operations. These costs can be considered to be external where they are not internalised by the driver / operator through taxes, tolls and other charges.

Marginal road infrastructure costs correspond to the increase in road maintenance and repair expenditures that are induced by higher traffic levels. The level of infrastructure damage generated by an individual vehicle varies according to several factors:

- **Vehicle type** – heavier vehicles tend to impose more damage on roads. The key driver of damage is the force imposed by each axle on the road – the axle load factor.
- **Road type** – Roads designed for higher traffic volumes (e.g. motorways) use more robust material and construction involving higher initial capital investment per kilometre. These roads tend to be more resistant to the damaging force inflicted by each vehicle compared to a road designed for lower traffic volumes.
- **Geographic location** – roads in areas with higher traffic volumes and frequent braking tend to be subject to more damage.
- **Road gradient and weather** – A further element is the gradient of roads and the severity of weather. Roads with higher gradients and/or more severe weather tend to be more susceptible to infrastructure damage compared to roads in other locations. This factor cannot be controlled for in the cost allocation methodology and hence MEC-I values are likely to capture the effect of weather wear on road surface.

Variable road maintenance costs (average cost methodology) are typically used as a proxy to calculate the Marginal External Costs of Infrastructure (MEC-I) where data availability limits the level of detail possible for the analysis. The proxy is based on the assumption that specific categories of road maintenance costs in a given year provide a reasonable indication of the damage to roads caused by vehicles, such as HGVs, using the roads in that year.

The ‘cost allocation’ method involves allocating variable maintenance expenditure totals for each road type and area type to each vehicle type based on an adjusted vehicle kilometre equivalency factor method. This methodological approach aims to quantify the proportion of annual maintenance expenditure for each road type and area type associated with the various types of vehicles to allow for an estimation of average cost per vehicle kilometre.

Over the medium to long term, substantial increases in traffic volumes are likely to impose requirements for incremental capital expenditure, but not necessarily year to year. For these reasons, most elements of capital expenditure have been excluded from measures of variable road maintenance costs in previous studies.

In the UK, capital expenditure data available at the local authority (LA) level but does not capture the income earned by local authorities for maintenance activities carried out for other LAs as is the case for revenue outturn data. This makes it difficult to allocate capital expenditure - some capital expenditure items may therefore result in double counting of expenditure for some local authorities and under estimation for others.

4.4.2 Methodological approach

The extended cost allocation methodology involves allocating road maintenance expenditure at the local authority level to 12 road / area types according to the volume and composition of traffic flows weighted by vehicle weight (axle load).

This approach is similar to the methodology used to calculate existing MEC-I values in the Data Book which are derived from the paper 'Surface Transport Costs and Charges: Great Britain 1998' by Sansom et al. (2001) and for the 2014 'Update of the Handbook on External Costs of Transport' by Ricardo AEA for DG Move (European Commission).

It should be noted that both studies estimated the MEC-I value for all vehicle types. The current study described in this technical report estimates MEC-I values for HGV vehicles only. Two key differences between the previous (Sansom et al) and revised approaches are as follows:

- **Level of spatial disaggregation** – the lowest level of spatial disaggregation used by Sansom et al was by 11 area types (urban, rural, London etc) and 3 road types (motorway/trunk, principal, other). The revised extended method uses data at the local authority level and across 3 road types.
  Cost allocation weighting – the Sansom et al approach used several cost drivers to allocate vehicle kilometres according to specific cost categories[3]: PCU-km, average gross vehicle weight-km, maximum gross vehicle weight km, and standard axle-km (ESAL factor).

4.4.3 Road maintenance expenditure

Revenue expenditure on local authority roads maintenance is funded through council tax receipts and business rates, as well as through the Revenue Support Grant provided by the Ministry of Housing Communities and Local Government.

Local authority revenue road expenditure typically covers routine maintenance activities required to keep the road network operational and activities to repair defects in the road surface. It also includes street lighting, footpath repair, maintenance of safety assets, maintenance of the drainage system, and seasonal activities such as salt spreading. Many of these activities can be considered fixed i.e. the amount of expenditure do not fluctuate in the short term with traffic flows. Only the variable cost items should be considered for use in a marginal cost analysis.

The authorities responsible for maintenance of the Great Britain trunk road network (Highways England, Wales Trunk Road Agents and the Scottish Government) incur expenditure in similar capital and revenue expenditure areas with a higher proportion of spend on upkeep of road surface, maintenance of safety assets and drainage systems.

Capital expenditure is funded by local authorities from a range of sources including borrowing and capital receipts, as well as central government grants distributed by the DfT. Local authority capital expenditure typically covers the structural renewal of road assets including road infrastructure, footways, bridges, drainage and lighting. Some of these cost items could be considered for inclusion in the marginal cost analysis if a feasible approach is identified to isolate the variable cost elements and allocate to road traffic flows.

An issue with including capital costs in a variable cost measure is the degree to which expenditure can be attributed to the particular year in which traffic flows occur. If the maintenance activity is not at regular

---

[3] The allocation across variable cost categories is summarised in Table 5.1 (page 31) of Sansom et al (2001)

intervals or sufficiently frequent, this expenditure may not be able to be attributed to traffic flows for a given year.

To determine whether an uplift could be applied to account for a historical underspend in road infrastructure renewals, an investigation was carried out to explore whether a link exists between the proportion of LA-managed A roads and local roads which are categorised as requiring maintenance[4] and the annual expenditure per road kilometre. Low road condition was not found to be well aligned with LA-level variable maintenance expenditure for many individual local authorities – areas with high maintenance spend per kilometre did not necessarily have a higher proportion of roads in poor condition. The conclusion from this investigation was that it would not be reasonable to incorporate capital road renewals expenditure into the road maintenance measure used in the analysis.

Capital expenditure cost items (structural maintenance of roads) are therefore excluded from the marginal cost analysis. For the purposes of this analysis, the current rate of expenditure on capital account maintenance cost items is assumed to be the amount required to maintain the network in a steady state and does not vary according to traffic flow volumes in the short term (less than two years).

Table 20 lists the cost items and respective cost category and indicates whether a cost item has been considered as part of the variable costs, thus included in the marginal costs analysis.

Table 20: MEC Infrastructure - Maintenance Expenditure Cost items included in the marginal cost analysis

Cost Item	Cost Category	Include in Variable Costs
Resurfacing	Environmental, safety and routine maintenance	Yes
Surface dressing	Environmental, safety and routine maintenance	Yes
Patching and minor repairs	Environmental, safety and routine maintenance	Yes
Drainage	Structural maintenance	Yes
Major repairs	Structural maintenance	Yes
Road markings	Environmental, safety and routine maintenance	Yes
Safety Maintenance	Environmental, safety and routine maintenance	Yes
Environmental Maintenance	Environmental, safety and routine maintenance	Yes
Bridges	Structural maintenance - bridges	No
Street lighting	Street lighting	No

[4] This information can be found on the Department for Transport, Road Condition Statistics - Table RDC0120 - Principal and non-principal classified roads where maintenance should be considered (categorised as red), by local authority in England, 2007/08 to 2018/19

Cost Item	Cost Category	Include in Variable Costs
Winter operations	Winter service	No
Maintenance planning	Highways maintenance planning, policy and strategy	No
Traffic management	Other traffic management Bus lane enforcement	No

Structural maintenance expenditure data indicate that local authority spending levels remain broadly consistent over time. However, routine maintenance expenditure saw a steady decline over the period since 2009/10. There is the risk that underspending by local authorities has occurred over this period which may result in a requirement for higher expenditure in future years.

Estimation of MEC-I values requires the use of base-year National Transport Model link-level data from 2015 and corresponding maintenance expenditure data from the same year. MEC-I values estimated using 2015 data may be influenced by local authority budget constraints. If maintenance expenditure levels recover in future years, this may result in higher estimated MEC-I values compared to those derived using 2015 data.

4.5 Data specification

This section summarizes data required for the MEC-I estimation procedure.

4.5.1 Traffic flow data

The following table (Table 21) summarises the traffic flow data used in the analysis.

Table 21: MEC Infrastructure - NTM vehicle kilometre and road length data

Country	Publication	Source	Data Items Available	Data Year	Data Update Frequency	Geographic Disaggregation Available	Format
England Scotland Wales	National Transport Model – link level data	DfT	Annual vehicle kilometres by: • Vehicle type • Area type • Road type • Local authority	2015 (base year actuals)	2 years (base year) Annual (forecast)	Link level	Excel / CSV
England Scotland Wales	National Transport Model – link level data	DfT	Road length kilometres by: • Number of lanes • Area type • Road type • Local authority	2015 (base year actuals)	2 years (base year) Annual (forecast)	Link level	Excel / CSV
England Scotland Wales	Road network size and condition - Total road length (kilometres) by road type and local authority in Great Britain Table RDL0202a	DfT	Road length kilometres by: • Principal motorways • Principal rural 'A' road • Principal urban 'A' road • Local authority	2015	Annual	Local authority	Excel

Table 22 presents the equivalent standardized axel load factor data used in this analysis.

Table 22: MEC Infrastructure - Equivalent Single Axle Load (ESAL) factor data

Country	Publication	Source	Data Items Available	Data years	Data Update Frequency	Geographic Disaggregation Available	Format
UK	Vehicle Kilometres by UK HGVs operating in Great Britain and Northern Ireland 2015-2018	Department for Transport	Annual vehicle kms by detailed heavy goods vehicle category Number of axles and weight range (tonnes)	2015 - 2018	Annual	UK-only	Excel

4.5.2 Road infrastructure expenditure data

A key requirement for estimating Marginal External Infrastructure Costs is the availability of expenditure data at a sufficiently detailed resolution.

In Great Britain, the level of detail provided by local authorities and infrastructure owners in their annual returns / annual accounts is satisfactory for isolating road maintenance costs.

It should be noted that the available data for some geographies may not be detailed enough to exclude some fixed expenditure items which are not directly related to vehicle traffic flows.

Variable costs include certain elements of annual highways and transport services revenue expenditure. These data are sourced from MHCLG General Fund Revenue Account Outturn Highways and Transport Services (RO2) reported annually by each Local Authority (England), Wales, Scotland and from the annual accounts of agencies responsible for motorway operations and maintenance.

The following table (Table 23) summarises the road maintenance expenditure data used in the analysis.

Table 23: MEC Infrastructure - Road maintenance expenditure data required for MEC-I estimation

Country	Publication	Source	Data Items Available	Data Years	Data Update Frequency	Geographic Disaggregation Available	Format
England	Revenue Outturn (RO): Highways and Transport Services (RO2) data	Ministry for Housing, Communities and Local Government	Structural maintenance - principal roads Structural maintenance - other LA roads Environmental, safety and routine maintenance - principal roads Environmental, safety and routine maintenance - other roads	2014/15 2015/16	Annual	Local authority	Excel
England	Highways England Annual Report - Resource Outturn	Highways England	Resource Outturn – Maintenance - Motorway Resource Outturn – Roads PFI - Motorway	2014/15 2015/16	Annual	Country	PDF

Country	Publication	Source	Data Items Available	Data Years	Data Update Frequency	Geographic Disaggregation Available	Format
Wales	Revenue outturn expenditure summary, by authority	StatsWales Welsh Government	Structural maintenance - principal roads Structural maintenance - other LA roads Environmental, safety and routine maintenance – all roads	2014/15 2015/16	Annual	Local authority	Excel
Wales	Welsh Government Final Budget Main Expenditure Group (MEG) Allocations	Welsh Government	Improve and Maintain Trunk Road Network (Domestic Routes)	2014/15 2015/16	Annual	Country	PDF
Scotland	Local authority revenue and capital outturn expenditure	Scottish Government Local Government Finance	Structural, environmental and safety maintenance and routine repairs – all roads	2014/15 2015/16	Annual	Local authority	Excel
Scotland	Scottish Transport Statistics	Scottish Transport Statistics. Chapter 10: Transport and Travel Finance in Scotland	Motorway - Routine and winter maintenance etc Motorway - Design, build, finance, operate payments	2014/15 2015/16	Annual	Country	PDF

4.6 Model assumptions

4.6.1 Base year assumptions

The following table (Table 24) summarise the 2015 local authority and trunk road authority expenditure data used in the analysis.

Table 24: MEC Infrastructure - Road maintenance expenditure, by broad road type category and region / country, 2015, £000s

	Total Road Maintenance Expenditure (per lane km)	London & Manchester Combined Authority Principal Roads	Trunk Road Motorway	Trunk A Road	Local Authority Motorway	Local Authority A Road	Local Authority Other Roads
South West	2.1	0	40,824	50,914	0	38,709	74,488
East of England	2.6	0	31,543	59,619	0	22,594	94,229
South East	3.2	0	83,515	54,395	415	77,937	101,645
North West	3.2	4,060	82,170	18,662	356	55,677	81,620
North East	2.3	0	5,396	26,323	237	18,034	28,048
East Midlands	2.1	0	24,193	43,752	0	17,594	49,060
West Midlands	3.1	0	51,939	29,219	140	31,892	91,360
Yorkshire and The Humber	2.7	0	49,420	19,769	40	31,868	73,396
London	7.9	74,619	8,597	0	0	47,990	112,339
Wales	3.2	0	12,721	69,925	0	29,534	81,059
Scotland	3.0	0	35,981	119,769	0	55,226	145,946

Source: see Table 23

The following tables (Table 25, Table 26 and Table 27) summarise the National Transport Model (NTM) vehicle kilometre and road length data used in the analysis.

Table 25: MEC Infrastructure - Rigid HGVs, million vkm, by MEC category and region / country, 2015

	London Motorway	Inner and Outer Conurbations Motorway	Other Urban Motorway	Rural Motorway	London A Road	Inner and Outer Conurbations A Road	Other Urban A Road	Rural A Road	London Other	Inner and Outer Conurbations Other	Other Urban Other	Rural Other
South West	0	0	0	267	0	0	145	497	0	0	80	150
East of England	0	0	0	344	0	0	227	591	0	0	83	146
South East	0	0	0	752	0	0	300	595	0	0	122	143
North West	0	259	0	375	0	177	102	201	0	95	48	52
North East	0	7	0	37	0	80	68	110	0	40	22	22
East Midlands	0	0	0	282	0	0	179	519	0	0	83	113
West Midlands	0	156	0	453	0	121	115	313	0	59	43	85
Yorkshire and The Humber	0	330	0	106	0	207	39	224	0	93	20	63
London	96	0	0	0	555	0	0	0	99	0	0	0
Wales	0	0	0	107	0	0	66	303	0	0	30	94
Scotland	0	121	0	180	0	101	112	621	0	56	36	129

Source: DfT National Transport Model – 2015 base year

Table 26: MEC Infrastructure - Artic HGVs, by MEC category and region / country, million vkm, 2015

	London Motorway	Inner and Outer Conurbations Motorway	Other Urban Motorway	Rural Motorway	London A Road	Inner and Outer Conurbations A Road	Other Urban A Road	Rural A Road	London Other	Inner and Outer Conurbations Other	Other Urban Other	Rural Other
South West	0	0	0	637	0	0	66	327	0	0	11	43
East of England	0	0	0	788	0	0	208	863	0	0	13	47
South East	1	0	0	1,322	0	0	153	481	0	0	16	27
North West	0	440	0	952	0	84	62	164	0	20	8	12
North East	0	7	0	71	0	54	59	136	0	5	4	4
East Midlands	0	0	0	744	0	0	183	846	0	0	15	46
West Midlands	0	289	0	982	0	58	95	304	0	14	8	28
Yorkshire and The Humber	0	858	0	417	0	131	33	295	0	22	3	22
London	161	0	0	0	133	0	0	0	6	0	0	0
Wales	0	0	0	191	0	0	36	232	0	0	4	21
Scotland	0	148	0	363	0	38	66	478	0	6	4	40

Source: DfT National Transport Model – 2015 base year

Table 27: MEC Infrastructure - Lane length km, by MEC category and region / country, 2015

	London Motorway	Inner and Outer Conurbations Motorway	Other Urban Motorway	Rural Motorway	London A Road	Inner and Outer Conurbations A Road	Other Urban A Road	Rural A Road	London Other	Inner and Outer Conurbations Other	Other Urban Other	Rural Other
South West	0	0	0	1,882	0	0	2,404	9,041	0	0	19,365	62,696
East of England	0	0	0	1,454	2	0	3,015	6,744	0	0	18,793	48,829
South East	2	0	0	3,849	2	0	4,724	8,281	0	0	31,066	50,999
North West	0	1,432	0	2,357	0	3,614	1,928	4,108	0	26,864	12,464	23,632
North East	0	63	0	186	0	1,230	1,187	2,241	0	11,064	6,299	11,342
East Midlands	0	1	0	1,115	0	5	2,459	6,930	0	0	18,019	36,690
West Midlands	0	476	0	1,919	0	1,949	1,606	5,115	0	16,739	8,565	29,569
Yorkshire and The Humber	0	1,533	0	746	0	3,790	629	3,512	0	27,771	4,607	22,864
London	396	0	0	0	5,056	0	0	0	25,425	0	0	0
Wales	0	0	0	700	0	0	1,284	8,298	0	0	9,631	40,195
Scotland	0	639	0	1,340	0	1,514	1,675	18,595	0	12,556	11,066	69,845

Source: DfT National Transport Model – 2015 base year

Several lookup tables are required to align traffic flow to expenditure data and allocate to MEC road type / area type combinations. For future MEC updates, it may be necessary to update these lookup tables with new data. The lookup tables are summarized below on Table 28.

Table 28: MEC Infrastructure - Administrative boundary and NTM lookup tables

Lookup table	Description	Source
DfT Local Authority Code to Upper Tier Local Authority Lookup – England, Wales and Scotland.	NTS data are provided with DfT LA codes. Lookup is required to map NTS data to expenditure data. Lookup table may need to be updated if changes to LA boundaries have occurred since previous update.	Lookup provided in technical documentation.

Lookup table	Description	Source
Lower Tier Local Authority to Upper Tier Local Authority Lookup - England & Wales.	MHCLG expenditure data are provided at the lower tier level. Lookup is required to aggregate lower tier LA expenditure to upper tier LAs.	ONS Open Geography Portal/
NTM area type / road type to MEC category lookup table.	DfT's Data book contains 11 MEC categories. Lookup is used to allocate a MEC category code to the NTM input data.	Lookup provided in technical documentation/

4.6.2 Forecast scenario assumptions

The forecast indexation using GDP per person index has been retained from the current methodology.

4.7 Calculation procedures

This section sets out the calculation procedures to follow to estimate MEC Infrastructure values at the local authority level for each MEC category.

4.7.1 Step 1: Aggregate NTM link level data

The following data variables and category variables from the base National Transport Model (NTM) dataset are required for MEC-I calculation:

- Annual vehicle kilometres – Car, LGV, PSV, Rigid, Artic
- Road length
- Number of lanes
- Local Authority name
- Local Authority code
- NTM Area code
- Road Type code

NTM data are typically provided at the NTM area type and road type level. To provide link-level data for the MEC estimation procedure, DfT uses a separate program which disaggregates data from the standard NTM area and road type level (outlined in TAG Unit A5.4) to the link level[5]. For MEC-I analysis, data must be re-aggregated from the link level to the local authority level. The output of this operation needs to provide total vehicle kilometre and road length by vehicle type for each area type / road type combination. It should also provide the average number of lanes for each area type / road type combination.

The NTM datafile in MS Excel format is typically very large (approx. 350 mb) which can cause issues with opening and processing the file on the average PC.

It is recommended that the data file is opened and processed using a statistical software package (e.g. SPSS, Stata) or by creating a data-processing script in a high-level programming language such as Python or R and use a data analysis package. The output file should be produced in an Excel-readable format e.g. csv or xlsx.

[5] The data model used by DfT NTM team is not specifically designed to produce link-level outputs and can result in some inaccuracies being introduced to specific link-level segments. However, the errors are applied proportionally and do not have an impact when data are re-aggregated.

4.7.2 Step 2: Adjust vehicle kilometre data by ESAL factors for each vehicle type and NTM road type

HGVs cause significantly more damage to the road surface than a standard passenger car. The AASHO Road Test in 1961 observed that the damage of the road increases by the fourth power of the weight added to the axle, for example doubling the weight on the axle increases damage to the road surface by 16 times.

The ESAL factor formula is as follows:

$$ESAL\ factor = \left(\frac{W_1}{10}\right)^x + (A-1) \times \left(\frac{W-W_1}{10\times(A-1)}\right)^x \qquad (1)$$

where for each vehicle category, W_1 represents the load in tonnes on the first axle, the 10 value represents 10 tonnes, W represents the total load in tonnes, A represents the number of axles, and x represents the axle number factor.

A road class-specific axle number factor has been derived from the German study 'Guidelines for the Standardisation of Surfaces of Road Traffic Areas, 2012 Edition (RStO 12) which is presented in the Update of the Handbook on External Costs of Transport (2014) published by the European Commission. Values have been allocated to the equivalent UK road class as set out in the table below (Table 29).

Table 29: MEC Infrastructure - Axle number factor, by road class

Road Class	GB Road Class	Class Definition	Axle Number Factor
Motorways	Motorways	Motorways or municipal roads with freight traffic share > 6%	4.5
Other Trunk Roads	A Roads	Municipal roads with freight traffic share > 3 % and ≤ 6 %	4
Other roads	Other Roads	Municipal and district roads or municipal roads with freight traffic share ≤ 3 %	3.3

Source: Guidelines for the Standardisation of Surfaces of Road Traffic Areas (Germany), 2012 Edition (RStO 12)

For simplicity purposes, the axle number factor for the 'other trunk roads' category from the source study has been applied to all A roads. The ESAL factors for each vehicle type have been mapped to NTM road type categories as summarised in the following table (Table 30).

Table 30: MEC Infrastructure - ESAL factor by vehicle type and NTM road type

Road Type	NTM Road Type Code	Car	LGV	PSV	Rigid	Artic
Motorway	1	0.0000	0.004	0.35	0.40	1.36
Trunk Dual A	2	0.0001	0.008	0.42	0.46	1.59
Principal Dual A	3	0.0001	0.008	0.42	0.46	1.59
Trunk Single A	4	0.0001	0.008	0.42	0.46	1.59
Principal Single A	5	0.0001	0.008	0.42	0.46	1.59
B Roads	6	0.0003	0.019	0.56	0.57	1.98
C & Unclassified	7	0.0003	0.019	0.56	0.57	1.98
Motorway	8	0.0000	0.004	0.35	0.40	1.36
Trunk A (dual and single)	9	0.0001	0.008	0.42	0.46	1.59
Principal A (dual and single)	10	0.0001	0.008	0.42	0.46	1.59
B and C Roads	11	0.0003	0.019	0.56	0.57	1.98
Unclassified	12	0.0003	0.019	0.56	0.57	1.98

Source: Values calculated based on ESAL factor formula and road-specific axle number factors

ESAL factors are applied to actual vehicle kilometres (vkm) for each area type / road type combination. These data are the processed outputs from step 1. The resulting data represent ESAL-adjusted vehicle kms for each area type / road type combination.

4.7.3 Step 3: Allocate ESAL-adjusted vehicle kilometre to MEC categories

The next step is to allocate ESAL-adjusted vehicle kms to the 12 MEC categories in Data Book. These categories are allocated to 52 combinations of road and area type. A table describing the mapping of road and area type to MEC category is set out in Table 31.

Table 31: MEC Infrastructure - Area type and road type mapping to MEC categories

Area Type	Road Type	MEC category	MEC category name
Rural	Motorway	1	Rural Motorway
Rural	Trunk Dual A	2	Rural A road
Rural	Principal Dual A	2	Rural A road
Rural	Trunk Single A	2	Rural A road
Rural	Principal Single A	2	Rural A road
Rural	B Roads	3	Rural Other
Rural	C & Unclassified	3	Rural Other
London	Motorway	4	London Motorway
London	Trunk A (dual and single)	5	London A road
London	Principal A (dual and single)	5	London A road
London	B and C Roads	6	London Other
London	Unclassified	6	London Other
Inner and Outer Conurbations	Motorway	7	Inner and Outer Conurbations Motorway
Inner and Outer Conurbations	Trunk A (dual and single)	8	Inner and Outer Conurbations A road
Inner and Outer Conurbations	Principal A (dual and single)	8	Inner and Outer Conurbations A road
Inner and Outer Conurbations	B and C Roads	9	Inner and Outer Conurbations Other
Inner and Outer Conurbations	Unclassified	9	Inner and Outer Conurbations Other
Other Urban	Motorway	10	Other Urban Motorway
Other Urban	Trunk A (dual and single)	11	Other Urban A road
Other Urban	Principal A (dual and single)	11	Other Urban A road
Other Urban	B and C Roads	12	Other Urban Other
Other Urban	Unclassified	12	Other Urban Other

4.7.4 Step 4: Consolidate maintenance expenditure and allocate to MEC categories

Data available for the estimation of MEC-I values in Great Britain are derived from various sources.

Local authorities are responsible for A roads, local roads and in some case motorways within their geographical boundaries.

The bodies responsible for the management and improvement of trunk or national roads within Great Britain are:

- Highways England
- Transport Scotland
- North and Mid Wales Trunk Road Agent – lead authority Gwynedd Council
- South Wales Trunk Road Agent – lead authority Neath Port Talbot County Borough Council

Some combined authorities (TfGM in Manchester and TfL in London) are responsible for principal road maintenance expenditure within their geographical boundaries.

Expenditure data are typically available in financial years (FY) and must be converted to calendar years using data from two FYs.

As budgets are allocated centrally, maintenance expenditure on principal roads in each local authority must be allocated using an appropriate apportionment method. The recommended approach is to apportion using principal road lane km by local authority.

Local authority expenditure data must be presented net of other income derived from payments related to maintenance activities for other local authorities.

The table below (Table 32) sets out the expenditure allocation method for each road expenditure data source and the mapping to DfT's road type codes.

Table 32: MEC Infrastructure - Expenditure allocation methods – by road type & highways authority classification

Road Category	Expenditure Allocation Method	DfT Road Type Code (NTM)	Calendar Year
Combined Authority Principal Roads	Principal road lane km by local authority as % of combined authority total	3, 5, 10	2015
Trunk Road Motorway	Motorway lane km by local authority as % of total trunk road lane km	1, 8	2015
Trunk A Road	Trunk A road lane km by local authority as % of total trunk road lane km	2, 4, 9	2015
Local authority - Motorway	Total road length km by principal road type to calculate Proportion of motorway principal roads by local authority	N / A (add to trunk road motorway)	2015
Local authority - A Road	England – additional allocation not required Wales – Environmental, safety and routine maintenance expenditure totals are apportioned and extrapolated based on last available expenditure category totals. Scotland - expenditure total apportioned based on lane km	3, 5, 10	2015
Local authority – other roads	England - additional allocation not required Wales – Environmental, safety and routine maintenance expenditure total apportioned based on last available data Scotland - expenditure total apportioned based on lane km	6, 7, 11, 12	2015

The proportion of Local authority principal roads that are motorways must be calculated separately and subtracted from the principal A road total for the relevant local authorities.

Expenditure allocation is not required for local authority A roads and other roads in England as the data is already available in the required format.

Environmental, safety and routine maintenance expenditure data for Wales have not been published since 2008/09 at the required level of detail. Totals must be apportioned to the relevant cost items and extrapolated based on last available expenditure category totals to derive 2015 values.

Local authority maintenance expenditure data in Scotland is provided for a single ‘ maintenance & repairs’ category only. The recommended approach to apportion to the relevant cost items based on the proportion lane km length for principal roads and other roads.

Motorway maintenance expenditure is provided as a single value in each year i.e. is not provided at a more disaggregated spatial or cost category level. The recommended approach is to allocate trunk A road and motorway for individual local authorities based on trunk A road and motorway lane km as a percentage of total trunk road lane km in that local authority.

Highways England and Scottish Government PFI resource account payments should be adjusted to separate maintenance expenditure from the maintenance & operations total. The recommended approach is to apportion based on the maintenance spend as a percentage of total Highways England maintenance and operations annual spend.

A final stage is to consolidate maintenance expenditure calculated for trunk roads and local authority maintained roads into three final expenditure categories for each local authority: Motorway, A Roads and Other Roads.

4.7.5 Step 5: Calculate MEC-I values for each MEC category, vehicle type and local authority

Maintenance expenditure for the three final expenditure categories (Motorway, A Roads and Other Roads) should be allocated to the 12 MEC categories according to lane length km share within each road category (Motorway, A Roads and Other Roads).

The MEC-I value is calculated according to the following formula.

$$\text{MEC} - \text{I pence per vkm}\ _{MEC}^{LA} = \frac{\left(\text{Road type expenditure}_{MEC}^{LA} \times \frac{\text{vehicle type ESAL vkm}_{MEC}^{LA}}{\text{total ESAL vkm}_{MEC}^{LA}}\right)}{\text{vehicle type actual vkm}_{MEC}^{LA}} \qquad (2)$$

The process of the calculation formula can be described as follows:

1. Maintenance expenditure for a given vehicle type and road type is estimated based on the proportion of ESAL weighted vkm relative to total.
2. This apportioned expenditure value is divided by actual vehicle km for that vehicle type for each LA and MEC category.

The calculation results in a MEC-I pence per vkm value for each local authority, MEC category and HGV vehicle type calculated using a vehicle km weight for the relevant area aggregation.

4.8 MEC Infrastructure values

National MEC-I values are presented in Table 33 in 2020 prices.

Table 33: MEC Infrastructure – values in pence/vkm, Artics and Rigids, 2020 prices, base scenario

	Artics							Rigids						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inner and Outer Conurbations														
Motorways	4.16	4.62	5.17	5.80	6.49	7.28	8.15	1.23	1.36	1.53	1.71	1.91	2.14	2.40
A Roads	19.54	21.67	24.28	27.21	30.48	34.15	38.27	5.72	6.34	7.11	7.96	8.92	9.99	11.20
Other Roads	81.28	90.14	101.00	113.16	126.79	142.05	159.16	23.65	26.23	29.39	32.93	36.89	41.34	46.31
London														
Motorways	3.76	4.17	4.67	5.24	5.87	6.57	7.36	1.11	1.23	1.38	1.54	1.73	1.94	2.17
A Roads	36.54	40.52	45.40	50.87	57.00	63.86	71.55	10.69	11.86	13.28	14.88	16.68	18.69	20.94
Other Roads	181.77	201.60	225.88	253.08	283.55	317.70	355.95	52.88	58.65	65.72	73.63	82.50	92.43	103.56
Other Urban														
A Roads	14.02	15.55	17.42	19.52	21.87	24.50	27.45	4.10	4.55	5.10	5.71	6.40	7.17	8.03
Other Roads	51.25	56.84	63.69	71.36	79.95	89.57	100.36	14.99	16.62	18.62	20.87	23.38	26.19	29.35
Rural														
Motorways	4.14	4.59	5.14	5.76	6.45	7.23	8.10	1.22	1.35	1.52	1.70	1.90	2.13	2.39
A Roads	13.18	14.62	16.38	18.35	20.57	23.04	25.82	3.86	4.28	4.79	5.37	6.02	6.74	7.55
Other Roads	74.71	82.86	92.84	104.02	116.55	130.58	146.31	21.88	24.27	27.19	30.47	34.14	38.25	42.85

Regional MEC-I values are presented in Table 34 and Table 35 in 2020 prices, respectively, for rigid and artic.

Table 34: MEC Infrastructure – regional values pence per vehicle km 2020 – Rigid HGV, 2020 prices

	London			Inner and Outer Conurbations			Other Urban		Rural		
	Motorways	**A Roads**	**Other Roads**	**Motorways**	**A Roads**	**Other Roads**	**A Roads**	**Other Roads**	**Motorways**	**A Roads**	**Other Roads**
South West							5.6	10.2	1.4	3.8	15.3
East of England	0.6	1.8					2.9	15.4	0.9	1.8	14.5
South East	1.4	12.0					6.0	15.0	1.3	3.6	20.1
North West				1.5	7.9	15.1	3.3	19.5	1.2	4.0	27.5
North East				4.3	4.3	8.4	3.5	10.6	1.2	2.5	26.1
East Midlands				0.6	11.4		2.1	7.1	0.7	1.2	13.5
West Midlands				0.8	4.8	27.4	1.8	9.1	0.9	2.3	14.3
Yorkshire and The Humber				0.9	3.4	22.8	4.0	9.5	0.9	1.5	14.0
London	1.1	10.7	52.9								
Wales							5.9	17.2	2.1	10.9	30.2
Scotland				1.6	4.3	22.0	4.2	29.3	1.5	6.0	26.6

Table 35: MEC Infrastructure – regional values pence per vehicle km 2020 – Artic HGV, 2020 prices

	London			Inner and Outer Conurbations			Other Urban		Rural		
	Motorways	**A Roads**	**Other Roads**	**Motorways**	**A Roads**	**Other Roads**	**A Roads**	**Other Roads**	**Motorways**	**A Roads**	**Other Roads**
South West							19.1	35.2	4.8	13.1	52.6
East of England	2.0	6.1					9.8	52.8	3.0	6.2	49.9
South East	4.9	41.0					20.6	51.5	4.6	12.3	69.1
North West				5.2	27.0	51.9	11.3	67.1	4.1	13.8	94.4
North East				14.5	14.9	29.0	12.1	36.3	4.2	8.6	89.7
East Midlands				2.2	38.8		7.0	24.5	2.5	4.1	46.3
West Midlands				2.7	16.3	94.0	6.2	31.3	3.2	7.8	49.3
Yorkshire and The Humber				3.0	11.7	78.2	13.5	32.7	3.1	5.1	48.2
London	3.8	36.5	181.8								
Wales							20.0	58.7	7.0	37.3	103.8
Scotland				5.5	14.8	75.7	14.5	97.7	5.2	20.6	88.0

National MEC-I values are presented in 2020 prices on Figure 6 (2025 impacts) and in Table 33. In general, ‘Motorways’ have the lowest marginal external cost, followed by ‘A Roads’ and ‘Other Roads’. The lowest and highest MEC-I value was identified for ‘Motorways’ and ‘Other Roads’ in London, respectively. Artics generally have much higher external infrastructure cost than rigids, especially for the ‘Other Roads’ category. This is because artics usually carry higher load, which leads to a higher weighting borne by artics in calculating MEC-I. MEC-I values were also evaluated at regional level and can be found in Table 34 and in Table 35, 2020 prices for rigid and articulated HGV, respectively.

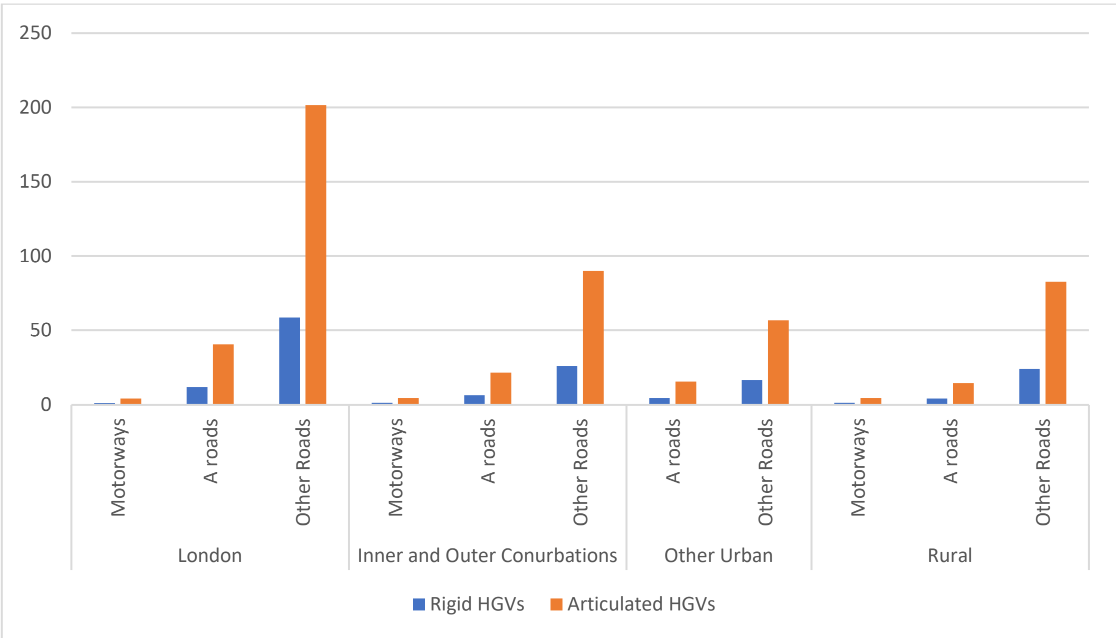


Figure 6: MEC-I values, pence per vkm, 2025 impact, 2020 prices, by HGV type

MEC-I values calculated using the updated methodology tend to be similar or lower than values computed based on the previous method, both for rigid and articulated HGVs (see Figure 7). The major exceptions are A-roads and Other roads in London area, where the new values are more than 50% higher than the previous ones. This is a result of a more detailed approach to calculation of regional MEC values on the local authority level, which enabled to capture the differences for the London area. The expenditures of London local authorities on road maintenance and related services to keep the required road infrastructure standards are much higher than in other areas.

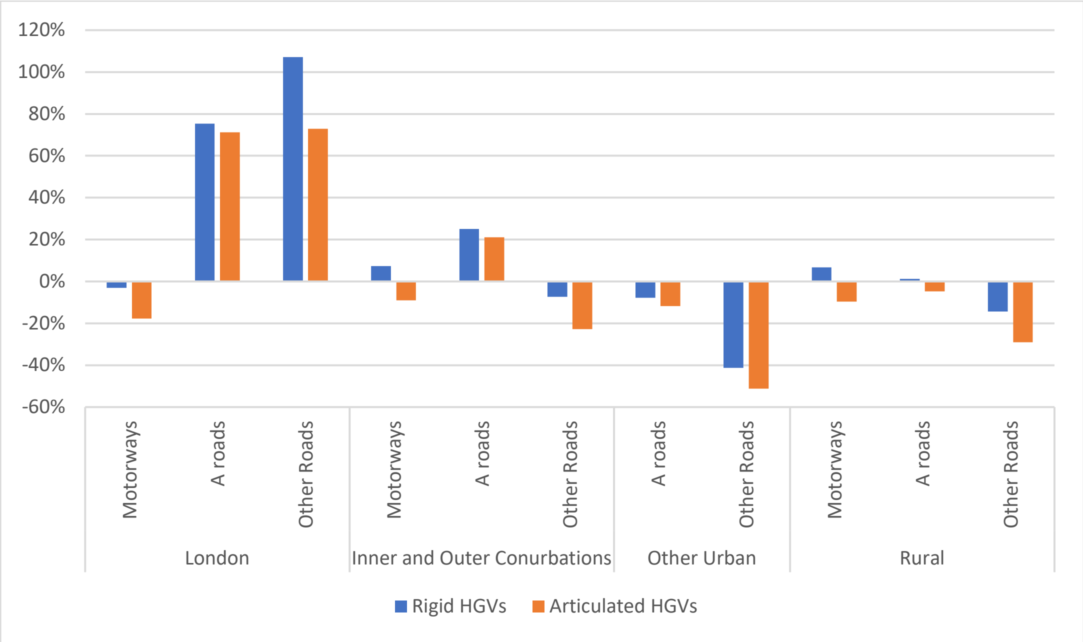


Figure 7: Difference between the MEC-I values computed using the new and the previous methodology, by HGV type, 2025 impact, 2020 prices, previous values = 100%

4.9 Sensitivity scenarios

A review of the influence of future adoption of EV / Hydrogen technologies, HGV platooning, and other technologies of road freight automation was carried out.

The change in fleet composition and adoption of EV / Hydrogen technologies may result in some in average weight within rigid and artic classes, however the impact is expected to be have effects that are within the margin of error of the estimated MEC values.

As a result, a sensitivity scenario has not been applied for MEC-I forecast values.

4.10 Indexation and updates

The following summarises the Inflation and indexation procedures applied to produce forecast values for the Data Book:

- MEC-I values are presented in 2020 prices in pence per vehicle kilometre for each forecast year.
- MEC-I values were calculated using 2015 data in 2015 prices (base year values).
- The GDP deflator series from the May 2019 Data Book (‘annual parameters’ sheet) was used to inflate 2015 based year values to 2020 prices.
- The GDP per person series from the May 2019 Data Book (‘annual parameters’ sheet) was used as the indexation series to inflate base year values in 2020 prices to the relevant forecast year (2020 to 2050).

Future updates will need to align to the current TAG base year and price year at the time of when update is being carried out.

- The model will require periodic updates to maintain robustness and consistency with the latest expenditure and traffic flow data. MEC-I values do not necessarily need to be updated in line with NTM base year data – in balancing the requirement for an update, the likely magnitude of changes over time for each data item should be considered.

Future updates of MEC-I values should follow the calculation procedures as set out in section 4.7. A summary of the update frequency, source and availability of data required for MEC-I update are provided in Table 36.

Table 36: MEC-I update data requirements

Data Update Item	Source	Availability	Data update Frequency
Annual vehicle kilometres	National Transport Model – link level data	On request from DfT Transport Appraisal and Strategic Modelling Team	18 months to 2 years (base year) Annual (forecast)
Road length kilometres	National Transport Model – link level data	On request from DfT Transport Appraisal and Strategic Modelling Team	18 months to 2 years (base year) Annual (forecast)
Annual vehicle kms by detailed heavy goods vehicle category	Vehicle Kilometres by UK HGVs operating in Great Britain and Northern Ireland	On request from DfT Road Freight Statistics Team	Annual
England	Revenue Outturn (RO): Highways and Transport Services (RO2) data	Published data tables - Ministry for Housing, Communities and Local Government	Annual
England	Highways England Annual Report - Resource Outturn	Published report - Highways England	Annual
Wales	Revenue outturn expenditure summary, by authority	Statistics Portal - StatsWales	Annual
Wales	Welsh Government Final Budget - Main Expenditure Group (MEG) Allocations – Resource Budget - Motorway & Trunk Road Operations	Published report - Welsh Government	Annual
Scotland	Local authority revenue and capital outturn expenditure	Published data tables - Scottish Government Local Government Finance	Annual
Scotland	Scottish Transport Statistics	Published report - Scottish Transport Statistics. Chapter 10: Transport and Travel Finance in Scotland	Annual

4.11 Limitations and recommendations

Infrastructure costs are not expected to be affected substantially by future changes to the UK HGV fleet or adoption of EV / Hydrogen technologies. The change in fleet composition may result in some in average weight within rigid and artic classes, however the impact is expected to be have effects that are within the margin of error of the estimated MEC values. As a result, a sensitivity scenario has not been applied for MEC-I forecast value.

5 Noise

5.1 Introduction

Marginal External Costs (MECs) are primarily used to inform and optimise pricing schemes and modal change support schemes (the objective of this research study). They reflect external costs of an additional vehicle (or vehicle kilometre) added to the transport system. In case of MEC of road freight in the UK, they reflect the impact of an additional unit of HGV traffic entering the UK road network.

Two major impacts are usually considered when assessing noise impacts:

- Annoyance: relating to the disturbance which individuals experience when exposed to (traffic) noise.
- Health impacts: related to the long-term exposure to noise, mainly stress related health effects like hypertension and myocardial infarction. It can be assumed that these two effects are independent, i.e. the potential long-term health risk is not taken into account in people's perceived noise annoyance.

Marginal noise costs are highly dependent on local factors. Three general key cost drivers for marginal noise costs can be distinguished:

- Population density close to the emission source: this cost driver gives an indication of the population exposed to the noise. Generally spoken, the closer to an emission source, the more nuisance will occur, and the higher the marginal costs will be. A rough indication of the population density close to the emission source could be made by distinguishing area types (urban, suburban, rural).
- Existing noise levels (depending on traffic volume, traffic mix and speed): along an already busy road the noise costs of an additional vehicle are small compared to a comparable situation along a rural road. The higher the existing background noise level, the lower the marginal costs of an additional vehicle. As a proxy for the existing noise levels area type (urban, suburban, rural) and traffic situation (thin or dense traffic) can be used.
- Time of the day: noise disturbances at night will lead to higher marginal costs than at other times of the day.
- In road transport the sound emitted is mainly made up of the sound of the propulsion system and the sound of road/tyre contact. The ratio of both sources depends on the speed of the vehicle. Besides vehicle speed, other important cost drivers are vehicle type (e.g. share of heavy trucks), the type of tyres, and the vehicle’s state of maintenance. Closely related to these are cost drivers like vehicle age, the slope of the road, and the type of road surface (including the presence of noise barriers).

This section aims to outline the approach used to quantify the MEC for noise (MEC-N) when extra units of HGV traffic are added to one kilometre of road.

5.2 Current approach

The current methodology of calculating marginal external costs of noise generated by road freight is based on the study by Sansom et al. published in 2001. Sansom et al. used a series of case studies to investigate noise levels and costs for a number of road types assuming typical speeds and traffic flows. They have quantified marginal cost by looking at noise change from a 10% increase in traffic for each road type. They have used average population density data for 11 area types. Sansom et al. have considered disaggregated outputs as follows:

- 11 area types (3 for London, 2 for conurbations, 5 other urban, rural);
- 3 road types (motorway, trunk and principal, other);
- 5 vehicle types (car, light delivery vehicle, rigid heavy goods vehicle, articulated heavy goods vehicle, public service vehicle); and,
- 2 time periods (weekday peak from 0700-1000 and 1600-1900, other times)

There are several limitations and uncertainties related to the current methodology:

- Although Sansom et al. study appears to have considered 5 levels of vehicles, including a rigid and an articulated heavy goods vehicle category, it is not clear how the noise calculations have taken this into account. The noise calculations have been undertaken using CRTN which uses a single heavy vehicle category as the basis of calculations. The report does not describe any adjustments to account for additional categories.
- The study reflects average vehicle fleet composition as of 1998.
- Area types used in the 2001 study were compatible with National Road Traffic Forecast 97, but are not compatible with NTM, where area types are based on population density rather than the size of built up area. The updated methodology will allow to calculate MEC-N by density-based area types.

The study highlighted several areas where uncertainties occur and where further research is recommended. Over the last 20 years, there has been significant progress in many of these areas:

- **Night traffic.** A lot of heavy freight traffic is night traffic, when the marginal impacts are higher due to lower traffic levels and the sleep disturbance it creates.
- **Noise impact monetization**. Current method is based on property prices. Over the last couple of years noise valuation methods were updated to include health impacts at lower noise thresholds, as reflected in TAG approach and Data Book.
- **Congestion levels**. As mentioned in the 2001 study, there is a logarithmic relationship between traffic volume and noise, and on routes with high levels of existing traffic, even large numbers of extra vehicles will only produce small increases in noise levels. However, the study does not consider congestion impacts.

5.3 Best practice methodologies review

5.3.1 General MEC-N methodologies

Methodologies for noise external costs calculations are well-established and generally follow one of two alternative approaches: a bottom-up or a top-down approach. The bottom-up approach, developed in the ExternE-project and generally called the ‘Impact Pathway Approach’, aims at estimating marginal costs, whilst the top-down approach produces average values. For noise, average values differ significantly from marginal values, and average external costs of noise are not a very good proxy for MEC-N, so since the development of the Impact Pathway Approach, a top-down method is used for estimation of MEC-N only on European level, where detailed data is less available, and the level of generalisation is high (Table 37).

Table 37: MEC Noise – best practice methodologies

Study	Coverage	Approach
Ricardo-AEA (2014), Update of the Handbook on External Costs of Transport	EU	Top down
COWI (2004), Marginal costs of traffic noise - generalised values for pricing policies	Denmark	Bottom up
VTI (2016), Estimation of the marginal cost for road noise and rail noise	Sweden	Bottom up
CE Delft (2008). Handbook on estimation of external costs in the transport sector	EU	Top down
CE Delft (2011). External cost of transport in Europe. Update study for 2008.	EU	Top down
INFRAS/IWW (2004). External costs of transport - update methodology.	EU	Top down
Sansom (2001), Surface Transport Costs and Charges: Great Britain 1998	UK	Top down

The top-down approach uses the willingness to pay or the willingness to accept (compensation) for silence and the health effects and multiplies these unit values with the national data on noise exposure for different noise classes. The top-down approach considers exposure rates for a whole country (differentiated for noise classes) and divides it by total mileage driven on the roads.

The starting point of the bottom-up approach is the micro level and looking at a vehicle as a source of the noise emission. This approach allows for consideration of rolling and propulsion noise and their relation to various vehicle-related parameters (vehicle type, tyres, design, etc). In this approach two scenarios are calculated: a reference scenario reflecting the default level of traffic volume, speed distribution, vehicle technologies, etc., and a marginal scenario which is based on the reference scenario but includes additional unit of traffic. The difference in damage costs of both scenarios represents the marginal external noise costs.

5.3.2 Road noise calculation methods

A critical review of main road traffic noise calculation methods was conducted to assess and compare the available methodologies and their suitability for the project objectives. Seven key methods of predicting source noise emissions from heavy vehicles under free-flowing conditions were identified, compared and assessed against the criteria defined in section 5.2. This was complemented by the results of a recent comparative study published in 2019 and undertaken by Peng et al. where a special focus given to the way each model captures HGV vehicles typology.

1. UK method (CRTN)
2. Swiss method (SonRoad)
3. French method (NMPB2008)
4. Japanese method (ASJ-RTN)
5. American method (FHWA TNM)
6. Scandinavian method (Nord2005)
7. EU method (CNOSSOS-EU)

All of the above methods use a single category of light vehicles. However, this category is not the focus of this research project and as such is not discussed further. This category of vehicles will nevertheless be considered in the assessments, since it is a significant component of the overall noise emissions at receptor points where impacts are assessed.

The first three prediction methods (UK, Swiss, French) use source emission models based on one category of heavy vehicles. The latter four methods (Japanese, American, Scandinavian, EU) use source emission models based on two categories of heavy vehicles, split into 2-axle rigid trucks and multi-axle trucks.

Peng et al. devised a six-category heavy vehicle model as summarised in the table below for Australian roads (Table 38). The model uses a hybrid of existing prediction methods where it relies on the Japanese model for predicting source emissions from rigid trucks (HV1 and HV2) and an extended version of Nord2005 for predicting source emissions from articulated trucks (HV3 to HV6). The reason for using a hybrid approach was to ensure a good correlation between predictions and measurements carried out on Australian roads for different heavy vehicle categories.

Table 38: MEC Noise - six-category vehicle model by J. Peng et al.

Vehicle Type	Vehicle Group	Calculation Basis
2 axle rigid trucks	HV1	*ASJ-RTN*
3, 4 axle rigid trucks	HV2	*ASJ-RTN*
3, 4, 5 axle articulated trucks	HV3	*Extended Nord2005*
6 axle articulated trucks	HV4	*Extended Nord2005*
9 axle B-doubles, heavy truck and trailer	HV5	*Extended Nord2005*
12 axle B-triples, road trains or equivalent	HV6	*Extended Nord2005*

As noted above, Nord2005 consists of two categories of heavy vehicles (HV1 and HV2). It predicts rolling and propulsion noise separately, before combining the two components to derive an overall vehicle sound power level for the vehicle category. For extending the calculations to account for articulated trucks (HV3 to HV6), Peng et al. made adjustments to the rolling noise emissions by applying a 3 dB increase in noise emissions per doubling of wheel count to account for the increase in road/tyre contact noise. No adjustments were made to propulsion noise.

Their comparison of the main road traffic noise calculation methods also showed there was a reasonable correlation between the sound power levels predicted using Nord2005 (2 axle rigid trucks) and CRTN (1-category heavy vehicle). In the case of sound power levels for multi-axle trucks, CRTN and Nord2005 (extended model with 6 axle trucks) provided a good correlation at low traffic speeds of 50kph. At top speeds of 110kph that were investigated, Nord2005 resulted in sound power levels which were around 3dB higher, accounting for the increased road/tyre noise with increased speeds, where the number of axles were higher.

The study concluded that, compared to measurements under Australian conditions, CRTN is reasonably accurate where 2-axle rigid trucks are prominent in the heavy vehicle mix, however prediction performance reduces as the proportion of multi-axle trucks increase. This may be due to the underlying assumption in the study that the definition of heavy vehicles in CRTN is still as per the definition in the document. The definition of a heavy vehicle in CRTN is based on vehicle weight rather than the number of axles, and originally included all vehicles with an unladen weight exceeding 1525kg. This may have been historically more representative of 4 axle trucks prevalent at the time the original model was developed. However later guidance in Design Manual for Roads and Bridges 11:3:7 HD 213/11 revised the definition of a heavy vehicle in 'Annex 4 Additional Advice to CRTN Procedures' in November 2011. This was to account for the fact that *"…since this classification system was first introduced in 1975, the proportion of vehicles within the range 1.525 tonnes to 3.5 tonnes has grown significantly and the maximum permissible weight of heavy vehicles has increased from 38 to 44 tonnes. Therefore, the range in vehicle noise emissions within the heavy vehicle category has increased. To address this problem, it is recommended that the heavy vehicle category is redefined as vehicles with unladen weight greater than 3.5 tonnes…."*. This is the current practice in the UK.

5.4 Methodology selection

5.4.1 Methodology options assessment

The review of available approaches resulted in identification of three methodology options available to address MEC Noise of HGV traffic (Table 39).

Table 39: MEC Noise – methodology options

Approach	Scope	Advantages	Disadvantages	Data Requirements
Top-down approach	In scope	Improvement to existing values	Results in average external costs which in case of noise are a poor proxy for marginal external costs	Feasible with existing data sets
Developing a bottom-up methodology based on Nord 2005 noise model (Recommended)	In scope	Significant improvement to the existing approach, compliant with TAG noise impact valuation data, reflects state-of-the-art research on HGV impacts on noise	Simplified approach to noise modelling	Feasible with existing data sets
Developing a bottom-up methodology based on detailed UK noise maps	Out of scope	Significant improvement to the existing approach, compliant with TAG noise impact valuation data	Time and data intensive. Strategic noise mapping calculation methods, and physical road network and classification would have to be coordinated to enable sufficient accuracy of data aggregation	Requires detailed strategic noise mapping data

5.4.2 Recommended methodology

Based on the review of the noise calculation methods, Nord2005 was used in this study to predict noise emissions. The method correlates reasonably well with CRTN, provides flexibility in studying different mix of heavy vehicles on the road network and allows for potential changes in noise arising from policy or technology to be investigated (e.g. changes in propulsion noise due to use of electric heavy vehicles). The rolling and propulsion noise were predicted separately and combined to obtain sound power level for the vehicle category. The method considered two categories of heavy vehicles (HV1 and HV2).

As part of this project, analysis was undertaken to look at day and night impacts separately, using annual average traffic flows, since noise impacts are sensitive to time of the day. The time periods considered in Sansom et al. (2001) study were for 'weekday peak' and 'all other time periods in the week'. This approach is not compatible with how noise impacts are currently calculated in the UK, discussed further below. The intermittent nature of transport sources may affect perception including the levels of annoyance during different times of the day (peak vs off peak). However, research shows that annual average is more representative of the long-term nature of potential health impacts on the community which may arise from noise. Most significantly, Sansom et al. study did not consider night-time impacts since the available methodology at the time did not allow a robust evaluation.

Considering other disaggregation criteria, the area and road types in this study were aligned with TAG categories. As mentioned, MEC-N are highly dependent on congestion levels, so a differentiation between congestion free flow and congested traffic conditions were considered and included in the methodology (Table 40) to calculate intermediate MEC-N values. The final MEC-N values presented in this report were aggregated across congestion levels. Intermediate MEC-N values are available in the calculation model accompanying the report.

Table 40: MEC Noise - recommended disaggregation method

Congestion Levels	**Inner and Outer Conurbations**		
	Motorways	**A Roads**	**Other Roads**
Free flow (congestion bands 1-3)			
Congested (congestion bands 4-5) flowing at 75% or more capacity			
Congestion Levels	**Other Urban**		
	Motorways	**A Roads**	**Other Roads**
Free flow (congestion bands 1-3)			
Congested (congestion bands 4-5) flowing at 75% or more capacity			
Congestion Levels	**Rural**		
	Motorways	**A Roads**	**Other Roads**
Free flow (congestion bands 1-3)			
Congested (congestion bands 4-5) flowing at 75% or more capacity			

The Sansom et al. study quantified the amenity effect of noise (e.g. community annoyance) with a noise threshold of 55 dB L_{Aeq}. This project approach was based on latest TAG methodology which takes into account health effects including sleep disturbance, amenity, AMI (heart attack risk), stroke and dementia. This approach considers noise levels down to 45 dB $L_{Aeq,16hr}$ during day to measure amenity effects. Stroke and dementia effects start at 47dB $L_{Aeq,16hr}$. At night, noise levels as low as 45 $L_{Aeq,8hr}$ are used to measure sleep disturbance.

For valuation of noise, Sansom et al. relied on property prices using hedonic pricing. The method assumed that a 1 dB(A) increase in noise levels just above the threshold of annoyance (e.g. 56dB(A)) leads to an identical economic value as a 1 dB(A) increase at 80 dB(A). Task 1-798 used the latest TAG methodology, which is based on the value of health effects. TAG distinguishes the higher monetary value of 1 dB(A) change as the noise levels increase.

5.5 Adopted methodology outline

5.5.1 Overview

The framework for calculating the marginal external cost for noise for additional HGV traffic is shown diagrammatically in the figure below (Figure 8: MEC Noise – methodology framework).

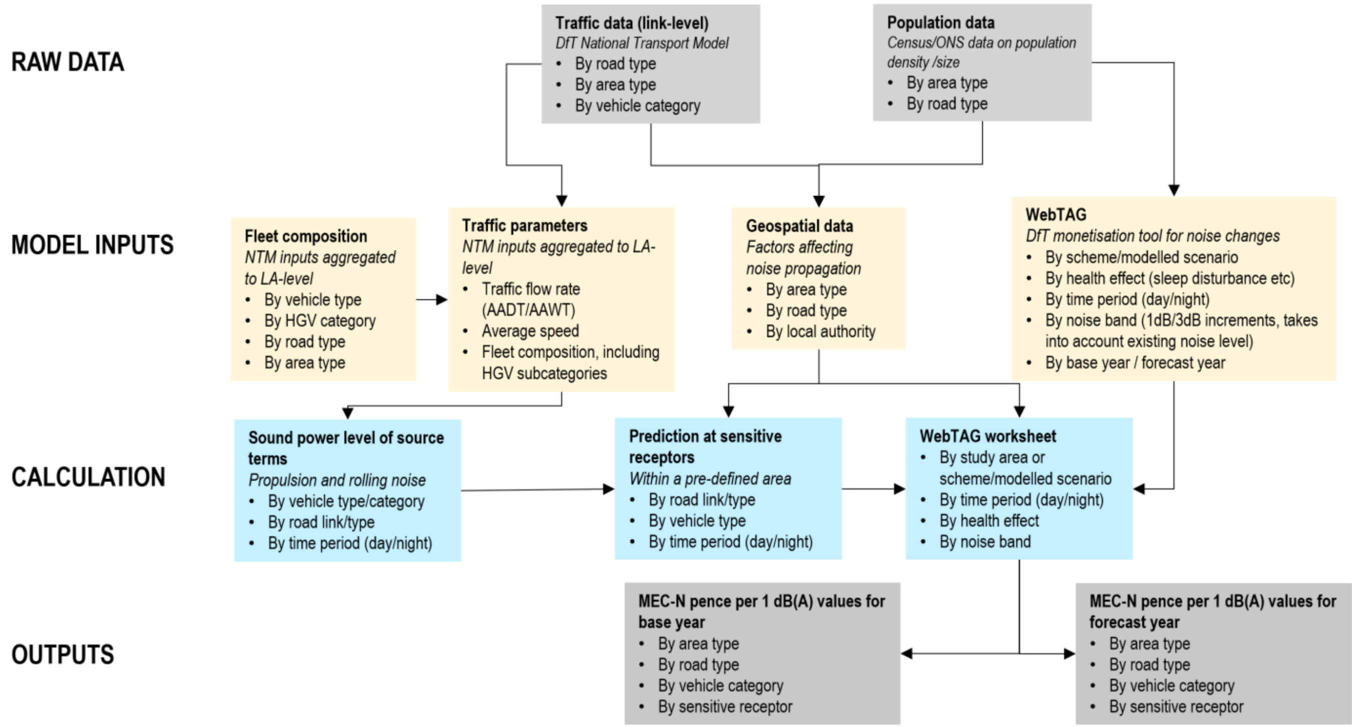


Figure 8: MEC Noise – methodology framework

The marginal economic cost was calculated using a bottom-up approach, where the noise generated by the road was calculated and an economic cost was applied to it based on the noise levels at sensitive receptors or households located in proximity to it. The process shown in the framework can be simplified as shown in the figure below (Figure 9).

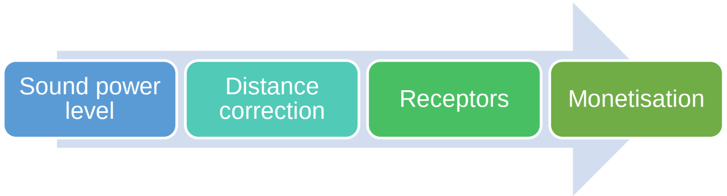


Figure 9: MEC Noise – key calculation steps

The methodology behind each of the four key stages of the calculation is described in the following subsections. More detailed information regarding the calculation procedure is provided in Section 5.9.

5.5.2 Sound power level

Road traffic noise levels were calculated based on the traffic flow on the road, the fleet composition and the average traffic speed. The overall received noise levels considered in this project consisted of noise contributions from light vehicles (passenger cars) and heavy goods vehicles. For MEC-N, the sound power level of the road was calculated taking into account contributions from these vehicle categories, with contributions from heavy goods vehicles calculated separately for rigid and articulated HGVs.

The noise contribution for each vehicle category was determined by calculating the noise produced by the two main vehicular noise sources shown in Figure 10 – propulsion noise and rolling noise.

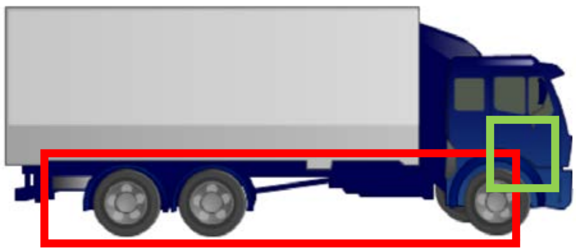


Figure 10: MEC Noise – Vehicular noise sources considered

Propulsion noise is concerned with engine noise and processes that make the vehicle move. Rolling noise is generated by the interaction of the vehicle's tyres with the road surface. For HGVs, rolling noise is affected by the number of axles on the vehicle. This means that articulated HGVs produce more rolling noise than rigid HGVs, based on the assumption that they have more axles. As part of the MEC-N calculations, the noise contributions from propulsion and rolling noise components were combined and factored to take into account the traffic flow and average speed.

5.5.3 Distance correction

The overall sound power level was converted to a reference sound pressure level at a reference distance of 10m and was corrected for distance to show how road traffic noise levels change as sound propagates further away from the road. A number of correction factors that affect sound propagation were omitted for simplicity, such as ground effects (except in rural areas) and screening from buildings. However, some adjustments were made as part of 'population count' calculations to minimise the influence of these factors. Further details of the assumptions relating to distance correction are provided in section 5.8.2.

5.5.4 Receptors

Monetisation of additional road freight for noise is intrinsically linked to the population size that would be affected by road traffic noise. One of the main limitations of simplified noise calculations based on distance bands is that precise noise levels at individual receptors are not known. In reality the noise levels at each receiver would be determined by a number of complex and site-specific factors, including but not limited to, screening from buildings, soft ground absorption, angle-of-view of a road segment and the masking influence from ambient noise levels from non-specific sources. These factors could be taken into account more robustly by more detailed studies (3D noise modelling). As part of this study, a number of assumptions were made as described in section 5.8.3.

The population size was estimated based on applying the relevant population density information to the "study area", taken to be a 1 km wide transect area perpendicular to both sides of the road that nominally extends up to 600m from the edge of the road, as shown below in Figure 11. A distance of 600m is consistent with the definition of a 'calculation area' in DMRB (2011).

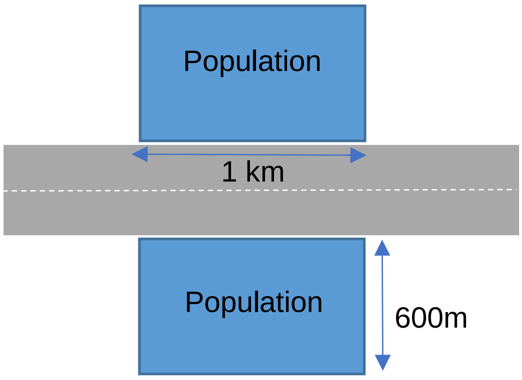


Figure 11: MEC Noise - scale of study area

Subject to refinements described later in the report, the population size was calculated at each of the distances that the sound pressure levels were predicted from the road and converted into households by applying the multiplier used in TAG. Assumptions relating to population density are provided in Section 5.8.3.

5.5.5 Monetisation

Monetisation of impacts was undertaken using the Data Book Unit A3 workbook for Noise. The Data Book computes the monetisation through comparison of noise levels predicted at households between two assessment scenarios. In this context, 'without scheme' scenarios are the base scenarios in each traffic forecast year (e.g. 2020, 2030 etc) and 'with scheme' scenarios are the same scenarios with additional HGV traffic.

TAG assigns each household in the study area to a 3dB noise band, with each noise band assigned a standard economic value based on the magnitude of the road traffic noise level and the difference in noise band between the base scenario and additional traffic scenario. To enable comparisons, the number of freight movements were adjusted in a way to give at least 3dB noise change for the assessment scenario under consideration.

The economic values are disaggregated to monetise a number of impacts related to noise, including sleep disturbance, risk of acute myocardial infarction (heart attack), dementia, stroke and amenity. Together, these impacts are summed to form the Net Present Value, which the standard calculation assumes to be a 60-year appraisal period. In this study, the assessment period for NPV was limited to one year. The calculations were undertaken separately for day and night periods.

To find the MEC for Noise, the Net Present Value (and/or disaggregated impacts) was divided by the number of additional rigid/articulated lorries required to generate the 3dB noise change, and further corrected to obtain the daily cost. The results in 2010 prices were transferred to 2020 prices. This provided a marginal economic cost per HGV for a kilometre of road.

5.6 Data specification

MEC-N was calculated based on information from the following four data sources:

- National Transport Model data for each road type, area, congestion level, and forecast year,
- Population density statistics for each area obtained from the Census,
- Source noise coefficients in third-octave band frequencies for cars and HGVs stated used in the Harmonoise and Nord 2005 road traffic noise prediction models, and
- Data Book Unit A3 for monetisation values.

5.7 Scenarios

A total of 430 scenarios were modelled to calculate the marginal cost. The scenarios consist of permutations of the following six variables:

- Year of traffic projection (2015, 2020, 2030, 2040, 2050)
- Road category (Motorway, A Road, Other)
- Area type (London, Inner and Outer Conurbations, Other Urban, Rural)
- Free flow and congested roads conditions
- HGV categories (Rigid, Articulated)
- Daytime and night-time traffic conditions

5.8 Model assumptions and inputs

5.8.1 Sound power levels

The calculations for the sound power levels for each assessment scenario were based on the following assumptions:

- Calculations were undertaken for a typical 1km length of road.
- Median data for traffic flows, speeds and percentage of heavy vehicles were used to represent each of the different road and area types under consideration.
- Rigid HGVs have two axles (class HGV1 in the traffic data).
- Articulated HGVs have 4 axles (class HGV2 in the traffic data).
- Source terms for rolling noise and propulsion noise provided in Harmonoise et al (2004) and Jonasson (2005) were used for light vehicles and the two HGV classes considered in this project. An outcome of this is that rolling noise for articulated HGVs is 3dB louder than for rigid HGVs as they have more axles.
- The sound power levels were converted to a sound pressure levels using the L_{Aeq} conversion shown in Sakamoto (2015).
- %HGVs for HGV1 and HGV2 were increased to achieve a 3dB change to align with TAG for assessing significant effects of noise on health and quality of life.

5.8.2 Prediction of noise levels

The noise predictions for each of the road types and areas were based on the following assumptions:

- Road traffic noise was predicted at various distances from the road links using the equations in the Calculation of Road Traffic Noise (1988).
- The source line of the road is 3.5m from the nearside carriageway and a nominal source height of 0.5m above road, located on the carriageway side.
- Noise effects from road surfacing type/age/condition were ignored.
- Ground topography was ignored. It is assumed that the land between the road and the receptors is flat.
- Road was assumed to be flat and straight and the receiver has a full angle-of-view of the road.
- Effects of screening from buildings, barriers or other large obstacles or features were ignored. This means that the road traffic noise levels predicted further away from the road, especially in urban areas, could be overestimated.
- Effects of ground absorption were ignored except in rural areas (hard/soft ground). This means that the road traffic noise levels predicted further away from the road in open areas with soft ground cover could be overestimated.
- With the following exceptions, the calculations were undertaken at the following distances from the edge of the nearside carriageway: 10m, 25m, 50m, 75m, 100m, 150m, 200m, 250m, 300m, 400m, 500m, 600m.

  - In 'London and Inner/Outer conurbations', the assessment distance was capped at 100m (both sides of the road link), based on professional judgement, to account for the reduced impact from noise at larger distances due to potential screening from buildings, reduced angle-of-view of the road and increased influence from masking effect by ambient noise.
  - In 'Other Urban' areas the assessment distance was capped at 300m (both sides of the road link), based on professional judgement, to account for the reduced impact from noise at larger distances due to potential screening from buildings, reduced angle-of-view of the road and increased influence from masking effect by ambient noise.
  - In 'Rural' areas use the full assessment distance of 600m (both sides of the road link) as per DMRB but assume soft ground absorption where the influence of above factors are less pronounced.
- A nominal receptor height of 1.5m above local ground level was assumed.
- No façade correction was applied (free-field conditions assumed).
- Effects of air absorption and site-specific meteorology were ignored (assumed moderate positive wind vector in line with sound propagation standards).

5.8.3 Receptors

For the purposes of this study, a number of assumptions were made to limit the potential undue influence from over-counting the population as described above.

Further assumptions are described below, to determine the number of receptors affected by noise changes along each of the road types and areas:

- Population density for each of the four area types was based on census data.
- Conversion of population/hectare to population/km^2.
- Receptors were assumed to be located on both sides of the road and are uniformly distributed with distance from the road (subject to simplifications above).
- All receptors have a full, unobstructed angle of view of the road.
- The study area (spatial envelope in which receptors are located) for all scenarios was limited to a maximum of 1 km x 600m area either side of the road as shown in Figure 11.The overall length of the road is 1km for convenience to reflect the unit of calculated MEC-N per vehicle km. The overall depth of the study area is 600m (either side of road) for consistency with the definition of ‘calculation area’ in DMRB.
- All receptors are dwellings, or “households” as referred to in TAG.

5.8.4 TAG

The TAG calculations assume the following:

- Opening Year: 2020
- Forecast Year: 2021
- Scheme type: Road
- Current Year: 2019
- Income and Price base year: 2010
- Appraisal period (years): 1
- Different Scenarios: No. of households experiencing 3dB change without and with scheme case in the opening year.

The price year used for calculations is later rebased according to the DfT’s requirements. This does not account for potential population growth in the affected area for the forecast years.

5.8.5 Derivation of MEC-N

The conversion of the 1-year NPV figures to marginal costs assumes that they can be calculated by taking into account the number of additional HGVs shown to generate the 3dB noise increase. This allows a MEC-N figure to be produced for a road of 1 km length per HGV per day.

The GDP deflator series from the May 2019 Data Book ('annual parameters' sheet) was used to inflate 2010 based year values to 2020 prices.

The GDP per person series from the May 2019 Data Book ('annual parameters' sheet) was used as the indexation series to uprate base year values (in 2020 prices) to the relevant forecast year (2020 to 2050).

5.9 Calculation procedure

5.9.1 Step 1: Calculation of sound power level

5.9.1.1 Calculate number of HGVs

Fleet composition details were available as percentages for two classes of HGVs – HGV1 and HGV2.

The percentage composition of each HGV category was used to determine the number of HGVs and light vehicles on the road from the overall traffic flows.

5.9.1.2 Calculate rolling noise

Jonasson et al (2004) and Jonasson (2006) provide source terms for rolling noise consisting of two coefficients, aR and bR. The data for the two coefficients are provided in third-octave bands between 25 Hz and 10 kHz for each of the three vehicle categories.

The A-weighted rolling noise sound power level for each vehicle category was calculated by adjusting the source terms for each third-octave band centre frequency according to the speed V of the road for each scenario. The adjustment is relative to a reference speed V_{ref} of 70 km/h, using the following equation:

$$aR + bR\left(\log_{10}\left(\frac{V}{V_{ref}}\right)\right) \qquad (1)$$

The adjusted third-octave band source terms were then added logarithmically added to calculate the overall rolling noise sound power level for each vehicle category.

5.9.1.3 Calculate propulsion noise

Jonasson et al (2004) and Jonasson (2006) provide source terms for propulsion noise consisting of two coefficients, aP and bP. The data for the two coefficients are provided in third-octave bands between 25 Hz and 10 kHz for each of the three vehicle categories.

The A-weighted propulsion noise sound power level for each vehicle category was calculated by adjusting the source terms for each third-octave band centre frequency according to the speed V of the road for each scenario. The adjustment is relative to a reference speed V_{ref} of 70 km/h, using the following equation:

$$aP + bP\left(\log_{10}\left(\frac{V-70}{V_{ref}}\right)\right) \qquad (2)$$

The adjusted third-octave band source terms were then added logarithmically added to calculate the overall propulsion noise sound power level for each vehicle category.

5.9.1.4 Overall sound level

For each of the three vehicle categories (light, HGV1, HGV2), the sound power level for a single vehicle is calculated by logarithmically adding the rolling noise and propulsion noise. The sound power level for each vehicle category was converted to a sound pressure level at a reference distance of 10m from the edge of the road and scaled up to represent the traffic flow for each road/area scenario using the following equation from Sakamoto (2015):

$$L_{Aeq,T,D} = L_{wA} + 10\log_{10} D - 10\log_{10} V + 10\log_{10} N_t + 10\log_{10}\left(\frac{3.6}{2T}\right) \qquad (3)$$

Where L_{Aeq} = the A-weighted equivalent continuous sound pressure level, L_{wA} = the A-weighted sound power level for a single vehicle, D = distance from road, V = speed in km/h, N_t = traffic flow for the vehicle category, T = time in seconds for the calculation period.

The total A-weighted sound pressure level was calculated by logarithmic addition of the L_{Aeq} values for each vehicle category.

5.9.1.5 Calculate HGVs required for 3dB change

To calculate the marginal cost, the traffic data was adjusted to determine the number of extra HGVs required for a 3dB change. This was done by:

- Keeping the number of light vehicles and HGV1 constant and increasing HGV2.
- Keeping the number of light vehicles and HGV2 constant and increasing HGV1.
- Repeating the process separately for day and night time periods.

The same process of calculating the sound power level and sound pressure level was repeated for all marginal scenarios. Appendix 5 provides a sample calculation for a selected scenario, to demonstrate the main steps in the process. The number of additional HGVs required to result in a 3dB change in each of the scenarios is summarised in Appendix 6.

5.9.2 Step 2: Distance correction

The total A-weighted sound pressure level at a reference distance of 10m from each road was corrected for distance to calculate noise at all distance bands. The distance correction has been applied by using the following calculation adapted from CRTN (1988), which takes into account the distance from the road's source line to the kerb:

$$L_{Aeq,T,D} = L_{Aeq,T,10m} - 10\log_{10}\left(\frac{\sqrt{(10+3.5)^2 + D^2}}{13.5}\right) \qquad (4)$$

Where:

L_{Aeq} = the A-weighted equivalent continuous sound pressure level

D = distance from road

T = time in seconds for the calculation period.

This process was repeated for all scenarios under consideration.

5.9.3 Step 3: Receptors

Prior to calculating the population size of the study area, the population density figures from the Census were converted from population/hectare to population/km^2, for alignment with the same measurement units used for calculating MEC-N.

Using the population density, the number of people living between each distance band were calculated (e.g. 25-50m from the road), parallel to a 1 km section of road. This figure included population within a given distance band on both side of the road (see Figure 11).

For input into TAG, the population figures were converted into "households" by assuming a factor of 2.3 people per household (as advised in TAG). The total number of households was calculated by summing all of the households shown for each of the distance bands.

This process was repeated for each scenario.

5.9.4 Step 4: TAG and Derivation of MEC-N

The information created in Section 5.9.3 was transposed into the Data Book, which calculates the Net Present Value and other monetised noise impacts.

The calculations copied into each workbook compare one of the traffic forecast scenarios with the equivalent scenario that has additional HGV1 or HGV2 vehicles. For example, 2020 A Roads in London is compared with 2020 A Roads in London with additional HGV1 traffic sufficient to result in a 3dB noise increase.

The conversion of the 1-year NPV figures to marginal costs per vehicle kilometre per day was determined by:

$$M_i = \frac{W_i}{365\,F_i} \qquad (5)$$

Where:

M = Marginal Economic Cost for Noise (MEC-N)

W = NPV or disaggregated noise impact from TAG

F = additional HGV freight

i = MEC scenario (combination of year, road type, HGV type, area type, congested/non-congested, day/night period).

The results in 2010 prices were transferred to 2020 prices. The calculated MEC-N values (pence/vehicle kilometre) for the 2020 scenario are provided in Section 5.10.

5.10 MEC Noise values

MEC Noise values are presented in Table 41 in 2020 prices.

Table 41: MEC Noise – values in pence/vkm, Artics, Rigids 2020 prices, base scenario

	Artics							Rigids						
	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
Inner and Outer Conurbations														
Motorways	2.11	2.07	2.02	1.97	1.92	1.88	1.85	0.97	0.96	0.94	0.91	0.88	0.87	0.85
A Roads	15.42	15.10	14.78	14.46	14.14	13.81	13.49	5.43	5.32	5.21	5.07	4.94	4.79	4.65
Other Roads	74.22	70.98	67.76	65.74	63.73	62.62	61.50	26.83	25.65	24.48	23.73	22.98	22.61	22.23
London														
Motorways	3.16	3.05	2.95	2.86	2.75	2.57	2.39	1.52	1.47	1.43	1.39	1.34	1.25	1.16
A Roads	21.69	20.95	20.21	19.58	18.96	18.83	18.70	8.43	8.13	7.83	7.58	7.33	7.26	7.19
Other Roads	155.83	147.61	139.52	141.11	142.40	140.26	138.15	58.74	55.59	52.51	53.21	53.82	53.09	52.35
Other Urban														
A Roads	20.05	19.59	19.14	18.71	18.29	17.90	17.53	7.35	7.18	7.02	6.84	6.66	6.52	6.39
Other Roads	88.47	86.61	84.72	81.51	78.31	75.94	73.59	31.76	31.13	30.49	29.32	28.15	27.29	26.44
Rural														
Motorways	0.45	0.44	0.42	0.41	0.40	0.39	0.38	0.21	0.20	0.20	0.19	0.19	0.18	0.18
A Roads	2.94	2.86	2.78	2.69	2.60	2.56	2.53	1.18	1.15	1.12	1.08	1.04	1.03	1.01
Other Roads	12.07	12.44	12.81	12.27	11.74	11.40	11.07	4.54	4.69	4.84	4.66	4.49	4.37	4.25

The calculated MEC-N values (pence/vehicle kilometre) for the 2025 scenario are provided on Figure 12, for 2025 impacts and in Table 41. The MEC-N values for ‘Other Roads’ are substantially higher than the corresponding values for ‘A roads’ and ‘Motorways’ in any given area type, HGV category and year of traffic projection. The total MEC-N costs for ‘Other Roads’ are smaller than for other road types, but a disproportionately smaller number of additional HGVs are required to result in a significant noise change. This results in a much higher MEC-N per vehicle km.

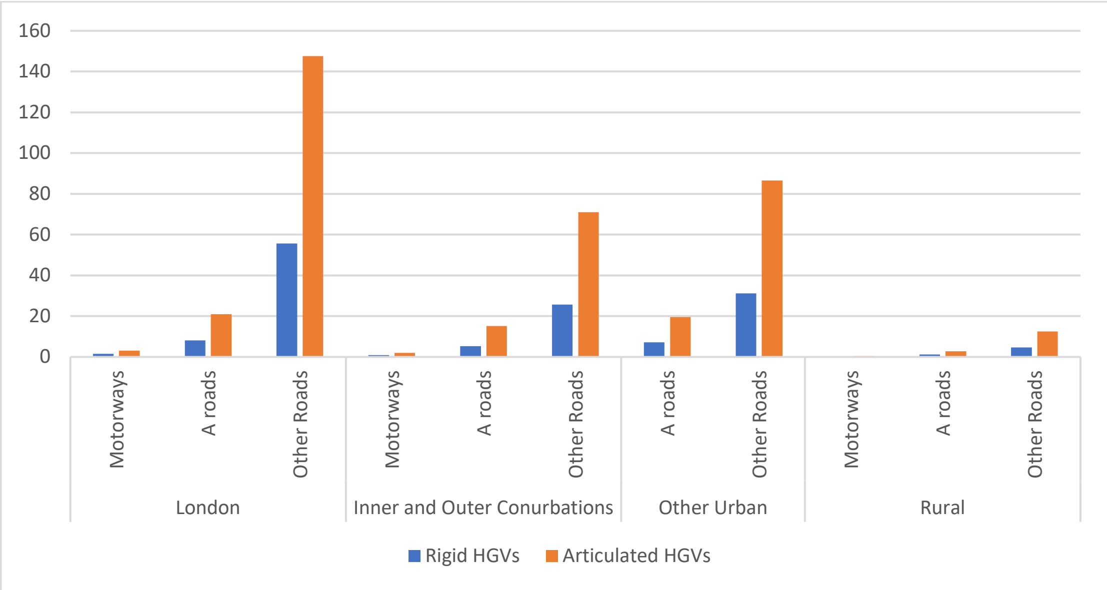


Figure 12: MEC-N values, pence per vkm, 2025 impact, 2020 prices, by HGV type

MEC-N values calculated using the updated methodology tend to be much higher than values computed based on the previous method for Other roads, both for rigid and articulated HGVs (see Figure 13). This is a result of the fact, that the current bottom-up methodology enables to capture the noise impacts for different traffic conditions. Although the total MEC-N costs for ‘Other Roads’ are smaller than for other road types, due to traffic composition a disproportionately smaller number of additional HGVs are required to result in a significant noise change.

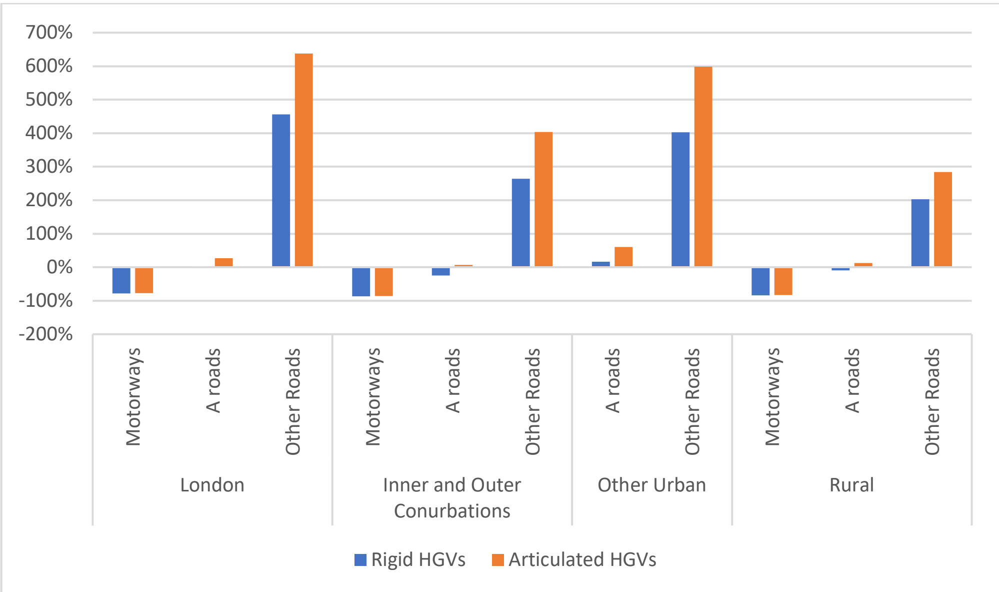


Figure 13: Difference between the MEC-N values computed using the new and the previous methodology, by HGV type, 2025 impact, 2020 prices, previous values = 100%

5.11 Sensitivity scenarios

A review of the influence of fuel types and technology on noise emissions from HGVs identified that currently there is a limited evidence base to be able to calculate potential impacts as part of MEC-N. Therefore, the sensitivity scenarios which involve alternative fuel types and technology are not considered as part of this study.

5.12 Indexation and updates

The model will require regular updates to maintain integrity and robustness. Table 42 reports the key MEC Noise parameters that will need updating and the regularity of update intervals. The update intervals are meant only as a guide and consider the likely magnitude of changes over time for each parameter that would warrant a revision.

Table 42: MEC Noise – model parameters and updating intervals

Parameter	Recommended update frequency
Traffic volumes, number of HGVs	Should be updated every 5 years based on the NTM.
Unit value of noise	Should be updated every 5 years to reflect any changes to TAG.
Population density	Should be updated every 5 years based on Census Data

5.13 Limitations and recommendations

The MEC-N assessment method and outcomes described in this report depend crucially on the assumption that the value per additional vehicle kilometre is a linear interpolation of the value of a 3dB change in the noise levels (i.e. a doubling of energy). A large relative change in the HGV flow is required to achieve such a change. This approach was adopted partly for practical reasons to align the calculations with the Data Book and partly because a 3dB change in environmental noise over a period of time is widely considered to be the smallest perceptible change.

It may be desirable to undertake further analysis based on 1dB step changes, using a modified version of the Data Book, to assess the sensitivity of MEC-N values to this assumption. Due to the non-linear (logarithmic) nature of sound level addition, it is likely that a disproportionally smaller number of additional HGVs would be needed to result in a 1dB change in overall noise, in a given scenario. This is particularly relevant to the 'Other Roads' category as discussed in 6.10.

Impacts from noise are very site specific. Apart from the traffic related factors (flow volumes, speeds, heavy vehicles) which were taken into account as part of this study, the parameters which affect accurate determination of noise levels at a receiver include, but are not limited to, distance, screening, ground effects. The valuation of noise will further be affected by the population living at the specific receiver. Therefore, a simplified approach to modelling noise propagation introduced some uncertainties and limitations on the study. In the long run, it may be possible to adapt future rounds of strategic noise mapping, to allow for more detailed MEC-N studies to be conducted at a national level. However, this would require the underlying calculation methods, as well as the physical road network and classification, to be aligned with the preferred MEC-N methodology which might not be compatible with the requirements of strategic noise mapping.

6 Behaviour

6.1 Introduction

The behavioral marginal external costs (i.e. driver frustration / stress, fear of accidents, community severance) are not currently differentiated by the DfT. An uplift of 10% to total value of quantified external costs excluding infrastructure and taxation (6 pence per mile uplift) was used in the last refresh of the Mode Shift Benefit Values (DfT, 2014) as a proxy for all other external costs MEC-Other, including behavioral costs.

An initial review by Atkins and Jacobs (2019) of appraisal approaches for MEC-Other (MEC-O) documented alternative methods and recommendations for updating these values. The review concluded that MEC-O could be simplified through the amalgamation of various external cost categories into distinct groups, including a behavior-specific category (MEC-B). The external costs falling into this category are:

- Driver frustration / stress
- Fear of accidents

Behavioral external cost categories are generally complex to measure, due to both complex impact and uncertain valuation approaches. The methodology presented in this report is built upon the recent research results on the level of frustration and stress experienced by drivers encountering HGVs.

The MEC-B values were disaggregated according to area type; road type; congestion band and year. At this stage of research on the subject, there is not enough evidence to differentiate between impacts caused by rigid and articulated vehicles, so the values are presented for both HGV categories are the same.

6.2 Current approach

At present, there are no monetised values for quantifying external costs of behavioural impacts.

- Driver frustration
- Community severance
- Fear of accidents

The current approach set out by the DfT uses the values provided by Maibach et al. (2008). Maibach et al provides values for:

- Up and downstream processes (3% of total value of external costs)
- Soil and water pollution (2%)
- Nature and Landscape (not considered Maibach et al (2008) to be significant for marginal changes in road freight traffic)

In the absence of quantifiable evident an uplift has been accepted in previous Mode Shift Benefit values. An uplift of 10% to other external costs (6 pence per mile uplift) excluding infrastructure and taxation was used in the last refresh of the Mode Shift Benefit Values (DfT, 2014). Mode Shift Benefits values are estimates of the benefit of removing a lorry mile from the road network in Great Britain by transferring the goods to rail or water freight, presented on Table 43.

Table 43: Modal Shift Benefits values by road type and component (pence per lorry mile, 2020 values in 2015 prices)

MEC Categories	Motorway		A Roads	Other	Weighted Average
	High	Low			
Congestion	99	24	72	78	57
Accidents	0.5	0.5	5.6	5.5	2.7
Noise	9	7	8	14	8
Pollution	0	0	0.1	0.2	0.1
GHG	6	6	7	9	7
Infrastructure	7	7	24	171	18
Other (roads)	6	6	6	6	6
Taxation	-31	-31	-32	-40	-31
Rail	-8	-8	-8	-8	-8
Total	89	12	82	235	58

6.3 Best practice methodologies review

6.3.1 Driver frustration/stress

As part of Highways England Task 1-705 (Information and Road Layout Research) a literature review was carried out to summarise the available evidence relating to the methodology of assessing driver stress and anxiety. The review therefore draws heavily on insights acquired from Task 1-705.

Task 1-705 covered academic papers and ‘grey’ literature relevant to driver stress, anxiety and frustration. In addition, guidance documents for transport appraisal were collected from the UK and overseas including France, Germany, Sweden, Australia and New Zealand). The review also considered a number of previous Highways England’s reports on journey quality and related topics. Although the literature review considered stress and anxiety relating to all vehicle types, there are some references to the impact of HGVs. The following sources were used in the review:

- Atkins and Jacobs (2019). Task 1-705 Road Layout and Information.
- DfT (2009). Mode Shift Benefit Values: Technical report
- DfT (2017) Social impact appraisal. TAG, TAG Unit 4.1,
- Highways Agency (1993) Vehicle travellers. Design Manual for Roads and Bridges, Vol.11 Section 3 Part 9
- Highways England (2017) Customer experience of changes in speed limits within roadworks. Unpublished Report.
- Highways England (2018a) Customer Insight Programme - Smart vs Standard Motorways Research. Unpublished Report
- Highways England (2018b) Behavioural insight programme - negative driving behaviours research. Unpublished Report
- Mehler, B., Reimer, B., Wang, Y. (2011) A comparison of heart rate and heart rate variability indices in distinguishing single task driving and driving under secondary cognitive workload. Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design
- Murphy, P., Casey, J., McDonald, J. (2014) Experimental study of the factors that influence driver frustration on the A9. Proceedings of the European Transport Conference 2014.,
- Murphy, P., Casey, J., McDonald, J. (2016) Experimental study of the factors that influence driver frustration - a Stated Preference approach - an update. Proceedings of the European Transport Conference 2016.
- New Zealand Transport Authority (2017) Economic Evaluation Manual Economic Evaluation Manual, NZTA
- Transport Scotland (2018) Scottish Transport Analysis Guidance Technical Database. The

Scottish Government, Edinburgh

- Welsh Government (2008) Welsh Transport Planning and Appraisal Guidance (WelTAG). The Welsh Assembly Government, Cardiff

The Design Manual for Roads and Bridges defines driver stress as “the adverse mental and physiological effects experienced by a driver traversing a road network” and identifies its three main components (Highways Agency 1993, 4.1-4.5), as below:

- Frustration caused by the inability to drive at a speed consistent to one’s expectations in relation to the standard of the road
- Fear caused by the possibility of collision with other vehicles or with pedestrians (suggesting driver frustration/stress may also be conflated with fear of accidents)
- Route uncertainty

With regards to the presence of HGVs, Highways England (2017) found that the size, number and speed of HGVs, and the inability to overtake, tends to increase fear of driving during roadworks. Driver stress may also depend on the characteristics of the driver, such as gender, age, health status, skills and experience of driving, attitudes towards driving, propensity for aggressive behaviour, and knowledge of the route.

The following sub-headings present a detailed review of selected papers and their methodological approach in assessing driver stress and anxiety.

6.3.1.1 Stated preference studies

Work commissioned by Transport Scotland on driver frustration was the only study that looked at valuing aspects of driver stress. The results of this study were first reported in Murphy et al. (2014) and updated in Murphy et al. (2016). This study did not provide monetary valuations of driver stress but provides travel time uplifts to account for traffic situations associated with stress. However, these can be converted to monetary values by applying the value of travel time. This study consisted of two stages. In the first stage, participants watched computer-simulated videos of different driving conditions, and rated their level of frustration in response to each video. The second stage was a stated preference exercise where participants were asked to choose routes for a trip, described by text and images. The attributes of the exercise were the number and type of vehicles ahead, presence of oncoming traffic, speed, presence of speed cameras, travel time and proportion of HGVs.

The effect of HGVs seemed to indicate that a higher percentage of HGVs is associated with greater driver frustration only in longer platoons, but it is not a large effect. The modelling work also derived a time multiplier (proxy for frustration level), which suggested increases of 0.0476 for each HGV in the platoon ahead of traffic.

By modelling the route choices, it was possible to derive the willingness to travel longer times to avoid scenarios such as the presence of heavy goods vehicles ahead, oncoming traffic, and speed below desired speed. A very high correlation was found between this willingness to travel further and the driver frustration index derived in the first stage of the study for similar driving conditions.

Benefits/limitations: Stated preference studies are a powerful approach for eliciting people’s preferences for non-market goods and services. This is done through surveys which construct surrogate (hypothetical) markets for non-market goods using various attributes. However, they are expensive to administer and resource intensive.

Data inputs: Large sample size (> 200 people) of different population demographic’s

Outputs: Willingness to pay estimates derived from the (representative) sample for supplying the non-market good(s) in question. This could be related to WTP for a marginal change in the number of HGV vehicles on the road network.

6.3.1.2 Qualitative assessment

Driver stress is generally not considered during the transport appraisal process, but is sometimes included as part of other elements. For instance, the DfT’s guidance for transport appraisal (TAG) treats driver stress as one aspect of journey quality, covered in the section on social impact appraisal, last updated in 2017 (DfT 2017). The document suggests that, similar to other aspects of journey quality, a qualitative assessment of driver stress is appropriate in most cases, using the methods in the Design Manual for Roads and Bridges. TAG also suggests that the impact of policies on journey quality "is likely to be large (beneficial or adverse) where the numbers of travellers affected is high (more than 10,000)" (DfT 2017, 6.2.7). However, the guidance does not encourage valuation of journey quality, including driver stress, mentioning that "currently, there is limited evidence of monetary valuations of quality specific to road users" (DfT 2017, 6.3.12).

Benefits/limitations: Qualitative assessment is the recommended approach of the documenting how changes in journey quality (of which driver stress is a factor) can be recorded. While this may be appropriate for appraisal of new transport schemes, it is not useful for quantifying the MEC of HGV transport.

Data inputs: Qualitative interviews and associated data recording.

Outputs: Interview and qualitative summaries of factors that influence driver stress. These could be categorically scored.

6.3.1.3 Travel time value uplift

The guidance of Transport Scotland (Scot-TAG) for transport practitioners working on Scottish-based transport projects supports the view that journey quality benefits should be assessed qualitatively (Transport Scotland 2018, 9.2.2.8). However, it suggests a method for assessing driver frustration, using travel time value uplifts derived from Murphy et al. (2014, 2016), applied to three traffic situations (identified by microsimulation modelling): the presence of oncoming traffic, the degree to which speed is below desired speed, and the number of HGVs in the platoon ahead. Travel time multipliers quantify driver frustration in terms of drivers' perception of the journey time uplift due to frustration.

Benefits/limitations: Travel time uplift can be considered a proxy for driver frustration/stress and the value of time in transport appraisal has a well-established methodological framework for valuation. However, data on marginal delays caused by additional unit of HGV traffic entering the network is not readily available.

Data inputs: Data tend to be route specific but could be averaged according to journey time uplift for different road types, area types and congestion bands. Input data is not readily available so would need to be estimated.

Outputs: Journey time uplift figures (appropriately disaggregated) that can be monetised according to the economic value of time.

6.3.2 Fear of accidents

Fear of accidents is described as "Presence of other vehicles, inadequate sight distances, possibility of pedestrians stepping into the road, presence of central reservation or safety barriers (or not); inadequate lighting; of the width of the road/carriageway/lane; presence of roadworks; the absence of lane markings, cats' eyes and hard shoulders."

People with fear of accidents worry they might hurt themselves or someone else, they also fear causing property damage. Under Transport Analysis Guidance Unit A4-2 Social Impact Appraisal, fear of potential accidents is a sub element of traveller stress in determining the overall journey quality.

A literature review has been conducted on valuation of fear of accident in the context of impacts of marginal changes in freight traffic. The following sources have been reviewed:

- Adler, D. M. (2004) Fear Assessment: Cost benefit analysis and the pricing of fear and anxiety.
- AECOM & Transport Scotland (2016). Experimental study of the factors that influence driver frustration – a stated preference approach – an update.
- DfT (2009). Mode Shift Benefit values: Technical report.
- DfT, (2014). TAG Unit A4.1.Social Impact Appraisal
- DfT (2014b). Mode Shift Benefit Values: Refresh

- DMRB (1993). Vehicle Travellers: Volume 11 Section 3 Part 9
- MTRU (2014). Heavy Goods Vehicles- do they pay for the damage they cause? Report prepared for Campaign for Better Transport
- Zeidner, M. & Shechter, M. (1994). Reduction of test anxiety: a first attempt at economic Evaluation, 7 Anxiety, Stress & Copiting 1

Although no study has been found that attempts to quantify fear of road accidents in the UK, a few studies have explored methods for quantified fear in other contexts or have provided inputs to this discussion, listed in Table 44.

Table 44: MEC Behaviour - studies reviewed for fear of accidents

List of Studies Reviewed	Overview	Approach & Parameters Used
Adler, D. M. (2004) Fear Assessment: Cost benefit analysis and the pricing of fear and anxiety.	This study argues for the inclusion and quantification of fear assessment in CBA to aid agency decisions.	Fear assessment based on contingency valuation with WTP/WTA values
AECOM & Transport Scotland (2016). Experimental study of the factors that influence driver frustration – a stated preference approach – an update.	The study aimed to monetise driver frustration amount of time that a vehicle in the Paramics microsimulation model spends in a platoon.	Stated preference study and Paramics microsimulation model
Metropolitan Transport Research Unit (2014). Heavy Goods Vehicles- do they pay for the damage they cause?	Assesses how taxes and charges can be said to “pay” for HGVs’ external costs, and what those costs may be, using existing values from European and UK research.	10% uplift as per Maibach et al. (2008) evidence

The following sub-headings present a more detailed review of selected papers and their methodological approach in assessing fear of accidents.

6.3.2.1 Contingency valuation

In a study *Fear Assessment: Cost benefit analysis and the pricing of fear and anxiety* conducted by Adler, D. M. (2004), Adler argues most agencies never engage in fear of assessment because it is normative difficult to predict and value. The author recommends that fear assessment should be part of CBA and discusses how best to measure fear on a monetary scale. The study makes the case for fear assessments to take an ‘unblundled form’ and analyses different methodologies for pricing fear and anxiety. Two methodologies that can be used to ascribe costs and benefits to be used in CBA are:

- Contingency valuation: where respondent is asked whether he or she would be Willing To Pay (WTP) a certain sum of money for a benefit, or WTP a certain amount of money for a benefit or Willing To Accept (WTA) a certain amount of money for a welfare-set. This method is argued to be better suited to reveal the cost of the welfare equivalent of fear state.
- Revealed preference studies: also a standard source of WTP/WTA but this methodology uses behaviour to infer a valuation.

The study further analyses two forms of contingency valuation:

- Quality adjusted life years to dollars technique - a widely used welfare scale in health economics, where respondents are asked to rank outcomes on scale of 0-1, 0 representing death and 1 very best state. It is less ideal because often the scale is not well understood as a welfare scale.
- Contingency valuation methods respondents are asked to use a money scale – for instance how much are you willing to pay to not have fear of accident while driving on the road

The study does not provide relevant examples to the context of fear of road accidents nor provides monetised values of fear. The only study identified to have used direct valuation of fear and anxiety was

Zeidner and Shechter (1994), who carried out a contingency valuation study of exam anxiety among Israeli students focused on fear state. The WTP values elicited in the study reflected the students WTP to avoid the combination of instinctive (impact that occurs in virtue of fear's experimental features) and instrumental costs (professional success) of fear.

Although this study suggests possible methods for pricing fear assessment, it does not provide technical guidance (or inputs/sources) on pricing fear in the context of freight related accidents.

6.3.2.2 Travel time value uplift

A stated preference study was administered in 2016 as part of an experimental study TRL and AECOM to understand driver frustration on the A9 (T) between Perth and Inverness in Scotland. The study aimed to monetise driver frustration, which was based on the amount of time that a vehicle in the Paramics microsimulation model spends in a platoon. The overriding assumption was that if there was no vehicle in front of a modelled vehicle to curtail its speed, then the driver would not be stressed / frustrated. However, where a vehicle was driving within a set headway of the vehicle in front, then the driver was considered to be in a platoon and as such the driver would be 'frustrated' and a higher value of time should be applied to the time that they were in said platoon. This difference in value of time multiplied by the time spent in a platoon is effectively the 'frustration benefit'.

A stated preference survey was used, and respondents were asked to think of a recent journey that they made on the same road as the context for their choices in the SP game (involving different values and levels for each variable). This was complemented by a TRL simulation exercise involving showing respondents short video clips which were rated on a scale for level of frustration and their intention to overtake. The preferred stated preference model used showed driver frustration depends on number of cars and HGV in a platoon, speed, incoming traffic and average speed cameras.

Based on TAG Unit A4-2 's description of fear of accidents, this model only captures the part of the fear of accidents impact such as presence of other vehicles and inadequate sight distances. This methodology is not recommended for quantifying fear of accidents as it would underestimate such impact and simultaneous would double count with driver frustration.

The Design Manual for Roads and Bridges further contributes to this discussion by highlighting that frustration is a contributory factor to stress, but also highlights 'fear' and 'uncertainty with regards the route being followed'. According to the DMRB fear is the highest when speeds, flows and the proportion of heavy vehicles are all high. All these factors become more important in adverse weather conditions. This suggests that an additional truck on the road would increase fear of accidents.

6.3.2.3 10% uplift as per Maibach et al. (2008)

The Metropolitan Transport Research Unit prepared a report for Campaign for Better Transport in 2014 focusing on assessing how taxes and charges can be said to "pay" for HGVs' external costs, and what those costs may be, using existing values from European and UK research. The studies used in this report that contained fear of accident impacts are summarised in Table 44Table 45 below.

Table 45: MEC Behaviour - comparison of average HGV values which include fear of accidents impacts

	SLM (2005 prices)	**MSB pence per mile for HGV (2010 prices)**
Quantified	71.9	77.5
Unquantified	16.9	6.4
Unquantified % of total	19%	8%
Included in unquantified	• upstream and downstream effects • driver frustration/stress • fear of accidents • restriction of cycling and walking • community severance • visual intrusion	• up and downstream processes • driver frustration/stress • fear of accidents • community severance (inc. restriction on cycling and walking) • visual intrusion • soil and water pollution • nature and landscape

These are in different years' prices and not directly comparable across studies

The Sensitive Lorry Miles (SLM) values were used by DfT to assess the value of reducing HGV traffic until 2010, they were originated by the Strategic Rail Authority's consultant. While the Modal Shift Benefit report (MSB) uses locally derived values with some from another EU overview report (Delft 2008). Both reports calculate the 'Other' unquantified impacts (driver frustration, fear of accidents, community severance and visual intrusion) based on evidence identified in Maibach et al. (2008). This is an uplift equivalent to 10% of the weighted average total value estimated for the other external costs already covered.

6.3.3 Community severance

Community severance is often defined as the separation of local communities by transport interventions or road traffic. In the context of freight being transported by road, community severance can be understood as the change in the level of severance arising from a marginal change of HGV kilometre on the network.

Community severance impacts are difficult to measure, and no standardised estimates are known. As a result, the marginal external costs of severance have not been studied in depth and no comparative studies were identified in the literature. The existing knowledge on severance was found mainly related to specific transport interventions and infrastructure (i.e. appraisal of new transport schemes). The current approach for dealing with community severance assessments in the UK guidance is predominantly based on qualitative assessments but with some quantitative analysis.

The reviewed literature included studies based on stated preference surveys to calculate people's willingness to walk longer times to avoid crossing busy roads (see Wixey et al. 2005), qualitative methods to assess pedestrian perceptions and crossing ratios (see Hine, 1996) and studies on the correlation between walkability indices derived from household surveys and trip purposes (see Manaugh and El-Geneidy, 2011). The following sources were reviewed:

- DfT (2017) Social impact appraisal. TAG, TAG Unit 4.1
- DfT (2009). Mode Shift Benefit Values: Technical report
- Anciaes, P. R., Jones, P., & Mindell, J. S. (2016). Community severance: where is it found and at what cost? Transport Reviews, 36(3), 293-317.
- Wixey, S., Jones, P., Lucas, K., & Aldridge, M. (2005). Measuring accessibility as experienced by different socially disadvantaged groups. London, Transit Studies Group, University of Westminster.
- Hine, J. (1996). Pedestrian travel experiences—Assessing the impact of traffic on behaviour and perceptions of safety using an in-depth interview technique. Journal of Transport Geography, 4, 179–199
- Manaugh, K., & El-Geneidy, A. (2011). Validating walkability indices: How do different households respond to the walkability of their neighborhood? Transportation research part D: transport and environment, 16(4), 309-315.
- Tomlinson, P., & James, E. (2005). Understanding community severance part 2: Monetisation of severance impacts (Report for the UK Department of Transport).

The following sub-headings present a more detailed review of selected papers and their methodological approach in assessing community severance impacts.

6.3.3.1 Stated preference and household surveys

Work by Wixley et al (2005) employed a stated preference survey to calculate people's willingness to walk longer times to avoid crossing busy roads. Barriers to accessibility were measured from the 'crossability' perspective (i.e how easy is it to cross the barrier?). Other dimensions of severance were not covered in the study (e.g. does the barrier reduce the quality of the walking experience?). It is unclear how this could be linked to marginal change in HGV traffic alone without the construction of a new survey instrument.

Benefits/limitations: Stated preference studies are a powerful approach for eliciting people's preferences for non-market goods and services. This is done through surveys which construct surrogate (hypothetical) markets for non-market goods using various attributes. However, they are expensive to administer and resource intensive (for both survey implementation and econometric modelling).

Data inputs: Large sample size (> 200 people) of different population demographics.

Outputs: Willingness to pay estimates derived from the (representative) sample for supplying the non-market good(s) in question. This could be related to WTP for a marginal change in the number of HGV vehicles on the road network that reduces severance impacts.

6.3.3.2 Qualitative assessment

Qualitative assessment is an approach for measuring community severance through interview techniques used in conjunction with videotape recording of different traffic conditions in various street environments. This generally takes the form of a bottom up approach (see Hine et al., 1996) that can be disaggregated by different social groups.

Benefits/limitations: Qualitative assessment is the recommended approach for documenting how changes in journey quality (of which driver stress is a factor) can be recorded. While this may be appropriate for appraisal of new transport schemes, it is not useful for quantifying the MEC of HGV transport.

Data inputs: Qualitative interviews and associated data recording.

Outputs: Interview and qualitative summaries of factors that influence community severance. These could be categorically scored.

6.3.3.3 Travel time uplift

Reviews by Tomlinson et al (2005) suggest the impacts of severance can be monetised on the basis of time lost to pedestrians when attempting to cross carriageways (i.e. as a function of the infrastructure and its use). This approach is used by Sweden, Denmark and Germany in terms of the barrier effect (i.e. considering factors such as traffic flows, the need to cross the road and traffic speed). A value of time saving is required to convert the forecast changes in travel time resulting from a marginal change in HGV extent on the network into monetary values that can be used in appraisal.

Benefits/limitations: Although examples exist where travellers trade travel time for cost, market prices for travel time are not easily obtainable and, in the absence of market prices, alternative techniques are required to estimate willingness-to-pay (e.g. revealed or stated preference methods). Fortunately**,** the Data Book contains values of travel time savings for working and non-working time that should be used in most economic appraisals of transport projects.

Data inputs: Data inputs vary depending on the appraisal guidelines applied. For instance, when severance is valued as 'time lost' by pedestrians, waiting times are required (usually as a function of the type of road and the traffic volume).

Outputs: Monetised effects of severance as a function of time loss.

6.4 Methodology selection

6.4.1 Methodology options assessment

Several methodology options were identified to address marginal behavioural external costs of HGV traffic (Table 46). Because it is a relatively new area of impact assessment, including monetization of impacts, the options available differ for different components of MEC Behaviour.

Table 46: MEC Behaviour – methodology options

Approach	MEC elements	Scope	Advantages	Disadvantages
Update values using existing approach	• Drivers frustration/ stress, • Fear of Accidents • Community severance	In scope	Cost effective, potentially adequate concerning relatively small share of behavioural MECs in the total MECs	Does not allow for a proper recognition of behavioural impacts, which are increasingly important from a decision-making point of view

Approach	MEC elements	Scope	Advantages	Disadvantages
Contingency valuation approach	Fear of accidents	Out of Scope	Improvement on existing values, captures the most recent trends and values	Time and data intensive. Requires a study UK wide that is statistically robust.
Time uplift approach	• Drivers frustration/stress • Fear of accidents	Out of scope	Time uplift approach allows for quantification of traffic-related behavioural impacts. The approach minimizes the risk of double counting by including both drivers frustration/stress and fear of accidents.	Lack of data on average changes in travel time as a direct function of HGV use. Therefore, marginal external costs would have to be proxied by average external costs. No impacts on cyclists/pedestrians included.

6.4.2 Recommended methodology

Travel time uplift is the most promising approach to account for driver frustration/stress and fear of accidents as a result of changes to the number of HGVs on the network. Our recommended approach would be based on travel time multipliers concept developed by Murphy et al. (2014, 2016). These multipliers quantify driver frustration in terms of drivers' perception of different traffic conditions: the presence of oncoming traffic, the degree to which speed is below desired speed, and the density of HGVs on the road section.

Benefits/limitations: In the proposed methodology, a proportion of an average delay cost will be used to account for MEC Behaviour as a result of changes to the number of HGVs. Travel time uplift approach will utilize the value of time in transport appraisal, which has a well-established methodological framework for valuation. Due to lack of data on changes in travel time as a direct function of HGV use, the average external costs will be calculated as a proxy for marginal external costs. The impacts on cyclists/pedestrians will be included by adopting additional multipliers for congested secondary road sections in rural areas, where traffic-caused severance is perceived as significant.

Data inputs: Average delay data for different road types, area types and congestion bands.

Outputs: Journey time uplift figures (appropriately disaggregated) that can be monetised according to the economic value of time.

6.5 Adopted methodology outline

The methodology adopted to estimate MEC-B values covers the following behavioural impacts resulting from an additional HGV entering the system:

- Drivers frustration and stress
- Fear of Accidents

A bottom-up methodology approach was used based on research results on measurement and valuation of driver stress. The work commissioned by Transport Scotland on driver frustration was the only comprehensive study that looked at valuing aspects of driver stress. The results of this study were first reported in Murphy et al. (2014) and updated in Murphy et al. (2016). The study provides travel time uplifts to account for traffic situations associated with stress, including the stress response to encountering an HGV. Encountering an HGV was identified as one of three key causes for driver's frustration and stress (including fear of accidents).

The Murphy study was based on a comprehensive, two-stage approach:

- In the first stage, participants watched computer-simulated videos of different driving conditions and rated their level of frustration in response to each video.
- The second stage was a stated preference exercise where participants were asked to choose routes for a trip, described by text and images. The attributes of the exercise were the

number and type of vehicles ahead, presence of oncoming traffic, speed, presence of speed cameras, travel time and proportion of HGVs.

By modelling the route choices, it was possible to derive the willingness to travel longer times to avoid scenarios such as the presence of HGV ahead, oncoming traffic, and speed below desired speed. A very high correlation was found between this willingness to travel further and the driver frustration index derived in the first stage of the study for similar driving conditions, which confirms robustness of the approach and gives confidence in the results.

The effect of HGVs indicated that a higher percentage of HGVs is associated with greater driver frustration when driving in a platoon with an HGV. The research work also derived a time multiplier (proxy for frustration level), which suggested increases of 0.0476 for each HGV in the platoon ahead of traffic. This time uplift was used in our methodology and converted to monetary values by applying the value of travel time.

The overarching methodological approach is noted in Figure 14.

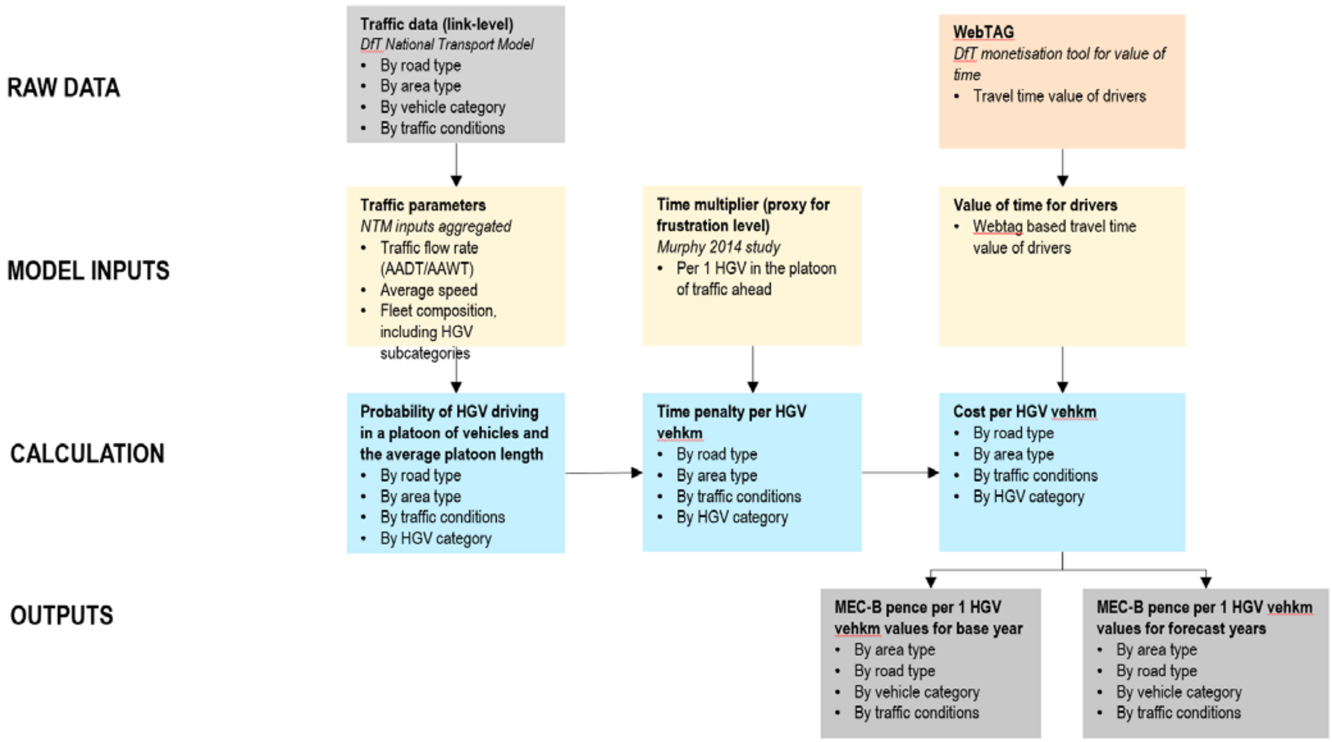


Figure 14: MEC Behaviour – methodological framework for calculations

6.6 Data specification

The MEC-B values were calculated based on data and information from the following data sources:

- National Transport Model data for each road type, area, congestion level, and forecast year.
- Murphy, P., Casey, J., McDonald, J. (2014) Experimental study of the factors that influence driver frustration on the A9. Proceedings of the European Transport Conference 2014.
- Murphy, P., Casey, J., McDonald, J. (2016) Experimental study of the factors that influence driver frustration - a Stated Preference approach - an update. Proceedings of the European Transport Conference 2016.
- Design Manual for Roads and Bridges (DMRB), volume 5, section 1, part 3.
- Data Book for time monetisation values.

6.7 Model assumptions

A dedicated calculation model for MEC-B was developed, using several key assumptions:

- Calculation of MEC-B was conducted by vehicle type, area type, road type and congestion level.

- Traffic volumes and average speed for each road type, area type, congestion level, and forecast year were used based on data from National Transport Model.
- HGV impacts on drivers stress and fear of accidents were represented as a single time multiplier on drivers' journey time without differentiation of vehicle types[6]. This is based on SSP and WTP research results 2014-2016. The journey time multiplier of 0.0476 was used for each driver encountering an HGV in a platoon of vehicles.
- Definition of a platoon of vehicles was based on general transport research results (Pursula and Enberg, 2000). The platoon is defined by a headway between vehicles being less than 3.5 seconds (h=3.5).
- Calculation of lane capacity for different road types was based on lane capacity parameters defined in Design Manual for Roads and Bridges (Appendix 1).
- Average road capacity utilization was assumed for different area types, road type and congestion level (Appendix 1).
- MEC-B values were calculated in 2020 prices and then rebased in line with DfT's requirements (Table 2)
- General model assumptions and inputs such as GDP growth and inflation were used based on Data Book.

6.8 Calculation procedure

The overarching calculation steps for the model are denoted in Figure 15. These are discussed further in the following sub sections.

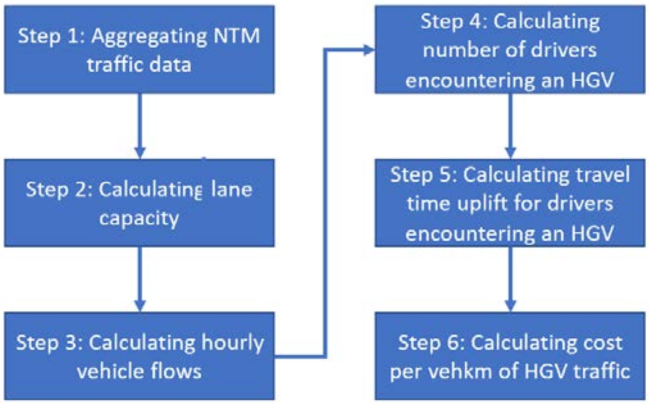


Figure 15: MEC Behaviour – overview of methodology calculations

6.8.1 Step 1: Aggregating NTM traffic data

Traffic volume and speed data was aggregated from link level to road and area type data for both rigids and artics. This data was used to compute the MEC-B values for the base year (2020) and forecast years in the NTM (2030; 2040 and 2050) and congestion bands (CB13 and CB45) for the associated road and area types.

6.8.2 Step 2: Calculating lane capacity

The second step was to calculate lane capacity for different area types, road types, and congestion levels. This calculation was based on the formula for capacity calculations sourced from DMRB.

$$c_i = A_j + B_j * HGV_i \quad (1)$$

[6] The research results underpinning the methodology do not provide sufficient evidence to distinguish between the impacts of rigid and articulated HGVs.

Where:

C - lane capacity;

A, B - parameters dependent on road standard

HGV - the percentage of HGVs

i - a combination of a road type, area type and congestion level

j - road type

The A and B values for different road types were assumed based on DRMB. The HGV percentage was sourced from NTM dataset, separately for different area types, road types, and congestion levels.

6.8.3 Step 3: Calculating hourly vehicle flows

The third step was to calculate hourly flows for different area types, road types, and congestion levels. The calculation was based on:

- Lane capacity for different area types, road types, and congestion levels calculated in the previous step.
- The assumptions on capacity utilization for different area types, road types, and congestion levels estimated based on the traffic levels provided in NTM database.

6.8.4 Step 4: Calculating number of drivers encountering an HGV

The next step was to calculate the number of drivers encountering an HGV in a platoon of traffic for one additional HGV entering the road network. The calculation was based on the probability of an HGV entering a platoon of traffic and the average length of the platoon. The correction for number of lanes was introduced to account for the fact that on multilane roads, most of HGVs use the slowest lane. The calculations were conducted separately for specific traffic conditions, defined as a combination of a road type, area type and congestion level. The following formula was used:

$$n_i = (l_i - 1)/m_i * p_i \qquad (2)$$

Where:

n – number of drivers encountering an HGV in a platoon of traffic

l – length of a platoon

p – probability of HGV entering a platoon of traffic

m – average number of lanes

i – a combination of a road type, area type and congestion level

The probability and length of a platoon were computed based on technical research on traffic platooning. The formula for calculation of probability of a vehicle being a part of a platoon for specific traffic conditions is as follows:

$$p_i = 1 - e^{-h*q_i} \qquad (3)$$

Where:

p – probability of the vehicle being a part of a platoon

h – headway threshold for a platoon;

q – vehicle flow rate [vehicles/second]

i – a combination of a road type, area type and congestion level

The formula for calculation of the average length of a platoon for specific traffic conditions is as follows:

$$l_i = e^{h * e_i} \quad (4)$$

Where:

l – the average length of a platoon

h – headway threshold for a platoon;

q – vehicle flow rate [vehicles/second]

i - a combination of a road type, area type and congestion level

6.8.5 Step 5: Calculating travel time uplift for drivers encountering an HGV

The next step was to calculate the travel time uplift for drivers encountering one additional HGV entering the road network.

- The calculation was conducted for 1 km of road.
- Average travel time on 1 km of road was calculated based on the average speed in specific driving conditions (a combination of a road type, area type and congestion level).
- Time multiplier of 0.0476 was used to calculate the time uplift for one driver encountering one additional HGV entering the road network
- The total time uplift was calculated as a sum of time uplifts for all drivers encountering one additional HGV entering the road network

The following formula was used:

$$t_i = \frac{d}{v_i} * m * n_i \quad (5)$$

Where:

t – total travel time uplift for drivers encountering one additional HGV entering the road network

d – length of the road link (here: 1 km)

v – average speed

m – travel time multiplier

n – number of drivers encountering an HGV in a platoon of traffic

i - a combination of a road type, area type and congestion level

The result of this calculation is a total travel time uplift for all drivers encountering one additional HGV entering a 1 km long link of road, differentiated by a road type, area type and congestion level. This represents the marginal impact of 1 vkm of HGV traffic on drivers perception of frustration, stress and fear of accidents.

6.8.6 Step 6: Calculating cost per vkm of HGV traffic

In the final step the monetary value was assigned to the computed travel time uplift for all drivers encountering one additional HGV entering a 1 km link of road to compute costs per 1 vkm of HGV traffic.

The value of one hour of drivers' time was calculated based on Data Book as a weighted average of VOT across different travel purposes: business, commuting, other. As MEC-B considers only impacts on drivers VOT values were weighted by the percentage of distance travelled by vehicles (occupancy factor = 1).

The resulting values represent the marginal costs of HGV impact on drivers perception of frustration, stress and fear of accidents for 1 vkm of HGV traffic.

6.9 MEC Behaviour values

The results for the different road types and area types in 2020 price year are presented in Table 47.

Table 47: MEC Behaviour – values in pence/vkm, Artics and Rigids, 2020 prices, base scenario

	Artics							Rigids						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inner and Outer Conurbations														
Motorways	0.11	0.13	0.17	0.21	0.27	0.34	0.41	0.11	0.13	0.16	0.21	0.27	0.34	0.41
A Roads	0.89	1.00	1.16	1.37	1.63	1.90	2.21	0.66	0.76	0.90	1.09	1.31	1.56	1.85
Other Roads	0.27	0.31	0.37	0.44	0.51	0.60	0.70	0.19	0.23	0.27	0.33	0.39	0.46	0.54
London														
Motorways	0.08	0.09	0.11	0.16	0.22	0.28	0.34	0.07	0.08	0.10	0.14	0.20	0.25	0.30
A Roads	2.22	2.54	2.98	3.46	4.04	4.58	5.17	1.87	2.17	2.58	3.03	3.57	4.08	4.64
Other Roads	0.44	0.51	0.61	0.75	0.92	1.08	1.26	0.26	0.33	0.41	0.52	0.66	0.78	0.93
Other Urban														
A Roads	0.81	0.91	1.06	1.25	1.48	1.71	1.97	0.51	0.59	0.70	0.85	1.03	1.22	1.43
Other Roads	0.19	0.22	0.27	0.32	0.38	0.45	0.53	0.14	0.16	0.20	0.24	0.28	0.34	0.39
Rural														
Motorways	0.06	0.07	0.09	0.12	0.16	0.21	0.27	0.06	0.07	0.09	0.13	0.17	0.22	0.27
A Roads	0.07	0.08	0.09	0.11	0.13	0.17	0.20	0.05	0.05	0.07	0.08	0.10	0.13	0.16
Other Roads	0.01	0.01	0.02	0.02	0.02	0.02	0.03	0.00	0.00	0.01	0.01	0.01	0.01	0.01

The results for the different road and area types in 2020 price year are presented in Table 47 and the 2025 MEC-B values, in 2020 prices, in Figure 16. It shows that 'A Roads' exhibit the largest MEC Behaviour values, while 'Motorways' have the largest value for Rural areas. The highest MEC-B values are identified for 'A Road' in London and the lowest for 'Other Roads' in the Rural. In general, artics introduce slightly higher marginal external cost then rigids for all area and road types.

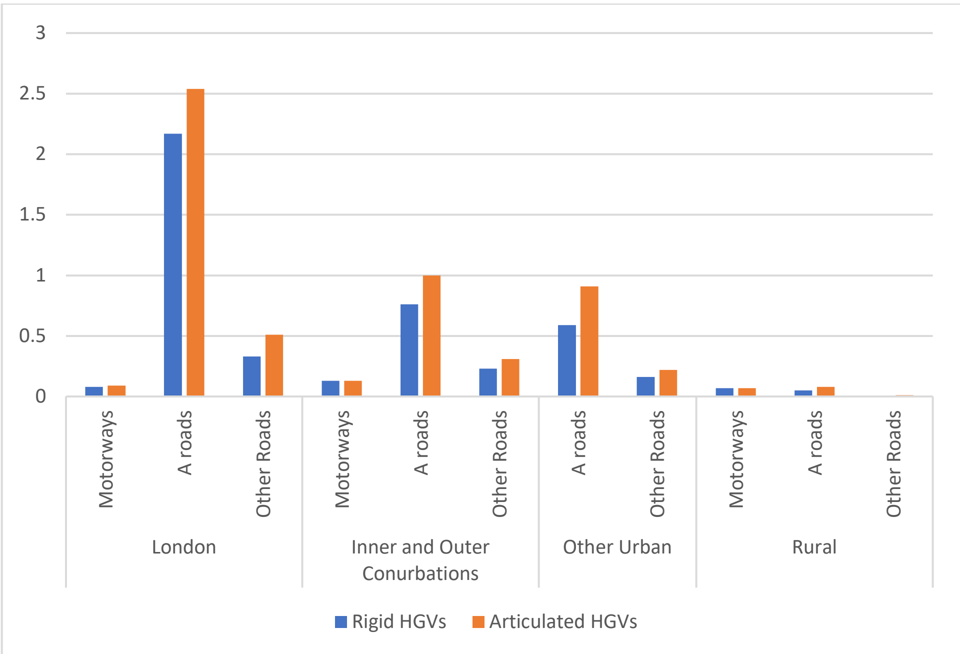


Figure 16: MEC-B values, pence per vkm, 2025 impact, 2020 prices, by HGV type

The methodology previously used for MECs calculation did not include computing separate MEC-B values, so the comparison between previous and current MEC-B values is not possible.

6.10 Sensitivity scenarios

A review of the influence of HGV platooning and other technologies of road freight automation on drivers frustration, stress and fear of accidents identified that currently there is a limited evidence base to be able to calculate potential impacts as part of MEC-B. Therefore, the sensitivity scenarios which involve alternative technology are not considered as part of this study.

6.11 Indexation and updates

The model will require regular updates to maintain integrity and robustness. Table 48 reports the key parameters that will need updating and the regularity of update intervals. The update intervals are meant only as a guide and consider the likely magnitude of changes over time for each parameter that would warrant a revision.

Table 48: MEC Behaviour – model parameters and updating intervals

Parameter	Recommended Update Frequency
Traffic volumes	Should be updated every 5 years based on the NTM.
Value of time	Should be updated every 5 years based on TAG.
Travel time uplift	Should be reviewed internally by the DfT every 5 years with reference to the available literature on HGVs impact on drivers stress and frustration.

6.12 Limitations and recommendations

The model is currently limited by the following factors:

- Due to lack of research on differences in stress and frustration generated by different HGV types (rigid and articulated vehicles), the model does account for the impact of an average HGV vehicle,
- The model accounts for stress and frustration of a driver encountering an HGV in a platoon of vehicles. The impacts of other driving patters, such us stress impacts related to driving along an HGV are not reflected in the available research results.
- In terms of scope, the model does not consider the effects of community severance due to lack of suitable research on measuring and valuation of this type of impact.

It is recommended that further research is conducted in all the areas mentioned above.

7 Environment

7.1 Introduction

7.1.1 Background

Environmental external costs associated with HGV transport are borne from both visual effects and vehicle emissions. Both impact categories are generally difficult to measure, due to complex impact pathways and uncertain valuation approaches. Omission of these impacts could result in a systematic undervaluation of the impact associated with marginal changes to HGV traffic. The external costs falling into this category are:

- Soil and Water Pollution
- Nature and Landscape
- Visual intrusion

Environmental damages arising from road freight transport are primarily generated from vehicle emissions that result in soil and water pollution and habitat degradation (Ricardo, 2019). For these cost categories, knowledge about the detailed impact patterns and dose response relationships is less developed than for other MECs. Often, negative impacts of transport activities on the natural environment are anecdotal and the magnitude and extent of impacts is challenging to quantify. Consequently, repair costs (or avoided cost) are sometimes estimated as proximate to damages instead of directly valuing the ecosystem effects that arise from damages

DfT currently considers these impacts through calculation of the MEC categories, where environment is considered within the MEC-Other category. This MEC has historically been calculated as a simple uplift factor relative to the other MECs of 6 pence per vehicle mile across all area and road types (see DfT (2009) for further information). The calculation of values was largely based on work by Maibach et al (2008) that provides estimates for most of the categories of external cost that are currently included in MEC-Other (up and downstream processes; soil and water pollution; nature and landscape; driver frustration and stress; fear of accidents; community severance and visual intrusion).

7.1.2 Initial review of impacts and approaches

An initial review of appraisal approaches for MEC-Other (see Section 7.3 below) documented a range of recommendations for updating the MEC values. The review concluded that MEC-Other could be simplified through the amalgamation of various external cost categories into distinct groups, including an environment-specific category (MEC-E). The review suggested the external costs falling into this revised category should be ‘Soil and Water Pollution’ and ‘Nature and Landscape’.

Habitat degradation results in a reduction to social welfare through changes to the provision of a range of ecosystem services, including but not limited to recreation; biodiversity; visual amenity; water quality and carbon storage (Eftec, 2019). Work by Natural England (2016) has already demonstrated that increases in emissions tends to result in an increase to the level of habitat degradation. These changes tend to occur in habitats within 100m of the roadway and the magnitude of these impacts’ changes in a non-linear fashion the further from the roadway the habitat is (Natural England, 2016).

The review recommended MEC-E values should be derived from a dose response function that explores how a change in vehicle emissions (specifically nitrous oxides) will result in a change to the level of habitat degradation. This approach reflects best practice as outlined by Defra (2007a) for determining and valuing environmental impacts through the impact pathway approach. The review also recommended travel through sensitive/unique landscapes should considered via the application of a penalty mechanism that applies an uplift factor to MEC-E for travel through National Parks and Areas of Outstanding Natural Beauty (AONBs). This is important because these sites are highly prized for their natural characteristics and the MEC values need to consider the higher marginal costs associated with HGV traffic in these areas.

The review recommended the impacts measured through the dose response function are monetised using the avoided cost approach – i.e. the restoration costs for restoring degraded habitat due to vehicle emissions. Restoration costs are used as proxies for the reduction in ecosystem service provision as a function of habitat degradation.

7.1.3 Emissions and impacts

Vehicle engines emit many types of pollutants, including nitrogen oxides (NO_X), volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO_2), particulate matter, sulphur dioxide (SO_2) and lead (Defra, 2019a). Changes in emissions are mainly related to driving style, fuel type and the temperature of combustion. Most of the UK's HGV vehicle fleet is diesel powered, thus emitting higher volumes of NO_X and particulate matter than petrol engines.

High levels of NO_X emissions can have a negative effect on vegetation, including leaf damage and reduced growth where emissions exceed 'critical loads' (Natural England, 2016). The critical load is the threshold level for the deposition of a pollutant above which harmful indirect effects can be shown on a habitat or species. There are two primary impact pathways – eutrophication and acidification[7] (Jones et al., 2014). Both impacts arise from wet and dry deposition of nitrogen (N), where wet deposition is more diffuse while dry deposition tends to be from point sources.

Emissions of particulate matter are associated with visibility degradation and have been linked with a range of adverse human health effects. However, particulate emissions are not included in the MEC calculations since there is no substantial evidence that suggests particulate matter causes adverse effects on ecosystems (Natural England, 2016). Additionally, there are no air quality objectives, critical loads or levels for fine particles that need to be considered for the protection of habitats.

7.1.4 Outputs

This section provides supporting information to accompany the relevant Excel model for the derivation of MEC-E values. The methodological approach and associated assumptions and limitations inherent in the calculations are denoted. The MEC-E values were disaggregated according to area type; road type; congestion band and year as per the specifications of DfT. The MEC's were also calculated irrespective of congestion band through the application of a weighted average of the MEC values based on the number of vehicle kilometres travelled according to each congestion band. Values are supplied for both rigid and articulated vehicles (herein referred to as 'rigids' and 'artics'). Sensitivity analysis was applied to the value estimates through the application of a 'medium' and 'high' scenario in conjunction with the NTM forecast data on traffic flows and emissions.

7.2 Current approach

The current approach set out by DfT for environmental MECs uses the values provided by Maibach et al. (2008). Maibach et al. (2008) provides an overview of relevant European studies and some values per vehicle kilometre for HGVs in Germany (2000 price base). The study provides values for two of the categories of environmental external costs:

i. Soil and Water Pollution
ii. Nature and Landscape

Soil and Water Pollution refers to the negative impacts of traffic on soil from the emission of heavy metals and polycyclic aromatic hydrocarbons (PAH). Pollutants lead to plant damage and decreased soil fertility alongside infrastructure. Maibach et al. (2008) suggest that the value of these costs is equivalent to about 2% of the total value placed on the categories of external costs we have already valued.

Nature and Landscape refers to the impacts of traffic on habitats, biodiversity and landscape aesthetics. Maibach et al. (2008) do explore nature and landscape but from the context of habitat loss and disturbance as a function of infrastructure and not its (marginal) use. Consequently, DfT consider

[7] Eutrophication refers to the excessive richness of nutrients in a lake or other body of water, which causes a dense growth of plant life and depletion of oxygen. Acidification refers to the excessive build-up of nitrogen in soil which causes a reduction in the pH level. This can have adverse effects on species abundance and composition in ecosystems.

this category of costs not to be significant for marginal changes in road freight traffic.

The values provided in Maibach et al. (2008) suggest that at an aggregate level the value of these two categories of external cost might be equivalent to about 3% of the value of the impacts the DfT have valued already. It is important to note, however, that Maibach et al. (2008) state that the values provided for Germany should not be applied elsewhere without first considering the need to adjust them for the specific situation in which they are to be used. Therefore, DfT have only used the values to provide a broad indication of the scale of the impacts and these values do not cover all the external costs that may be present.

7.3 Best practice methodologies review

A range of approaches exist to document the marginal environmental impact associated with transport schemes (i.e. landscape and nature and soil and water pollution) usually though not exclusively using Before-After, Control-Impact type methods. This review provides a discussion of the broader literature concerning estimation and monetisation of environmental impacts, not exclusively arising from transport use. The following sources were used in the review:

- Defra (2007b). An economic analysis to inform the review of the Air Quality Strategy.
- Department for Transport (2016). Value for Money Supplementary Guidance on Landscape.
- Department for Transport (2009). Mode Shift Benefit Values: Technical report
- INFRAS/IWW (2004). External costs of transport - update methodology.
- Maibach et al (2008). Handbook on estimation of external costs in the transport sector. Produced within the study Internalisation Measures and Policies for All external Cost of Transport (IMPACT).
- Ott, Baur and Kaufmann (2006). New Energy Externalities Developments for Sustainability (NEEDS). Assessment of biodiversity losses.
- Ricci and Friedrich (1999). Calculating transport environmental costs.
- Eftec (2019). Valuation of Landscape Impacts of Transport Interventions & Mitigations Using an Ecosystem Services Approach.
- Van Essen et al (2011). External cost of transport in Europe. Update study for 2008.

The outcome of the review was identification of three broad approaches (ecosystem services assessment, landscape scale assessment and dose response/restoration cost) to measure impacts to the environment arising from transport schemes. An overview of the review is provided in Table 49.

Table 49: MEC Environment – best practice methodologies

Source	Ecosystem Services Assessment	Landscape Scale Assessment	Dose Response / Restoration Cost
Maibach et al (2008)		x	x
Department for Transport (2009)			x
Eftec et al (2019)	x		
Department for Transport (2016)		x	
Van Essen et al (2011)		x	x
Defra (2007b)			x
Ott, Baur and Kaufmann (2006)			x
INFRAS/IWW (2004)			x
Ricci and Friedrich (1999)			x

7.3.1 Ecosystem services assessment

Work by Eftec et al (2019) focuses on taking an ecosystem services approach to appraisal of transport schemes based on new infrastructure schemes. The report reviews current qualitative/quantitative and supplementary monetary approaches to appraising landscape impacts of transport schemes and considers how to develop monetary values for landscape impacts, based on value transfer using an ecosystem services approach. The authors suggest work is needed to investigate the marginal impact of transport schemes on the recreation value of a site, and the visual amenity of landscapes (where primary valuation work is necessary).

Benefits/limitations: The approach is limited by a strong focus on appraisal of new transport schemes, as opposed to quantification of existing impacts arising from vehicle use.

Datasets: Input data necessary includes information on landscape impacts, value transfer and primary valuation work (i.e. from revealed or stated preference surveys).

Outputs: Monetary valuation of ecosystem services impacted by transport schemes.

Recommendation: The approach is not well suited to assessing marginal changes from transport use and is too detailed for a high-level appraisal.

7.3.2 Landscape scale assessment

Work by the Departement for Transport, (2016) provides guidance on using an indicative approach to monetising the impact of an infrastructure scheme on landscape, using a bottom up approach. The landscape assessment process can be disaggregated into seven steps that identify the landscape characteristics, measure impact and denote levels of mitigation.

Benefits/limitations: The approach is focused on the evaluation of environmental impacts from new transport schemes, as opposed to quantification of marginal changes from use. The assessment process is unlikely to be suitable for measuring how marginal changes arising from use impact nature and landscape.

Data inputs: Datasets necessary for this approach include determination of land type, landscape features, identify landscape footprint, and the landscape 'look-up' values outlined to value the monetary impact of a scheme.

Outputs: Monetary valuation of landscape scale impacts of a scheme.

Recommendation: The approach is not well suited to assessing marginal changes from transport use and is too detailed for a high-level appraisal.

7.3.3 Dose response and restoration cost

Several studies (e.g. Department for Transport, 2016; Van Essen et al, 2011; Defra, 2007; Ott, Baur and Kaufmann (2006); INFRAS, 2004; Ricci and Friedrich, 1999) have employed a dose response[8] approach to monetise the impacts of environmental pollution associated with transport use. Most approaches work by documenting the exposure of either habitat, water or soils to contaminants (e.g. vehicular emissions). The level of exposure (contamination) is then either paired with market prices for the environmental good/service (e.g. provision of freshwater) or the repair cost for enhancing the natural asset back to a good condition (i.e. the baseline level of contamination) relative to the area of habitat impacted. Some approaches also explore critical loads to determine how excess deposition of pollutants might have an adverse impact on ecosystems. The specific methodologies tend to be a combination of top-down or bottom-up approaches and are often not disaggregated by different road or area type attributes.

Benefits/limitations: The combinations of approaches are suitable for assessing habitat or soil/water

[8] The dose–response relationship describes the magnitude of the response of an organism, as a function of exposure to a stressor (for example, dose response functions linking air pollution to habitat damage).

pollution as a function of marginal changes in pollutants. Data on impacts is also widely available (i.e. vehicular emissions) although the dose response functions from habitats are less clearly articulated in the literature. Parameter estimates for monetary impacts are available through various forms, including habitat restoration cost.

Data inputs: Emissions data for different vehicle types, disaggregated by road type and area. Normalised parameter estimates for habitat damages or area of habitats impacted by emissions (e.g. the dose response). Transfer values to monetise habitat damages or indexed values for restoration costs.

Outputs: Monetary valuation of environmental pollution as a function of different pollutants (e.g. specific vehicular emissions).

Recommendation: The approach is well suited to assessing marginal changes from transport use although various high-level assumptions are necessary to measure emissions impacts.

7.3.4 Uplift factor

An alternative approach to account for environmental damages is to use a simple weighted average uplift factor (corresponding to both soil and water pollution and nature and landscape). This would be similar to the current approach that considers cost categories in the MEC-Other category and would reflect the relative proportion of the MEC that can be attributed to environmental pollution. Indeed, Maibach et al. (2008) suggest that at an aggregate level the value of environmental pollution might be equivalent to about 2-3% of the value of all other impact categories. The relative uplift values could be informed by the updated MEC estimates derived from Van Essen et al (2011).

Benefits/limitations: The approach is relatively simple to calculate and uses previous MEC estimates documented in the literature for a variety of cost categories to determine the relative uplifts. However, a relative uplift factor is an over simplification of the complexities of environmental impacts and this is unlikely to improve the estimation of external costs beyond the current methodology.

Data inputs: The monetised value of all other MEC categories featured here and cross referencing to value estimates documented by Van Essen et al (2011).

Outputs: A relative uplift factor.

Recommendation: Approach is an oversimplification of determining environmental impacts and will not result in more accurate distribution of marginal cost across cost categories.

7.4 Methodology selection

7.4.1 Methodology options assessment

Several methodology options were identified to address marginal environmental external costs of HGV traffic (Table 50). Because it is a relatively new area of impact assessment the options available differ for different components of MEC Environment.

Table 50: MEC Environment – methodology options

Approach	Scope	Advantages	Disadvantages	Data Requirements
Ecosystem services assessment	Out of scope	Provides a high-level breakdown of cost across various ecosystem service categories.	This approach focuses on impacts of infrastructure interventions rather than on traffic change impacts	Detailed localized datasets required
Landscape scale assessment	Out of scope	High level systems approach currently used in transport scheme appraisal.	This approach focuses on impacts of infrastructure interventions rather than on traffic change impacts	Detailed localized datasets required

Approach	Scope	Advantages	Disadvantages	Data Requirements
Dose response and restoration cost method & Environmentally sensitive areas (ESAs) penalty (Recommended)	Out of scope	Significant improvement to the existing approach, reflects state-of-the-art research on nature and landscape impacts of road traffic	Reliance on restoration costs as proxy for the social cost of pollution for different habitat types	Feasible with existing data sets
Updating the uplift factor	In scope	Improvement of the existing values with updated data sets	An over simplification of the complexities of environmental impacts and this is unlikely to improve the estimation of external costs	Feasible with existing data sets

7.4.2 Recommended methodology

7.4.2.1 Dose response and restoration cost

Based on the available evidence, there is scope to improve the current methodology for calculating 'soil and water pollution' and 'landscape and nature' impacts. Due to issues of double counting, we suggest combining soil and water pollution and nature and landscape impacts into one category termed 'environmental damages'.

This review demonstrates that applying a dose-response function to document the marginal impacts of (HGV) transport use would be an improvement on the current methodology. The dose-response relationship describes the magnitude of the response of a habitat/species as a function of exposure to pollutants over time. Such an approach is well suited to documenting how marginal changes in road use (and associated emissions) impact the immediate environment adjacent to roads. These impacts include damages to ecosystems (which includes different habitat types and the supply of ecosystem services) and can be measured as a function of road type and marginal changes in HGV use. Distance decay relationships between road type and habitat are variable and are a function of multiple parameters, including vehicle speed, road type, habitat type and congestion[9].

Benefits/limitations: Dose-response functions are well suited to measuring how marginal changes (in the emissions of pollutants) may impact natural assets. The approach is habitats focused which allows variation in the intensity of emissions and pollutants to be considered relative to different habitat types that may be more susceptible to pollution and/or more distinctive. A key limitation of the approach is the reliance on restoration costs as proxy for the social cost of pollution.

Data inputs: Disaggregated breakdown of habitat types across the UK's road network (for motorways, A roads and other roads). Average emissions of HGVs disaggregated by vehicle type (rigid and articulated) and road type. Distance decay relationship for habitat damages arising from vehicular emissions disaggregated by different road types. Look up values based on restoration costs for different habitat types.

Outputs: The model will supply a disaggregated output of restoration costs (based on area) for different habitat types as a function of average HGV emissions for different road types.

7.4.2.2 Environmentally sensitive areas (ESAs) penalty

In addition to employing a dose response function we also suggest including a penalty factor for marginal changes in HGV transport through environmentally sensitive areas (ESA's). This could be used to apply a per kilometre penalty (an uplift to the MEC-E values) for transport through environmentally sensitive

[9] Work by Natural England (2016) suggests vegetation is impacted by exposure to motor vehicle pollution at distances of up to 200 m from roads and that there is potential for this distance to be greater. Recent transect studies provide further evidence of the impacts on individual species from exposure to nitrogen oxides (NO_x) and nitrogen dioxide (NO_2) associated with vehicle emissions. These impacts are greatest within the first 50-100 m from roads but may be discernible at greater distances. A number of field studies have sampled and analysed soils, and consistently demonstrate that heavy metal concentrations from vehicle emissions decline within 5–10 m and may not be discernible beyond 50 m from roads.

areas (see Appendix 2 for map of ESAs in England). Other work by the European Commission, (2003) has also explored environmental impacts from transport in sensitive areas, of which one recommended option was a mark-up of 25% on average tolls for roads in Europe that travel through sensitive areas.

The uplift factor proposed here is a conservative estimate of the costs that reflect the increased level of sensitivity associated with HGV transport through ESA's, where the impacts of environmental pollution are costlier since societal values for these areas are higher. The increased cost arises not because of changes to the magnitude of impact (which is likely but difficult to measure) but because pollution damages are exaggerated due to the value of these areas.

Benefits/limitations: A penalty uplift factor is a relatively simple way to account for changes in landscape types that may amplify the cost of pollution. However, the approach is deterministic and may be an oversimplified representation of the nature of environmental damages arising in ESA's as a result of HGV transport.

Data inputs: Length of major roads (km) in ESA's as of 2018.

Outputs: A map of roads where a penalty is applied.

7.5 Adopted methodology outline

The methodological framework developed is based on two overarching approaches: a dose response function and a penalty factor. The dose-response relationship describes the magnitude of habitat degradation as a function of exposure to NO_X emissions over time. Conceptually, the model estimates the cost of restoring degraded habitat (as a function of NO_X emissions) to a non-degraded state to infer the average marginal external cost associated with HGV transport. The overarching methodological approach is described in Figure 17, including model inputs and outputs.

In addition to employing a dose response function, a penalty mechanism accounts for marginal change in HGV traffic through particular environments (National Parks and AONBs)[10]. See Appendix 2 for a map of designations.

[10] It should be noted other statutory habitat designations do exist. See Appendix 3 for an appraisal summary table describing these designations and reasoning behind their inclusion/exclusion in the penalty mechanism. Note National Scenic Areas are equivalent to AONBs in Scotland.

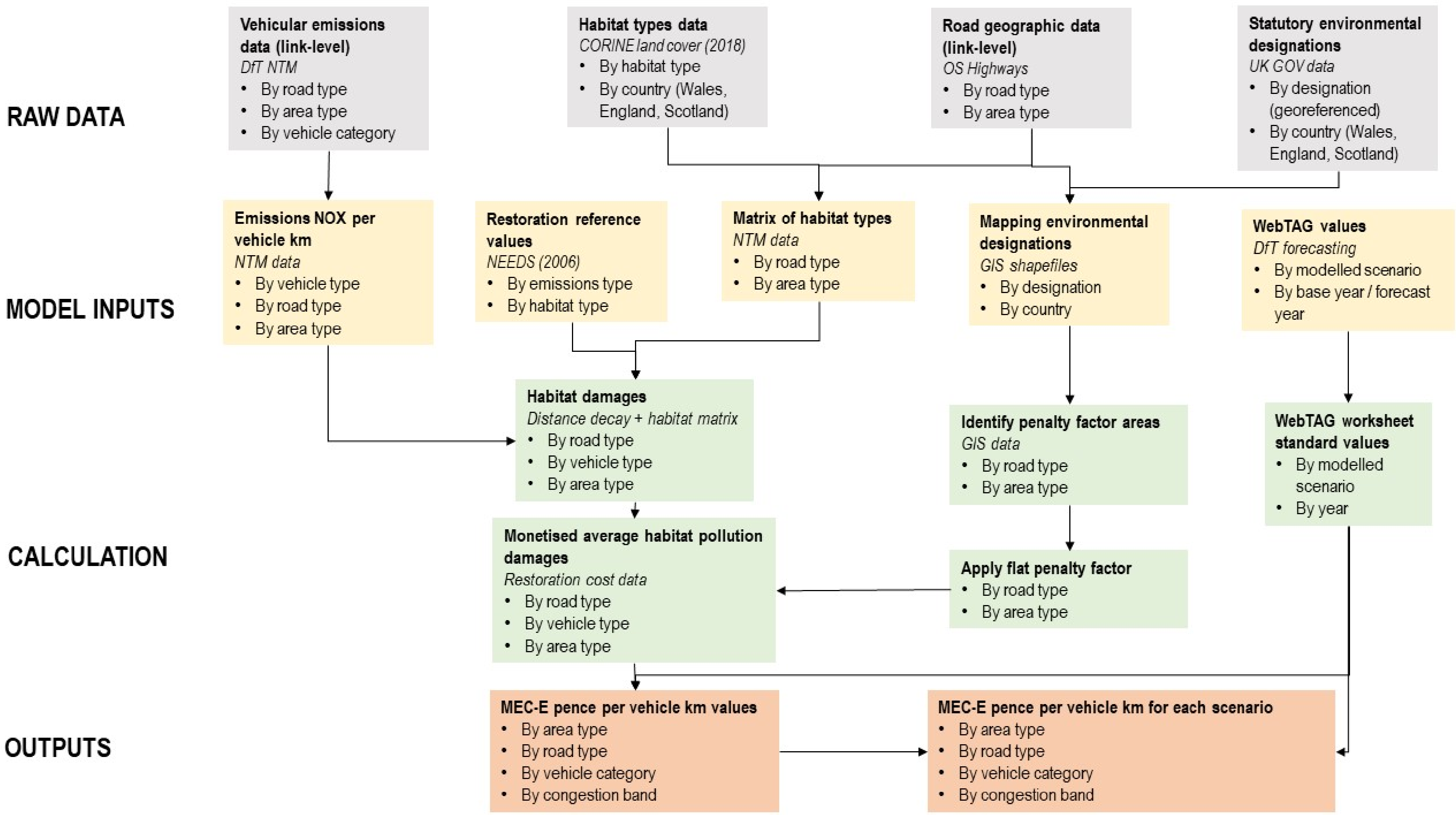


Figure 17: MEC Environment – methodological framework

7.6 Data specification

A list of data sources used for the MEC-E assessment is provided in Table 51. The data is all either open source/publicly available or supplied by Department for Transport for the purposes of the project. Most of the data is periodically updated at varying intervals. This will ensure the model can be updated periodically with relative ease.

Table 51: MEC Environment – Data sources used in the analysis

Data Type	Description	Coverage	Format	Update Frequency	Year	Sources
NTM Data (incl. emissions)	Output from the National Transport Model	GB	Wide	Annual	2019	Department for Transport
OS Highways	Shapefile of all road types in GB	GB	Shapefile	Annual	2019	Ordinance Survey (2019)
National Parks	Shapefile of GB national parks	GB	Shapefile	Periodic	2016	UK Gov data portal
AONBs	Shapefile of AONBs (National Scenic Areas for Scotland)	England, Wales, Scotland	Shapefile	Periodic	2019, 2019, 2018	UK Gov data portal
Habitat types	CORINE land cover types GIS dataset	GB	Shapefile	Periodic	2018	Copernicus land monitoring service
Habitat restoration cost	Database of estimated habitat restoration cost	GB	Matrix	n/a	Various	Ott, Baur and Kaufmann (2006) and Environment Agency (2015)
Critical loads and exceedance of emissions	Trends in critical load and critical level exceedances in the UK	UK	Table	Annual	2019	Rowe et al (2019)
GDP Deflators	GDP deflators reference values	UK	Long	Quarterly	2019	Department for Transport

7.7 Model assumptions

Two key assumptions underpin the overarching model. First, higher emissions result in greater habitat degradation that reduces biodiversity. Second, some landscapes and geographies denoted by certain designations are more valued by society meaning habitat degradation here is costlier. Additional assumptions underpinning the model are documented in Table 52.

Table 52: MEC Environment – Assumptions used in the model

Assumption	Description
Deposition	We have assumed NO_X emissions result in uniform (fixed) damages to habitat within 100m of the roadway as a function of NO_X deposition. In practice, emissions and associated deposition would follow a non-linear relationship (i.e. distance from roadside and habitat damages would follow a distance decay curve).
The baseline	The baseline habitat condition is denoted through the estimation of species richness associated with a range of non-degraded habitat types, based on work by Ott, Baur and Kaufmann (2006). A reference habitat (natural grassland) is assumed as the baseline from which changes to habitat are estimated. This is most representative of habitats adjacent to road networks in Great Britain.
Restoration costs	It is assumed that the current restoration costs in the UK are related to the existing level of ecosystem degradation. Damage costs are only likely to be incurred on land where the level of deposition already exceeds the critical load. This argument is considered by weighting the ecological impacts of a marginal deposition increase by the acidification and eutrophication pressure.
Impacted area	The model assumes only emissions deposited on natural land (i.e. not built on) can result in habitat damages. In addition, the model only considers land where the critical load is exceeded for habitat damages to occur.
Changes to habitat	Changes to habitat rely on computing the relative reduction in species richness that is assumed to result in a step change in habitat type through degradation due to NO_X deposition.
Emissions types	Particulate matter is not included in the assessment as there are no air quality objectives, critical loads or levels for fine particles that need to be considered for the protection of vegetation.
Penalty factor	Some landscapes are highly prized for their ecological and environmental characteristics. The penalty factor recognises the fact that environmental damages in National Parks and AONBs will bear a higher cost due to their elevated societal value.
Assigning restoration costs	Restoration costs seek to monetise the avoided cost of habitat degradation through a reduction in vehicular emissions. The restoration costs are calculated as the cost of restoration per potentially disappeared fraction (PDF) of species relative to the reference habitat type. The PDF accounts for the fraction of species richness that may potentially be lost due to environmental pollution. These values are computed for different habitat types.
Temporal factors	We assume that changes in N deposition will result in immediate changes in habitat condition. In practice, changes to deposition rates may result in lagged responses concerning habitat condition.
Types of deposition	Air pollutants are removed from the atmosphere through ‘wet deposition’, by rain, snow and fog, and by ‘dry deposition’, which is the direct uptake of gases and particles to land and water surfaces. Dry deposition results in point source pollution (i.e. the receptor is generally within close proximity to the emissions source) while wet deposition is more diffuse (tending to occur on higher ground with elevated rainfall patterns). The MEC-Air Quality has considered mainly wet deposition within its approach, so for this reason the model only considers dry deposition impacts.

7.8 Calculation procedures

The overarching calculation steps for the model are denoted in Figure 18. These are discussed further in the following sub sections.

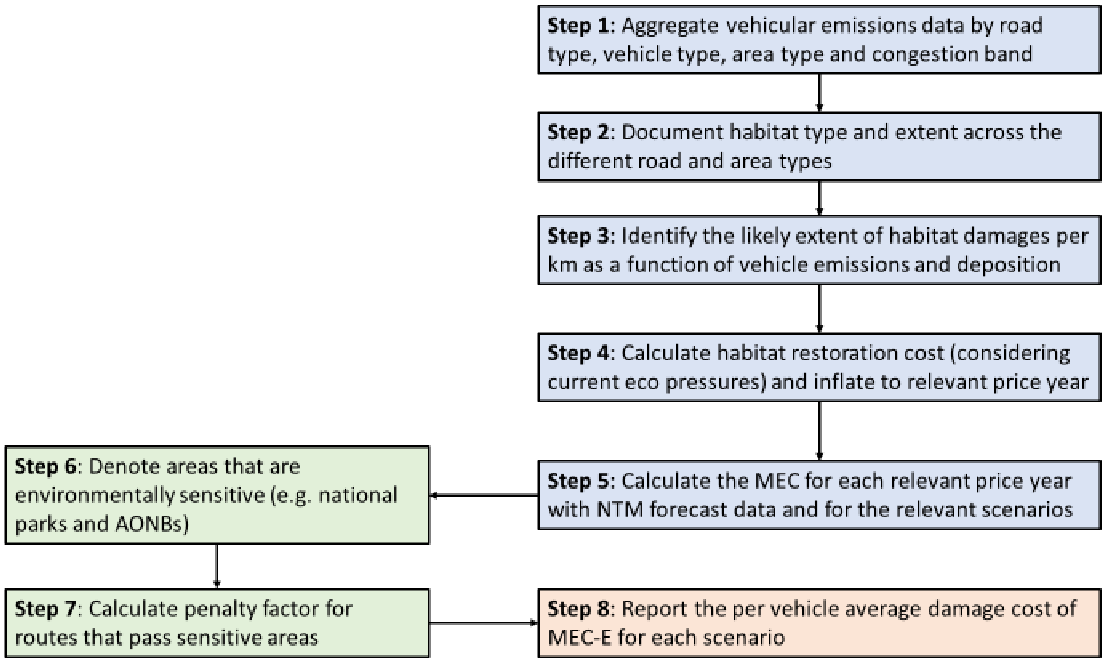


Figure 18: MEC Environment – overview of methodology calculations

7.8.1 Step 1: Aggregating vehicular emissions

Vehicular emissions data was aggregated from link level to road and area type data for both rigids and artics. This data was used to compute the average NO_X emissions per vehicle km travelled for the base year (2020), forecast years in the NTM (5 yearly intervals to 2050) and congestion bands (CB13 and CB45) for the associated road and area types.

7.8.2 Step 2: Documenting the habitat types

CORINE land cover map data (CLC, 2018) was used to estimate the proportion of various landcover categories for the different area and road types. The OS Mastermap dataset (Ordinance Survey, 2019) was used to split out the road types into the relevant road and area types. These corresponded to the following:

- Motorways (rural) / Motorways (urban)
- A roads (rural) / A roads (urban)
- Other roads (rural) / other roads (urban)

The area types were amalgamated into ‘urban’ and ‘rural’, where urban refers to ‘inner and outer conurbations’; ‘London’ and ‘other urban’ categories. A 100m buffer for each road type was used to document the area of each landcover type within the buffer. The area of the different (natural) landcover types was then calculated and this was used to determine the relative proportions of the different landcover types. The landcover types were then translated into the various habitat types used in the model (where the associated species richness for each habitat type was detailed). Additionally, the CLC data was used to determine the extent of natural and urban land cover that was associated with the different road types. For instance, within 100m of a motorway in a rural setting 80% of the landcover may be ‘natural’ while 20% may be non-natural.

It is worth noting that the habitat types are mapped at a coarse spatial scale and this is unlikely to capture the full extent of habitat heterogeneity that would likely persist adjacent to the various road types. This is a limitation of using the CLC data.

7.8.3 Step 3: Document habitat damages

The methodological approach for documenting habitat damages and associated restoration costs was largely based on work by Ott, Baur and Kaufmann (2006). The approach relies on documenting the potentially disappeared fraction (PDF) for each habitat type that would likely arise as a function of N deposition. The PDF is a metric that accounts for the fraction of species richness that may potentially be lost due to environmental pollution. These values are computed for the different habitat types.

The likely extent of habitat damages was calculated using the following formulae:

$$PDF = 1 - \frac{Sx}{Sy} \qquad (1)$$

$$PDF_c = X\frac{(PDF_a - PDF_b)}{R_m} \; for \begin{bmatrix} h_{11} & \cdots & h_{1R} \\ \vdots & \ddots & \vdots \\ h_{n1} & \cdots & h_{nR} \end{bmatrix} \qquad (2)$$

$$where\ R = \int (C_{u,n,c,t,a,m}) \qquad (3)$$

Where in (1) the PDF of vascular plant species is expressed as the relative difference between the number of species *S* for the reference habitat *y* (assumed to be natural grassland) over *S* for the alternative (actual) habitat type. In (2) the monetised value for a change in PDF from habitat condition *a* to habitat condition *b* is determined by calculating the difference between PDF_a and PDF_b multiplied by a species accumulation factor *X* for natural areas. The species accumulation factor is a multiplier that considers the regional effect of the changes to habitat condition on natural areas not included in the model (i.e. indirect effects exogenous to the model). See Ott, Baur and Kaufmann (2006) for further information on species accumulation factors.

This is divided by *R,* the indicative restoration cost (per m^2) for the different habitat types which is used to derive the restoration cost per *PDF* per m^2. *R* is defined in (3) as a function of various cost parameters (e.g. unsealing; re-naturalising; cultivation; tilling; afforestation and maintenance) specific for each habitat type.

7.8.4 Steps 4 and 5: Calculating the MEC values

To calculate the restoration cost as a function of vehicular emissions, several core parameters are included in the model (see Table 53).

Table 53: MEC Environment – parameter estimates used in the model

Parameter	Description
PDF	The PDFs for airborne emissions are derived from a Dutch model (Natuurplanner) where the changes in NO_X deposition are translated into changes in the PDF of plants (i.e. increases or decreases of the number of target species). The reference case for analysing the relationship between emissions and habitat degradation is derived from the Netherlands.
∆PDF	Delta PDF is a parameter that considers the change in PDF associated with a starting and target habitat type. The step change in habitat type is analogous to the effect of restoration from a 'degraded' to 'non-degraded' state.
Restoration cost	The cost per change in PDF for restoring a habitat from a degraded to a non-degraded state.
Weighting factor	To consider how severely a country is already influenced by depositions of NO_X a weighting factor is applied. This is based on information from Rowe et al (2019) detailing exceedance of critical loads in the UK (Appendix 4).

Parameter	Description
Reference habitat	The habitat type which is assumed to represent the most abundant habitat in areas adjacent to the road network. The reference type is used to standardise the PDF values for each alternative habitat type relative to the reference type (natural grassland).
Proportion of natural area	The proportion of natural area is measured through the CLC (2018) map data. This is calculated for each road type corresponding to both 'urban' and 'rural' areas.
Proportion of habitat	The proportion of each landcover type is calculated through the CLC (2018) map data. A buffer of 100m for each road type (disaggregated by area type) was used to document the proportions of landcover adjacent to each road.
NOX emissions	A parameter detailing the per vehicle per km emissions calculated by aggregating all emissions per pollutant divided by total vehicle km's travelled.
NOX deposition	The amount of deposition is determined by computing a ratio of N (dry) deposition to total emissions.
Penalty uplift factor	The penalty uplift factor applied to the MEC-E values for transport through sensitive/unique landscapes.

The calculations for deriving the associated external cost per kg deposition are denoted below:

$$NOx_d = \frac{E_t}{D_t} \qquad (4)$$

$$EC_k\ (pence\ per\ kg) = \Delta PDF_{n,t}\ [\ \prod(h, R_z)w\ ] \qquad (5)$$

$$EC_q\ (pence\ per\ veh\ km) = \prod NOx_d\ \int(r, v, a, c, y)\ EC \qquad (6)$$

In (4) the ratio of NO_X emissions to dry deposition is calculated by computing the ratio of total transport NO_X emissions E_t relative to total transport related NO_X dry deposition D_t for a given year (1990). Emissions data was sourced from Defra (2019b).

In (5) to derive the external cost (EC_k) per kg deposition, ΔPDF_n is scaled by the proportion of natural area for the relevant road and area type *t*. This is multiplied by the product of the restoration costs *R* according to each price year *z* for each habitat type *h* in a matrix. The restoration costs (where applicable) are converted from euros to pounds and are all reported for the 2020 price year, in addition to being inflated using Data Book GDP deflators to the impact price years in a separate reporting table. A weighting factor *w is* then applied to these costs that considers the proportion of natural land cover in the UK that exceeds the critical loads of N deposition.

In (6) the external cost per vehicle km travelled (EC_q) is calculated by first deriving the grams of NO_X emissions produced per km as a function of road type; area type; congestion band and year for both rigid and articulated vehicles. This is multiplied by the external cost of NO_X emissions (£ per kg deposition) to compute the average cost per vehicle kiloemtre travelled.

An interpolation has been made based on some interval years (2025, 2035 and 2045) where emissions estimates have not been forecast in the NTM.

7.8.5 Step 6: Denote environmentally sensitive areas

In addition to employing a dose response function, a penalty mechanism is also applied to account for HGV traffic through National Parks and (AONBs)[11]. These designations are considered to be appropriate since both operate at the landscape scale and reflect areas of high natural and social value and are not purely ecology focused. For a review of statutory designations and justification for inclusion/exclusion

[11] Note National Scenic Areas are equivalent to AONBs in Scotland.

please refer to Appendix 3.

The OS Mastermap data (Ordinance Survey, 2019) for roads in Great Britain is overlaid on this layer to identify roads that pass through the relevant designations where the associated penalty factor can be applied. This can then be incorporated into the Department for Transport's routing software for calculating the MSB grants.

7.8.6 Step 7: Calculate the penalty factor

The final MEC-E values were computed for the base (current), medium and high scenarios and reported for five-yearly intervals. The scenarios are discussed further in the following sub-sections but generally assume different rates of change concerning the HGV vehicle parc[12] and associated fuel types. Note the base scenario only changes the efficiency of vehicles, rather than fuel types. In addition, the MEC's were also calculated irrespective of congestion band through the application of a weighted average of the MEC values based on the number of vehicle kilometres travelled according to each congestion band.

7.8.7 Step 8: Reporting the MEC-E values

The final MEC-E values can be computed for the base (current), medium and high scenarios and reported for five-yearly intervals. The scenarios are discussed further in the following sub-sections but generally assume different rates of change concerning the HGV vehicle parc and associated fuel types. Note the base scenario only changes to the efficiency of vehicles, rather than fuel types. The total reported value is the combination of the external costs plus the application of any penalty factor that results in final MEC values. These values can then be used to calculate the MSBs for different route and vehicle combinations.

7.9 MEC Environment values

Results for the base scenario for the different road and area types in 2020 prices are presented in Table 54 and Table 55 for artics and rigids, respectively and in Figure 19 the MEC-E 2025 values. The base scenario represents the reference case in line with Transport Analysis Guidance and that of the NTM, which assumes all HGVs are diesel until 2050, with just vehicle efficiency improvements (12% for rigids and 21% for artics between 2015 and 2050).

The value estimates from this scenario are highest for 'other roads' in rural areas since the natural proportion of land cover is much higher (despite the fact that emissions on rural roads are generally lower than for other area types). Conversely, the least costly road type is motorways in inner and outer conurbations. The MEC-E values are on average higher for rigids than artics which is a function of the variation in NO_X emissions since artics tend to emit less NO_X per kilometre travelled than rigids.

[12] Vehicle parc refers to the number of vehicles in a region or country (in this context HGVs in the UK) broken down by multiple characteristics, including fuel type.

Table 54: MEC Environment – values in pence/vkm, Artics and Rigids, 2020 prices, base scenario

	Artics							Rigids						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inner and Outer Conurbations														
Motorways	0.06	0.04	0.02	0.02	0.02	0.02	0.02	0.07	0.04	0.02	0.02	0.02	0.02	0.02
A Roads	0.12	0.08	0.04	0.04	0.04	0.04	0.04	0.13	0.08	0.04	0.04	0.04	0.04	0.04
Other Roads	0.12	0.08	0.03	0.03	0.03	0.03	0.03	0.12	0.08	0.03	0.03	0.03	0.03	0.03
London														
Motorways	0.07	0.05	0.02	0.02	0.02	0.02	0.02	0.07	0.05	0.02	0.02	0.02	0.02	0.02
A Roads	0.21	0.14	0.06	0.06	0.06	0.06	0.07	0.21	0.13	0.06	0.06	0.06	0.06	0.06
Other Roads	0.17	0.11	0.05	0.05	0.04	0.04	0.05	0.18	0.11	0.05	0.05	0.05	0.05	0.05
Other Urban														
A Roads	0.09	0.06	0.03	0.03	0.03	0.03	0.03	0.10	0.06	0.03	0.03	0.03	0.03	0.03
Other Roads	0.11	0.07	0.03	0.03	0.03	0.03	0.03	0.11	0.07	0.03	0.03	0.03	0.03	0.03
Rural														
Motorways	0.10	0.06	0.03	0.03	0.03	0.03	0.03	0.10	0.06	0.03	0.03	0.03	0.03	0.03
A Roads	0.13	0.08	0.03	0.03	0.03	0.03	0.03	0.14	0.09	0.03	0.03	0.03	0.03	0.03
Other Roads	0.31	0.19	0.07	0.07	0.06	0.06	0.06	0.31	0.19	0.07	0.07	0.06	0.06	0.06

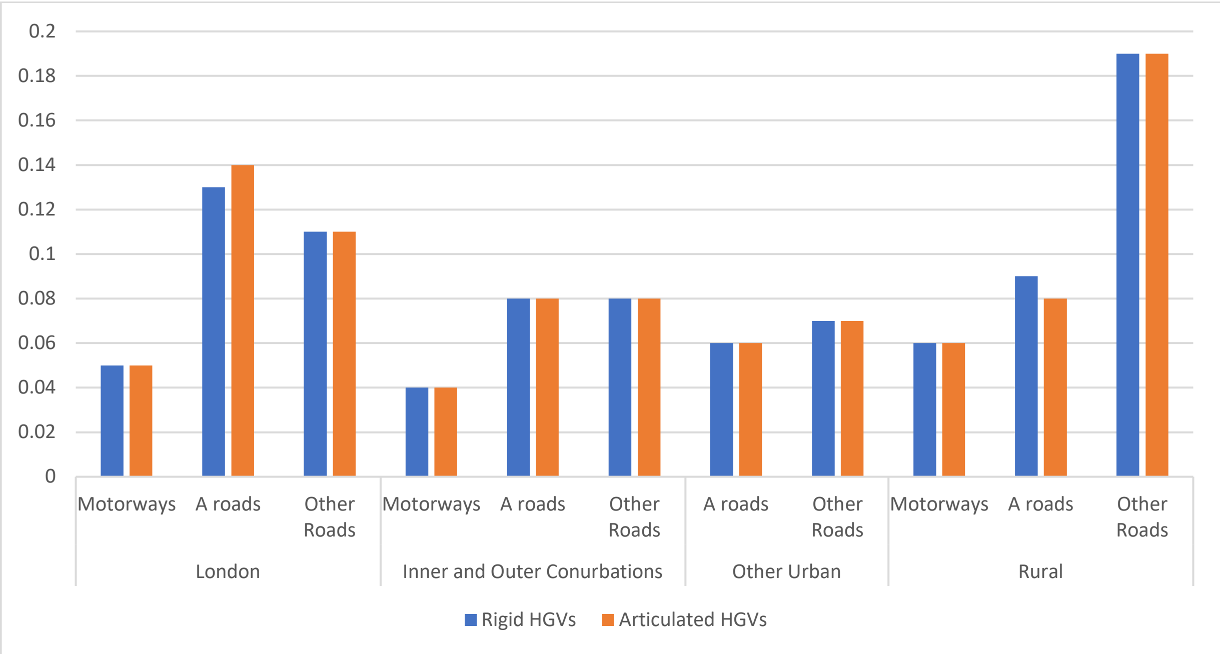


Figure 19: MEC-E values, pence per vkm, 2025 impact, 2020 prices, by HGV type

The methodology previously used for MECs calculation did not include computing separate MEC-E values, so the comparison between previous and current MEC-E values is not possible.

7.10 Sensitivity scenarios

A medium and high scenario of the MEC was created to account for the potential forecast of uptake of low carbon fuels. The scenarios have been defined as follows:

- Medium scenario - a balanced approach from Transport Energy Infrastructure Roadmap to 2050 (Element Energy, 2015), Technology Roadmap 2015 - Energy and Fuels (Automotive Council UK (2018).
- High scenario - based on the Hydrogen further ambition scenario in Zero Emission HGV

Infrastructure Requirements (Ricardo, 2019).

7.10.1 Medium scenario

Results for the medium scenario for the different road and area types in 2020 prices are presented in Table 55 for artics and rigids, respectively. The scenario is based on the approach documented in Element Energy (2015) and Automotive Council UK (2018). Both studies present a balanced approach to CO_2 emission reduction focused on natural technology evolution and use of already available low emissions fuels. The scenario corresponds with Government targets aiming to achieve an 80% reduction to CO_2 emissions by 2050.

The value estimates from this scenario result in a gradual decrease in the MEC-E value estimates, relative to the base scenario. For artics, this decrease is 65% over the period 2020 to 2050 while for rigids the reduction is higher, being 66% over the period 2020 to 2050. Because the scenario is related to fleet parc changes, the reduction in MECs tends to be a fixed across most different road and area types.

Table 55: MEC Environment – Medium Scenario pence/vkm,2020 prices (Rigids & Artics)

	Artics							Rigids						
	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
Inner and Outer Conurbations														
Motorways	0.06	0.04	0.01	0.01	0.01	0.01	0.01	0.06	0.04	0.01	0.01	0.01	0.01	0.01
A Roads	0.11	0.07	0.03	0.02	0.02	0.02	0.01	0.11	0.07	0.03	0.02	0.02	0.02	0.01
Other Roads	0.11	0.07	0.03	0.02	0.02	0.01	0.01	0.11	0.07	0.02	0.02	0.02	0.01	0.01
London														
Motorways	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0.06	0.04	0.01	0.01	0.01	0.01	0.01
A Roads	0.19	0.12	0.05	0.04	0.04	0.03	0.02	0.18	0.12	0.05	0.04	0.03	0.03	0.02
Other Roads	0.16	0.10	0.04	0.03	0.03	0.02	0.02	0.16	0.10	0.04	0.03	0.03	0.02	0.02
Other Urban														
A Roads	0.09	0.06	0.02	0.02	0.02	0.01	0.01	0.08	0.05	0.02	0.02	0.01	0.01	0.01
Other Roads	0.11	0.06	0.02	0.02	0.02	0.01	0.01	0.10	0.06	0.02	0.02	0.01	0.01	0.01
Rural														
Motorways	0.09	0.06	0.02	0.02	0.02	0.01	0.01	0.09	0.06	0.02	0.02	0.02	0.01	0.01
A Roads	0.12	0.07	0.03	0.02	0.02	0.02	0.01	0.13	0.08	0.03	0.02	0.02	0.02	0.01
Other Roads	0.28	0.17	0.06	0.05	0.04	0.03	0.02	0.28	0.17	0.05	0.05	0.04	0.03	0.02

7.10.2 High scenario

Results for the high scenario for the different road and area types in 2020 prices are presented in Table 56 for artics and rigids, respectively. The high scenario is based on the Hydrogen Further ambition scenario set out in the Net Zero report produced by Ricardo (2019) for the Committee on Climate Change. The scenario explores how a hydrogen-based fleet of HGVs would reduce emissions and results in almost zero CO_2 emissions by the year 2050.

The value estimates from this scenario result in a more progressive reduction in MEC values for HGVs over the period 2020 to 2030 (relative to the medium scenario) while hydrogen technology is becoming more mature, as shown on Table 56. For rigids, the high scenario delivers a more rapid reduction in emissions starting from the 2020 year, most likely because the scenario suggests hydrogen technology will be deployed quicker in the rigid than articulated fleet parc.

Beyond 2030, the reduction in emissions is more pronounced and over the period 2030 to 2050 this results in a 24% higher reduction in the MEC values compared to the medium scenario for both rigids and artics. Relative to the base scenario, the reduction in MEC-E over the period 2020 to 2050 is 96% for rigids and artics.

Table 56: MEC Environment – High Scenario pence/vkm,2020 prices (Rigids & Artics)

	Artics							Rigids						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inner and Outer Conurbations														
Motorways	0.06	0.04	0.02	0.01	0.01	0.00	0.00	0.06	0.04	0.02	0.01	0.01	0.00	0.00
A Roads	0.11	0.07	0.03	0.02	0.01	0.01	0.00	0.11	0.07	0.03	0.02	0.01	0.01	0.00
Other Roads	0.11	0.07	0.03	0.02	0.01	0.01	0.00	0.11	0.07	0.03	0.02	0.01	0.01	0.00
London														
Motorways	0.07	0.04	0.02	0.01	0.01	0.00	0.00	0.06	0.04	0.02	0.01	0.01	0.00	0.00
A Roads	0.19	0.12	0.05	0.04	0.02	0.01	0.00	0.18	0.12	0.05	0.04	0.02	0.01	0.00
Other Roads	0.16	0.10	0.04	0.03	0.02	0.01	0.00	0.16	0.10	0.04	0.03	0.02	0.01	0.00
Other Urban														
A Roads	0.09	0.06	0.03	0.02	0.01	0.01	0.00	0.08	0.05	0.02	0.02	0.01	0.01	0.00
Other Roads	0.11	0.07	0.03	0.02	0.01	0.01	0.00	0.10	0.06	0.02	0.02	0.01	0.01	0.00
Rural														
Motorways	0.09	0.06	0.02	0.02	0.01	0.01	0.00	0.09	0.06	0.02	0.02	0.01	0.01	0.00
A Roads	0.12	0.07	0.03	0.02	0.01	0.01	0.00	0.13	0.08	0.03	0.02	0.01	0.01	0.00
Other Roads	0.28	0.17	0.06	0.04	0.02	0.01	0.00	0.28	0.17	0.06	0.04	0.02	0.01	0.00

7.11 Indexation and updates

The model will require regular updates to maintain integrity and robustness. Table 57 reports the key parameters that will need updating and the regularity of update intervals. The update intervals are meant only as a guide and consider the likely magnitude of changes over time for each parameter that would warrant a revision. In the absence of major updates, the model can be updated through indexation with changes to inflation and price indices as reported by the Office for National Statistics.

Table 57: MEC Environment – model parameters and updating intervals

Parameter	Recommended Update Frequency
PDF	Update every 10 years based on changes in estimates derived from the Natuurplanner model estimates for the effects of N deposition on the occurrence of plant species.
ΔPDF	Linked to PDF above.
Restoration cost	Should be updated every 10 years if revised estimates have been published.
Weighting factor	Should be updated every 10 years based on changes to the critical load exceedances as a proportion of natural area for GB.
Reference habitat	Only needs updating based on changes to the composition of GB habitats.
Proportion of natural area	Should be revised every 15 years based on landcover map data or a similar source.
Proportion of habitat	Should be revised every 15 years based on landcover map data or a similar source.
Emissions estimates	Should be updated every 5 years based on the NTM for NO_X. May also consider particulate emissions in future model iterations.
NO_X deposition	Linked to NO_X emissions above.
Penalty uplift factor	Should be reviewed internally by the DfT every 5 years with reference to the available literature on the effect of transport emissions in sensitive landscapes.

7.12 Limitations and recommendations

The model is currently limited by three key factors: landcover mapping, scope and value categorisation. Habitat data was derived from the 2018 CLC map data. The choice of minimum mapping unit (MMU = 25 hectares) and minimum width of linear elements (MMW = 100 metres) in CLC mapping represent a trade-off between processing speed and detail of land cover information (European Environment Agency, 2017). Thus, the land cover data is unlikely to capture the heterogeneity in habitat types adjacent to roadsides and this should be considered in future updates. Accessing less coarse spatial data to document habitat types within the Strategic Road Network (SRN) is recommended.

In terms of scope, the model does not consider the effects of particulate matter pollution on ecosystems since the science is still emerging concerning critical loads and thresholds that may result in habitat damage arising from particulates. This may result in an underestimate of the MEC-E values, while noting that work by Natural England (2016) has found no significant effects concerning the ecological impact of particulates and dust on plant species.

The computation of MEC values according to the respective impact categories is important to derive accurate accounts concerning the marginal costs of HGV transport. To avoid double counting with MEC-Air Quality, MEC-E only considers N deposition within areas adjacent to the roadside (i.e. dry deposition). The approach documented for MEC-Air Quality considers wet deposition focused on four habitat types (acid grass; bogs; dunes; heathlands) (Defra, 2019c) that are all priority habitats[13]. It is recommended in future iterations that these impacts are considered in MEC-E instead to provide a more accurate representation of the environmental and ecosystem effects associated with HGV emissions. These impacts could be modelled using a similar approach taken here but with the added benefit of considering more habitat types in the analysis.

This revised approach to calculating the MEC values for environment has attempted to account for HGV transport through unique and sensitive landscapes. The penalty factors seeks to incentivise alternative transport modes through these areas by use of the revised MSB estimates. This relates to a more fundamental question for the Department regarding where incentives are best targeted to encourage alternative transport modes. For instance, it may be more appropriate to increase the penalty mechanism by a higher factor to add more weight in the MSBs to reduce HGV transport in sensitive areas. This largely depends on the viability of alterative transport modes in these areas. The former will be linked to the type of goods being transported (e.g. aggregates, feed-stocks, consumer goods, etc) and distances necessary.

Residual effects not considered in the model include visual effects (particularly in sensitive areas); species specific impacts focused on charismatic species and water and environment pollution damages arising from spill events. In addition, the model has focused on ecosystem effects attributed to N (dry) deposition. Other factors may be appropriate for consideration in further updates.

Future updates of the model should consider new and emerging work in the area of ecosystem services valuation and natural capital. For instance, recent work by Eftec (2019) has explored the valuation of landscape impacts associated with transport interventions using an ecosystem services approach. Such approaches have grown increasingly popular over time and are well aligned to the Government's future ambitions for adopting natural capital approaches. While not suitable for calculating the MEC values in this update, as the science evolves there may be scope to reconsider such approaches.

[13] For a list of priority habitats see http://archive.jncc.gov.uk/page-5706.

8 Up and Downstream Processes

8.1 Introduction

Up and down stream processes (indirect effects due to the production of energy, vehicles and transport infrastructure) are included in the 'other' category of Marginal External Costs (MECs). This document sets out the results of our review of the methodologies used for upstream and downstream impacts associated with vehicle production and disposal, and production of energy.

Up and downstream processes correspond to the activities related to the energy and fuel production sector, from exploration at primary fuel/energy source to the supply at the point of distribution in refuelling stations or in the electric grid, the activities involved in the vehicle production, from extraction of raw materials to assembly, and the end-of-life, from disposal of the vehicle to recycling of components and the activities related to infrastructure provision

The cost of up and downstream processes corresponds to the indirect effects arising from the production of energy, vehicles and transport infrastructure. These costs can be considered to be external where they are not internalized by the driver or operator through taxes, tolls and other charges. The costs of up and downstream processes are calculated based on the additional air pollution and climate change costs that result of the activities aforementioned. Not accounting for these emissions would result in a systematic undervaluation of the impact that HGV transport places both on the road network but also in the location where vehicles and fuels are produced.

Currently DfT considers these impacts through calculation of the marginal external cost (MEC) categories, where up and downstream processes are considered within MEC-Other (DfT, 2014)[14]. The calculation methodology was based on a simple uplift factor relative the other external costs MECs estimated. This methodology was largely based on work by Maibach et al. (2008) that provides an overall 10% uplift for the categories of external cost that are currently included in MEC-Other (up and downstream processes; soil and water pollution; nature and landscape; driver frustration and stress; fear of accidents; community severance and visual intrusion). DfT (2014) provided a broad indication of the 'marginal' element this category costs being equivalent to about 3% of the total value of the remaining external costs.

The MEC values are subsequently used to calculate the mode shift benefit (MSB) values used in the mode shift revenue support grants, that aim to incentivise changing transport modes for freight in Great Britain.

8.2 Current approach

Currently Maibach et al (2008) is the source of values used for up and downstream processes. A review and assessment of this methodology are presented in the next sections of this report.

8.3 Best practice methodologies review

A review of academic literature and industry reports was carried out to examine the potential for updating or revising the assumptions taking from Maibach et al (2008). The reports in scope are shown in the table below.

[14] current mode shift benefit values have been published by DfT in 2009 and refreshed in 2014

Table 58: MEC Up and Downstream processes – best practice methodologies

Scope	Author	Date	Report Title
Vehicles and Energy	Maibach et al	2008	Handbook on estimation of external costs in the transport sector
	van Essen et al	2011	External Costs of Transport in Europe
Vehicles	Odeh et al	2013	Current and Future Lifecycle Emissions of Key 'Low Carbon' Technologies and Alternatives
	Messagie	2014	Life Cycle Analysis of the Climate Impact of Electric Vehicles
	Tagliaferri et al	2016	Life cycle assessment of future electric and hybrid vehicles: a cradle-to-grave systems engineering approach
	Transport & Environment	2017	Electric vehicle life cycle analysis and raw material availability
	Schuller and Stuart	2018	From cradle to grave: e-mobility and the energy transition
	Patterson	2018	Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies
Energy	Schroten and Hoen	2016	Infrastructure and external cost coverage of road freight on EU28 motorways

The reports and publications reviewed have been assessed and the incumbent methodology and potential alternative have been assessed in detail. The first assessment undertaken for each report verifies if the relevant vehicle and fuel/energy types are in scope. If not, no further assessment is undertaken. The following sub-headings present a detailed review of selected papers and their methodological approach in up and downstream processes emissions.

8.3.1 Maibach et al (2008) Handbook on estimation of external costs in the transport sector

Maibach et al (2008) present detailed cost tables for up and downstream processes (fuel production, air pollution and climate change costs) in €ct/vkm for passenger cars and heavy-duty vehicles. Costs are disaggregated by gross vehicle weight (GVW) and Euro emissions standards up to Euro V.

Costs are only provided up to and including Euro V vehicles. No costs are provided for Euro VI vehicles. All HGVs sold since 2014 have been Euro VI compliant and the majority of the HGV parc will meet this standard within 10 to 15 years. Similarly, no costs are provided for electric or alternatively fuelled vehicles, which will make up an increasing share of the HGV fleet between now and 2050 and do not reflect the changing composition of the UK HGV fleet. Additional primary research would be required to bring the Maibach et al (2008) figures up to date.

Maibach et al (2008) is the current methodology used for estimating upstream and downstream vehicle and energy production impacts. In addition to the limitations listed above, the study combines vehicle and energy up and downstream impacts into a single figure. Ideally the two should be treated separately. This is particularly important as electric vehicles enter the fleet, as they will have higher production emissions and lower in-use emissions than a comparable diesel model. Also, the figures are for the German market and their energy supply is different to the UK. For example, they have a higher share of nuclear energy in their electricity generation. This methodology is no longer fit for purpose.

8.3.2 Van Essen et al (2011) External Costs of Transport in Europe

This study is an update to Maibach et al (2008). It considers all costs elements[15], but the calculations are conducted only for costs of the emission of air pollutants and greenhouse gases due to energy production and distribution.

Risks of energy production and distribution are excluded from calculations after the initial screening, as well as vehicle and infrastructure production, maintenance and disposal costs, as no recent and valid cost factors are available as reference points. On the vehicle and infrastructure side, the study refers Ecoplan/INFRAS study (2008), where the external costs of vehicle and infrastructure for road transport account for 50% of the total up and downstream costs (the other 50% are due to energy production and distribution).

The methodology used in this study to calculate energy production emissions is based on emission data (air pollutants, greenhouse gases) multiplied with cost factors (shadow prices) per pollutant for air pollution costs and climate change costs. The study specified data sources used for cost factors estimation (NEEDS, 2007).

8.3.3 Odeh et al (2013) Current and Future Lifecycle Emissions of Key 'Low Carbon' Technologies and Alternatives

This report was prepared by Ricardo-AEA for the Committee on Climate Change. It sets out to address similar research objectives to the current MECs project, by establishing a range of lifecycle emissions for technologies deployed in the UK, identifying key sources and locations of these emissions, and developing scenarios for potential changes in lifecycle emissions to 2050.

The report compares plug-in hybrid and battery electric drivetrains with ICE technology but only for cars. For HGVs, the scope is restricted to hydrogen fuel cell electric hybrid technology.

Material and grid emission intensities were estimated for 2010, 2020, 2030, 2040 and 2050 and used to estimate current and future lifecycle emissions. GHG emissions were calculated from these values.

8.3.4 Patterson (2018) Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies

This report was prepared by Ricardo for the LowCVP. The scope is broad and includes heavy duty trucks with conventional internal combustion engine, battery electric, hybrid and plug in hybrid drivetrains. For fuels and energy, it covers gas, diesel and electricity.

It considered the relative contribution of each life cycle stage (vehicle production, fuel production, vehicle use and vehicle disposal) to life cycle CO2e emissions.

The report estimates the proportion of vehicle life cycle emissions associated with each life cycle stage. It also identifies the factors which influence this breakdown, such as vehicle type, lifetime mileage and duty cycle

The paper provides estimates for the proportion of emissions associated with each life cycle stage, and how this is influenced by factors such as vehicle and fuel type, can be used to help build a model to show different pathways for life cycle emissions. However, it only provides figures for diesel and hybrid vehicles, so there are gaps around other alternative fuels and technologies that are increasingly entering the HGV parc.

Patterson (2018) is an up to date and comprehensive review of lifecycle emissions. While there are gaps and shortcomings in the research, the outputs from this study can be used to help develop a new methodology for estimating upstream and downstream vehicle impacts.

---

[15] Energy production and distribution; vehicle and infrastructure production, maintenance and disposal

8.3.5 Other studies

Other, less comprehensive studies were also reviewed:

- **Messagie (2014) Life Cycle Analysis of the Climate Impact of Electric Vehicles.** The study only considers cars, and only compares internal combustion engine (ICE) and electric drivetrains and is therefore not taken forward for further assessment.
- **Tagliaferri et al (2016) Life cycle assessment of future electric and hybrid 2 vehicles: a cradle-to-grave systems engineering approach.** The study only considers cars, and only compares internal combustion engine (ICE) and electric drivetrains and is therefore not taken forward for further assessment.
- **Transport & Environment (2017) Electric vehicle life cycle analysis and raw material availability.** The study only considers cars, and only compares internal combustion engine (ICE) and electric drivetrains and is therefore not taken forward for further assessment.
- **Schuller and Stuart (2018) From cradle to grave: e-mobility and the energy transition.** Scope (appropriate vehicle/energy types included in study?): No. The study only considers cars, and only compares internal combustion engine (ICE) and electric drivetrains and is therefore not taken forward for further assessment.
- **Schroten and Hoen (2016) Infrastructure and external cost coverage of road freight on EU28 motorways.** Although the report does include HGVs, it is only focused on EU28 motorways, and therefore doesn't provide a full picture of damage costs.

8.4 Methodology selection

8.4.1 Methodology options assessment

Several methodology options were identified to address marginal up and downstream external costs of HGV traffic (Table 59)

- Option 1: Continue using Maibach et al (2008),
- Option 2: Collect primary data to update Maibach et al (2008),
- Option 3: Develop and apply a new model.

Table 59: MEC Up and dowsntream – methodology options

Approach	Scope	Advantages	Disadvantages	Data requirements
Continue using Maibach et al (2008)	In scope	Well understood and already incorporated into the MECs methodologies	This review has identified multiple weaknesses with this approach, most pertinently that it doesn't reflect the introduction of Euro VI or alternatively fuelled vehicles and therefore doesn't reflect the current and future HGV fleet composition.	Detailed localized datasets required
Collect primary data to update Maibach et al (2008)	Out of scope	This approach would update the incumbent methodology and therefore it may be relatively easy to integrate outputs into the MEC figures.	Further primary research would need to be commissioned with appropriate budgets and timescales considered. However, the research has shown that embedded emissions are a very small proportion of total lifecycle emissions, and while this is expected to increase it will continue to be marginal. DfT would need to consider the costs involved in updating the Maibach et al (2008) figures and weigh these up against the likely marginal improvements to the accuracy of the MEC figures.	Detailed localized datasets required

Approach	Scope	Advantages	Disadvantages	Data requirements
Develop and apply a bespoke model based on Patterson (2018) (recommended)	In scope	A bespoke model to estimate changes in vehicle and energy upstream emissions, reflecting forecast changes to the fleet composition through to 2050. Based on UK data, reflects current datasets, and addresses many of the weaknesses noted in this literature review. For alternative fuel uptake the methodology is robust as it combines DEFRA's current Well-to-Tank (WTT) emissions factors with DfT's forecasts about changing fuel composition. For vehicle mix, this methodology improves on Maibach et al (2008) by using DfT's figures to show how changing fleet composition may impact on lifecycle emissions.	There is a lack of good primary data in the literature which focus either on HGVs or on alternative fuels (aside from hybrid and electric drivetrains). Model relies on experts' assumptions about the lifecycle impacts of gas vehicles, and the uplift in lifecycle emissions from internal combustion engine (ICE) vehicles to hybrid and plug-in vehicles were built based.	Feasible with existing data sets

8.4.2 Recommended methodology

The recommended methodology for MEC-UD processes calculation is to adopt a bespoke method of estimating changes in vehicle and energy upstream emissions, which reflects forecast changes to the fleet composition through to 2050. This bespoke model is based on the methodology outlined in the report prepared by Patterson (2018) 'Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies', under the umbrella of Ricardo and the LowCVP.

The bespoke model provides robust data which can be used to inform an update to the up and downstream MEC figures, albeit there are caveats due to the assumptions required. The model approach stands as follows:

- The emissions for the vehicle life cycle are split into WTW (Well-to-Wheel) and Embedded emissions (vehicle production & end-of-life).
- The WTW emissions are further disaggregated into Well-to-Tank (WTT) and TTW (Tank-to-Wheel) emissions
- CO_2, NO_x & PM_{10} WTT and TTW emission matrices are created for the artics and rigids for different fleet composition scenarios:
    - Base scenario: Diesel vehicles are continued as 100% of the vehicle parc.
    - Medium and High uptake scenario: The proportion of vehicle fleet uptake is calculated using various sources and applies to the artics and rigids despite its distinct technology development.
- TTW emissions for the base scenario are extracted from NTM model outputs. For each sensitivity scenario, using the diesel baseline, vehicles are substituted by the corresponding diesel equivalents based off the predicted proportion uptake of vehicle technologies for the respective scenario.
- The WTT emissions are calculated as a proportion of the TTW emissions of the vehicle, using DEFRA's conversion data.

8.5 Adopted methodology outline

8.5.1 Overview

Upstream and downstream processes correspond to the activities related to the energy and fuel production sector, from exploration at primary fuel/energy source to the supply at the point of distribution in refuelling stations or in the electric grid, the activities involved in the vehicle production, from extraction of raw materials to assembly, and the end-of-life, from disposal of the vehicle to recycling of components and the activities related to infrastructure provision.

Up and downstream processes (indirect effects due to the production of energy, vehicles and infrastructure) are, in the current methodology proposed by Maibach (2008), included in the 'Other' category of Marginal External Costs (MECs).

Maibach et al. (2008) provide values for up and downstream processes, soil and water pollution and nature and landscape. The values from Maibach et al (2008) suggest that at an aggregate level these three external costs account for roughly 10% of the value of all other monetised impacts.

Maibach et al (2008) present detailed cost tables for up and downstream processes (fuel production, air pollution and climate change costs) in €ct/vkm for passenger cars and heavy-duty vehicles. In this study the costs are disaggregated by gross vehicle weight (GVW) and Euro emissions standards up to Euro V. This approach poses several limitations, namely by not considering the emissions of vehicles after Euro V it does not take into account the current mix of the vehicle parc, since all HGVs sold since 2014 have been Euro VI compliant. It is expected that the majority of the HGV parc will meet this standard within 10 to 15 years (2025 – 2030). Similarly, Maibach et al. (2008) do not provide cost for electric or alternatively fuelled vehicles, which will make up an increasing share of the HGV fleet between now and 2050, which will be addressed in the current study by the sensitivity scenarios.

The results of the literature review demonstrate that diverse methodologies can be used for measuring upstream and downstream impacts associated with vehicle production and disposal, and production of energy.

8.5.2 Upstream and downstream emissions

Prior to presenting the methodological approach a clarification regarding the terminology of the different emission types is presented in the following section.

In this study the emissions for the vehicle life cycle have been classified as:

- Well-to-Wheel emissions: composed of Well-to-Tank and Tank-to-Wheel emissions.
- Embedded emissions.

In order to assure consistency with the industry standard designation of vehicle emissions, in this study we have adopted the following classification for upstream and downstream processes' emissions:

- Up and downstream processes: correspond to the combined effects of the Well-to-Tank emissions and embedded emissions.

In this study we have defined the emissions as follows:

Well-to-Tank (WTT): corresponds to the result of the activities from fuel production at the primary fuel source (refinery) to the supply at the point of distribution (refuelling stations). These activities cause emissions of pollutants due to extraction of raw materials, transformation and transport of the fuels and transmission of electricity. These emissions lead to external effects, mainly air pollutants (such as PM_{10}, $PM_{2.5}$ and NO_x), and climate change costs due to Well-to-Tank emissions of greenhouse gases (such as CO_2 and CH_4).

Tank-to-Wheel (TTW): the emissions that result from running a vehicle. The NTM model evaluates the emissions produced by the vehicles that travel in the road network, based on assumptions such as speed (congestion as an effect of speed reduction) and therefore will be utilised as the Tank-to-wheel emissions in this study. A caveat of this assumption is the exclusion of the impact of maintenance and servicing of vehicles on the emissions produced.

Embedded emissions: Embedded emissions correspond to the environmental impact associated with vehicle production (including extract of raw materials, processing, component manufacture, logistics, vehicle assembly and painting) and the corresponding end-of-life of the vehicle (including re-using components, recycling materials, energy recovery, and disposal to landfill). Although there are several studies related to commercial trucks emissions, only a limited number considers the whole HGV life cycle, accounting for embedded emissions. Embedded emissions from vehicle production and end-of-life have been reported to account for circa 1 to 4% of total vehicle life cycle CO_2 emissions for diesel vehicles. Also, it is important to note that due to higher lifetime mileages than other vehicles, namely light vehicle, the use phase dominates life cycle CO_2 emissions for medium and heavy-duty trucks (LowCVP Vehicle lifecycle - Ricardo 2018).

8.5.3 Methodological approach

From the examination of complementary work carried out for other elements road freight Marginal External Costs from HGV, not part of this research, it was noted that Air Quality MEC consists of the appraisal of pollutants along the UK road network. Therefore, to mitigate potential double counting of the externalities of road freight, the effects of environmental pollutants, namely PM_{10} and NO_x, have been excluded from the MECs up and downstream processes remit. Moreover, the effect of the pollutants is expressly related to the location where these are emitted. Both up and downstream processes take place in a different location to the road network (the majority of the oil supply is originally produced overseas and a great proportion of the vehicles that circulate in the UK are imported[16]) and therefore have not been considered in the domain of this study.

Another remark drawn from the evaluation of the Climate Change MEC, not part of this study research, was that the impacts of greenhouse gases emitted as a result of the vehicle use were covered by this MEC. These emissions that correspond to Tank-To-Wheel emissions, have been considered in the evaluation of the Climate Change MEC and therefore are not being considered as part of the evaluation of the MEC Up and Downstream.

The embedded emissions have been excluded from the analysis and therefore have not been accounted for in the MEC calculations for up and downstream processes part of this study. The average embedded costs may lead to an inaccurate examination of the marginal external costs and it is discouraged using average costs as a proxy to marginal embedded costs. In order to measure the impact of an additional vehicle kilometre on the road network on the production and specially on the end-of-life of the vehicle additional research (not in the scope of this study) would be required. There are several external factors that contribute to the demand for new vehicles and disposal of the parc such as financial health of the freight sector or age of the vehicle parc. Ultimately, the inclusion or not of the embedded costs poses minimal impact on the final values, as these costs account for circa 1% of the overall WTW costs.

The methodology adopted exclusively estimates the cost of Well-to-Tank emissions by converting the Tank-to-Wheel emissions, taken from NTM output, to Well-to-Tank emissions followed by the corresponding monetisation. To guarantee consistency with governmental guidelines, in this project we have followed DEFRA's guidance on the conversion between Tank-to-Wheel and Well-to-Tank emissions.

The average cost of the impact of HGV up and downstream emissions has been used as a proxy to estimate the marginal cost of one additional HGV in the road network. This approach can be validated for Well-to-Tank emissions, as there is a direct relationship between the volume of vehicles and the fuel supply and utilization.

8.5.4 Methodology framework

The methodology framework developed is based on the impact of the Well-to-Tank processes associated with the HGV activity on CO_2 emissions. In order to obtain the Well-to-Tank emissions in the UK road network, the NTM tailpipe emissions by road type, area type, congestion level and vehicle category have been factored using DEFRA's conversion factors (see section 8.8). A broad assumption was made regarding the NTM tailpipe emissions being equivalent to the Tank-to-Wheel emissions. The overarching methodological approach is presented in Figure 20, including model inputs and outputs.

[16] The motor industry: statistics and policy, Jennifer Brown and Chris Rhodes, House of Commons, 2018

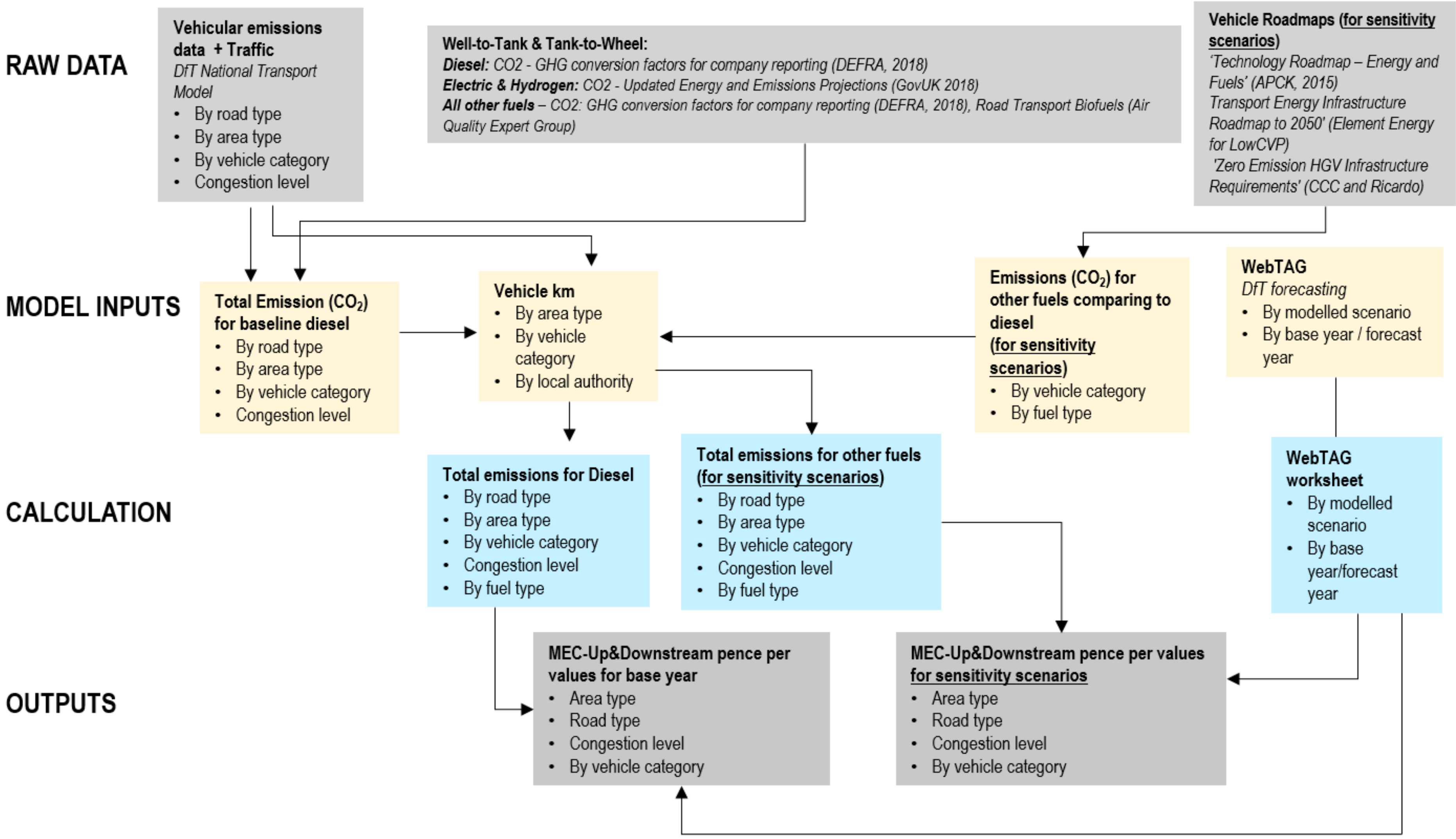


Figure 20: MEC Up and Downstream processes – methodological framework

8.6 Data specification

Data sources used for calculations and clarification of the methodology are presented on Table 62. Although the embedded emissions were excluded from the analysis of the up and downstream processes, the literature referenced in Table 62 was consulted and helped identifying the current gaps in the appraisal of marginal external costs for embedded emissions.

Table 60: MEC Up and Downstream processes – data sources

Data Type	Description	Coverage	Format	Update frequency	Year	Sources
NTM Data (including emissions)	Output from the National Transport Model	GB	Wide	Annual	2019	Department for Transport
GHG conversion factor for company reporting (CO_2)	Factors for TTW and WTT emissions	UK	Table	Periodic	2019	DEFRA
Updated Energy and Emissions Projections (EEP 2019)	Forecast for TTW Electricity emissions	UK	Table	Periodic	2019	BEIS, GovUK
Road Transport Biofuels	Factors for TTW emissions of Biofuel and Diesel blend	UK	Table	Periodic	2011	Air Quality Expert Group
Economics of Converting Renewable Power to Hydrogen	Factor for converting WTT emissions from Electricity to Hydrogen	UK	Table	Sporadic	2019	Glenk, G. and Reichelstein, S.
Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies	Embedded emissions for electric vehicles (for embedded emissions)	UK	Report/Table	Sporadic	2018	LowCVP, Ricardo
Lifecycle emissions from cars	Lifecycle carbon emissions (for embedded emissions)	UK	Report	Sporadic	2017	LowCVP
The not-so-green truth about current car CO_2 legislation	Lifecycle carbon emissions (for embedded emissions)	UK	Report	Sporadic	2018	Ricardo, Autocar
Cradle to Grave Lifecycle Analysis U.S. Light-Duty Vehicle-Fuel Pathways	Lifecycle carbon emissions (for embedded emissions)	US	Report/Table	Sporadic	2016	Argonne National Laboratory
GDP Deflators	GDP deflators reference values	UK	Long	Quarterly	2019	Department for Transport

8.7 Model assumptions and inputs

Model assumptions and inputs used for further calculations include:

- General model assumptions and inputs such as GDP growth, inflation and other economic indicators (TAG compliant).
- Traffic data form the NTM model 2019.
- The impact of tailpipe (Tank-to-wheel) emissions of PM_{10} and NOx are not included in calculations as they are a part of Air Quality MEC being outside of the scope of this study
- The impact of tailpipe (Tank-to-wheel) emissions of CO_2 are not included in calculations as they are a part of Climate Change MEC being outside of the scope of this study
- For the purpose of converting Tank-to-wheel to Well-to-tank emissions, it was assumed that NTM tailpipe emissions corresponded to Tank-to-Wheel emissions.

8.8 Calculation procedures

This section sets out the calculation procedures to estimate MEC-UD values.

8.8.1 Step 1: Aggregate NTM link level data

The following data variables and category variables from the base NTM dataset are required for MEC-UD calculation:

- Road type
- Area type
- Congestion band
- Vehicle type (Artic or Rigid)
- Year
- Sum of CO_2
- Sum of Annual vehicle kilometres – Rigid and Artic

National Transport Model (NTM) data are typically provided at area type and road type level. For the purpose of this study, NTM data has been output at link level, which may impact the data accuracy at link level.

NTM data was aggregated from link level to road and area type data for both rigids and artics. This data was used to compute the CO_2 emissions per vehicle kilometre travelled for the base year (2020), forecast years in the NTM (5 yearly intervals to 2050) and congestion bands (CB13 and CB45) for the associated road and area types.

8.8.2 Step 2: Conversion of Tank-to-Wheel emissions into Well-to-Tank

To calculate the WTT emissions as a function of the TTW emissions resulting directly from the NTM model, the following parameters have been included (see Table 61):

Table 61: MEC Up and Downstream processes – parameters used in the model

Parameter	Description
Factor TTW,WTT	The Factor TTW,WTT is the conversion factor from TTW to WTT to tank emissions by comparing the scale of emissions of TTW to WTT.
f_{TTW}	This emission factor expresses the emissions that result of the consumption of fuel (TTW), varying according to the fuel used.
f_{WTT}	This emission factor expresses the emissions that result of the production of fuel (WTT), varying according to the fuel used.
TTW	TTW emissions from NTM model 2019. The NTM produces forecasts of emissions of CO_2 (Carbon Dioxide), NOx (Nitrogen Oxides) and PM10 measured at the tailpipe and does not capture any up and downstream emissions produced. The estimates of emissions produced are dependent on the NTM input assumptions, which assume 100% diesel fleet till 2050.
WTT	The calculated WTT emissions as a result of applying the Factor TTW-TTW to the NTM CO_2 emissions.
Traded carbon prices	BEIS carbon prices, traded, central scenario,2018 £/tCO_{2e} (BEIS, 2019)

The calculation for deriving the WTT emissions is presented below:

$$Factor\ TTW, WTT = \frac{f_{WTT}}{f_{TTW}} \quad (1)$$

$$WTT = Factor\ TTW, WTT * TTW \quad (2)$$

In (1) the conversion factor between TTW and WTT is calculated. In (2) the WTT emissions are calculated by scaling the TTW emissions down by its emission factor and then scaling up by applying the WTT factor.

8.8.3 Step 3: Calculate MEC-UD values for each vehicle type, congestion band, road type and location type

Step 3 corresponds to the monetisation of the emissions by following the calculation (3), where the traded carbon prices[17] are multiplied by the WTT emissions:

$$MEC\ Up\ and\ downstream = WTT * Traded\ carbon\ prices \quad (3)$$

The final MEC-UD values can be computed for the base (current), medium and high scenarios and reported for five-yearly intervals. The scenarios are discussed further in the following sub-sections but largely they assume different TTW and WTT rates as the HGV vehicle parc and associated fuel types changes. Note the base scenario only accounts for alterations in vehicle efficiency, rather than changes in fuel types.

8.9 MEC Up and Downstream values

A base, medium and high scenario of the MEC was created to account for the forecast of potential uptake of low carbon fuels. The scenarios have been defined as follows:

- Base scenario – corresponds to the current DfT's forecast, where the HGV fleet is maintained 100% diesel with efficiency improvements only.
- Medium scenario - a balanced approach from *Transport Energy Infrastructure Roadmap to 2050* (Element Energy for LowCVP), *Technology Roadmap 2015 - Energy and Fuels*

[17] Activities classified as traded and non-traded sector based on definitions presented in 'TAG Unit A3 damage costs

(APCUK).

- High scenario - based on the Hydrogen further ambition scenario in *Zero Emission HGV Infrastructure Requirements* (Ricardo for the CCC).

Base scenario values are presented as the core MEC Up and Downstream values. Medium and high scenario values are presented in the following section.

Results for the base scenario for the different road and area types in 2020 prices are presented in Table 63 for artics and rigid and in Figure 21 (2025 impacts). The base scenario represents the reference case in line with Transport Analysis Guidance and that of the NTM, which assumes all HGVs will remain diesel fuelled until 2050, with just vehicle efficiency improvements (12% for rigids and 21% for artics between 2015 and 2050).

The value estimates from this scenario are highest for ‘other roads’ in London. Conversely, the least costly road type is rural ‘other roads’. MEC-UD values are on average marginally higher for artics than rigids which is a function of the variation in CO_2 emissions (artics tend to emit more CO_2 than rigids as they generally carry higher volumes of cargo). Motorways are not present for the ‘other urban’ area type and so no values are computed.

Table 62: MEC Up and Downstream processes – values in pence/vkm, Artics, Rigids 2020 prices, base scenario

	Artics							Rigids						
	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
Inner and Outer Conurbations														
Motorways	1.10	1.16	1.22	1.74	2.25	2.76	3.28	1.10	1.16	1.22	1.75	2.25	2.78	3.29
A Roads	1.20	1.25	1.30	1.86	2.40	2.98	3.56	1.15	1.19	1.23	1.75	2.25	2.79	3.32
Other Roads	1.26	1.25	1.23	1.71	2.13	2.62	3.09	1.24	1.24	1.21	1.68	2.09	2.56	3.03
London														
Motorways	1.09	1.14	1.19	1.71	2.20	2.72	3.22	1.10	1.16	1.21	1.74	2.24	2.76	3.27
A Roads	1.23	1.33	1.43	2.10	2.76	3.44	4.13	1.20	1.30	1.40	2.05	2.70	3.36	4.03
Other Roads	1.39	1.48	1.56	2.25	2.91	3.59	4.25	1.40	1.49	1.58	2.27	2.93	3.61	4.28
Other Urban														
A Roads	1.15	1.21	1.26	1.82	2.36	2.93	3.50	1.09	1.13	1.17	1.68	2.17	2.68	3.20
Other Roads	1.22	1.22	1.19	1.66	2.07	2.53	2.98	1.19	1.18	1.16	1.61	2.00	2.44	2.88
Rural														
Motorways	1.10	1.16	1.21	1.73	2.23	2.75	3.26	1.10	1.16	1.21	1.74	2.24	2.76	3.27
A Roads	1.03	1.08	1.13	1.61	2.07	2.55	3.01	1.01	1.05	1.10	1.56	2.01	2.47	2.93
Other Roads	0.93	0.96	0.97	1.38	1.76	2.16	2.55	0.93	0.95	0.97	1.37	1.74	2.14	2.53

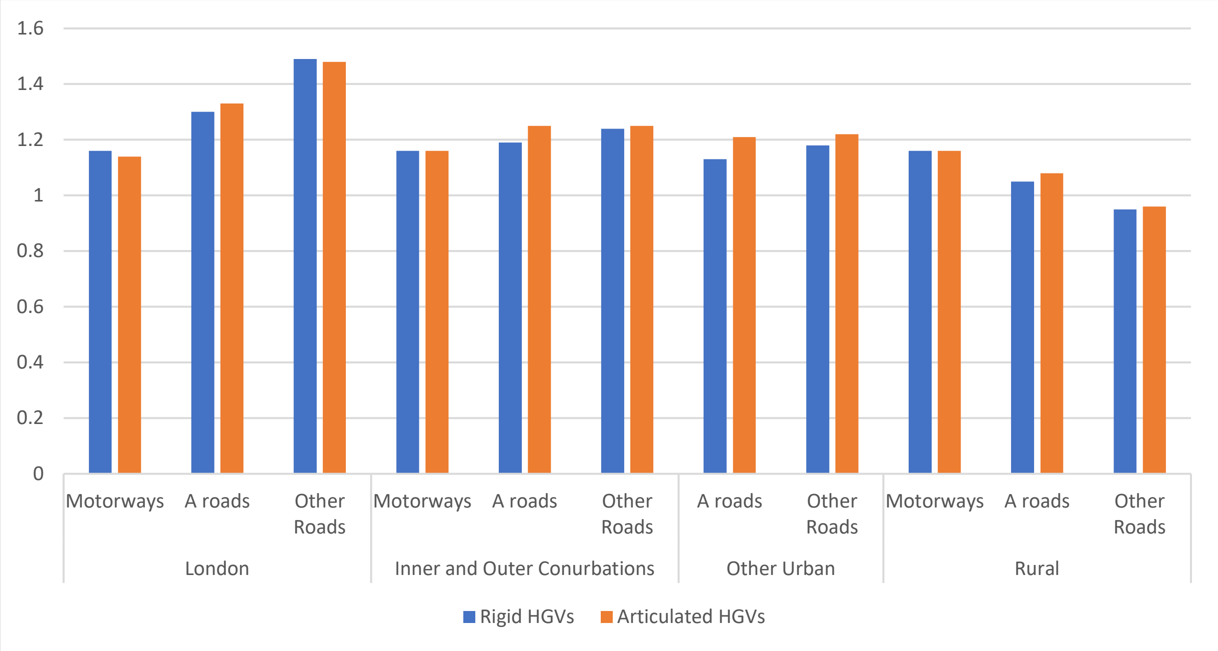


Figure 21: MEC-UD values, pence per vkm, 2025 impact, 2020 prices, by HGV type

8.10 Sensitivity scenarios

The values for the Medium scenario - a balanced approach from Transport Energy Infrastructure Roadmap to 2050 (Element Energy for LowCVP), Technology Roadmap 2015 - Energy and Fuels (APCUK) – and High scenario - based on the Hydrogen further ambition scenario in Zero Emission HGV Infrastructure Requirements (Ricardo for the CCC) - are presented in the sub-sections below

8.10.1 Medium scenario

Results for the medium scenario for the different road and area types in 2020 prices are presented in Table 65 for artics and rigids. The scenario is based on information documented by Ricardo (2018) for the Low Carbon Vehicle Partnership. The study presents a balanced approach to CO_2 emission reduction focused on natural technology evolution and use of already available low emissions fuels. The scenario aligns with the Government overarching target to achieve an 80% reduction of CO_2 emissions by 2050.

In line with the base scenario, the value estimates from this scenario are highest for ‘other roads’ in London. Conversely, the least costly road type is rural ‘other roads’. The MEC-UD values show a decrease relative to the base scenario, being the highest value approximately 40% lower than the corresponding figure in the base scenario. This reduction is a result of the change in the HGV fleet composition, with the uptake of low carbon vehicles, as well as the decarbonisation of the electric grid.

Table 63: MEC Up and Downstream processes – Medium Scenario pence/vkm,2020 prices (Rigid & Artic)

	Artics							Rigids						
	2020	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Inner and Outer Conurbations														
Motorways	1.09	1.17	1.21	1.58	1.82	1.92	1.92	1.10	1.18	1.22	1.58	1.83	1.93	1.92
A Roads	1.20	1.27	1.30	1.69	1.95	2.07	2.08	1.15	1.21	1.22	1.58	1.82	1.93	1.94
Other Roads	1.25	1.26	1.23	1.55	1.73	1.82	1.81	1.24	1.25	1.21	1.52	1.70	1.78	1.77
London														
Motorways	1.08	1.15	1.19	1.55	1.79	1.89	1.88	1.10	1.17	1.21	1.57	1.82	1.92	1.91
A Roads	1.22	1.35	1.43	1.90	2.24	2.39	2.41	1.20	1.32	1.40	1.86	2.19	2.34	2.36
Other Roads	1.38	1.49	1.56	2.03	2.36	2.49	2.49	1.40	1.51	1.58	2.05	2.38	2.51	2.50
Other Urban														
A Roads	1.14	1.22	1.26	1.65	1.92	2.03	2.05	1.08	1.15	1.17	1.52	1.76	1.86	1.87
Other roads	1.21	1.23	1.19	1.50	1.68	1.76	1.74	1.18	1.19	1.15	1.45	1.62	1.70	1.68
Rural														
Motorways	1.09	1.17	1.21	1.57	1.81	1.91	1.91	1.10	1.17	1.21	1.57	1.82	1.92	1.91
A Roads	1.02	1.09	1.12	1.46	1.68	1.77	1.76	1.00	1.07	1.09	1.41	1.63	1.72	1.71
Other Roads	0.93	0.97	0.97	1.25	1.42	1.50	1.49	0.92	0.96	0.97	1.24	1.41	1.49	1.48

8.10.2 High scenario

Results for the high scenario for the different road and area types in 2020 prices are presented in Table 67 for artics and rigids. The high scenario is based on the Hydrogen Further ambition scenario set out in the Net Zero report produced by the Committee on Climate Change (CCC). The scenario explores how a hydrogen-based fleet of HGVs would reduce emissions and results in almost zero CO_2 emissions by the year 2050.

In line with the base and medium scenario, the value estimates from this scenario are highest for ‘other roads’ in London. Conversely, the least costly road type is rural ‘other roads’. The MEC-UD values show a decrease relative to the medium scenario, being the lowest values roughly 40% lower and the highest value approximately 20% lower than the corresponding figures in the base scenario. This reduction is a result of the shift in the HGV fleet composition, with the highest uptake of hydrogen fuelled vehicles, as well as the decarbonisation of the electric grid.

Table 64: MEC Up and Downstream processes – High Scenario pence/vkm,2020 prices (Artics & Rigids)

	Artics							Rigids						
	2020	2025	2030	2035	2040	2045	2050	2020	2025	2030	2035	2040	2045	2050
Inner and Outer Conurbations														
Motorways	1.09	1.19	1.25	1.53	1.49	1.06	0.73	1.10	1.19	1.26	1.54	1.50	1.06	0.73
A Roads	1.20	1.29	1.34	1.64	1.60	1.14	0.79	1.15	1.22	1.26	1.54	1.49	1.07	0.74
Other Roads	1.25	1.28	1.26	1.50	1.42	1.00	0.69	1.24	1.27	1.24	1.47	1.39	0.98	0.68
London														
Motorways	1.08	1.17	1.23	1.50	1.46	1.04	0.72	1.10	1.19	1.25	1.53	1.49	1.06	0.73
A Roads	1.22	1.36	1.47	1.84	1.83	1.32	0.92	1.20	1.34	1.45	1.80	1.79	1.29	0.90
Other Roads	1.38	1.51	1.61	1.98	1.93	1.37	0.95	1.40	1.53	1.62	1.99	1.95	1.38	0.96
Other Urban														
A Roads	1.14	1.24	1.30	1.60	1.57	1.12	0.78	1.08	1.16	1.21	1.48	1.44	1.03	0.71
Other Roads	1.21	1.25	1.23	1.46	1.37	0.97	0.67	1.18	1.21	1.19	1.41	1.33	0.94	0.64
Rural														
Motorways	1.09	1.18	1.25	1.52	1.48	1.05	0.73	1.10	1.19	1.25	1.53	1.49	1.06	0.73
A Roads	1.02	1.11	1.16	1.41	1.37	0.97	0.67	1.00	1.08	1.13	1.37	1.33	0.95	0.65
Other Roads	0.93	0.98	1.00	1.21	1.17	0.83	0.57	0.92	0.98	1.00	1.20	1.16	0.82	0.56

8.11 Indexation and updates

The GDP deflator series from the May 2019 Data Book (‘annual parameters’ sheet) was used to inflate 2018 based year values to 2020 prices. The GDP per person series from the May 2019 Data Book (‘annual parameters’ sheet) was used as the indexation series to inflate base year values in 2020 prices to the relevant forecast year (2020 to 2050).

The MEC-UD model is largely based on current DEFRA and Department for BEIS work and publications. It is recommended for future updates to consider potential changes to shadow prices (i.e. price of CO2 and the willingness to pay to avoid the CO_2 emissions might change in the future given the growing awareness and concern regarding environmental issues).

The model will require regular updates to maintain integrity and robustness. Table 65 reports the main parameters that will need updating and the regularity of update intervals. The update intervals should be considered as guide only. In the absence of major updates, the model can be updated through indexation with changes to inflation and price indices as reported by the Office for National Statistics. Although, it is recommended that the overall methodology to estimate the MEC for Up and downstream processes is reviewed in 5 years, when further literature and studies are expected to have been published.

Table 65: MEC Up and Downstream – model parameters and updating intervals

Parameter	Recommended Update Frequency
Traded carbon prices	BEIS’s short-term traded carbon values are updated every year using the latest market data and assumptions.
Emissions estimates	Should be updated every 5 years based on the NTM for CO2. May also consider particulate emissions in future model iterations.
f_{TTW}	Should be reviewed yearly as new annual conversion factors are published every year
f_{WTT}	Same as above
MEC Up and downstream methodology	Should be reviewed internally by the DfT every 5 years with reference to the available literature on the appraisal of up and downstream emissions of freight vehicles. Considerations should be made on whether to include the embedded costs and a complete WTT emissions evaluation.

8.12 Limitations and recommendations

One of the main limitations of the approach adopted to calculate the MEC Up and Downstream was the exclusion of CO_2 embedded emissions from the analysis, due to limited publications available and very limited evidence on the net value of the externalities of HGV's raw materials (namely, metal and plastic) and other inputs such as the external cost of the disposal or re-using vehicle's components.

Additionally, Well-to-Tank and embedded emissions of PM_{10} and NO_x were not considered in this study for similar reasons as stated above, limited (or early research) on the appraisal of these pollutants' externalities.

For the purpose of converting Tank-to-wheel to Well-to-tank emissions, it was assumed that NTM tailpipe emissions largely corresponded to Tank-to-Wheel emissions. Further research is recommended to assess the impact of maintenance and servicing of vehicles on the emissions produced by freight vehicles which has been excluded from this study. These emissions are estimated to correspond to a minor proportion of the overall Tank-to-Wheel emissions.

9 Summary and recommendations

This study presents the methodology for updating the values for the following MEC categories:

- Infrastructure,
- Accidents,
- Noise
- Environment, including soil and water pollution, nature and landscape
- Behaviour, including driver frustration and stress and fear of accidents
- Up and downstream processes

The methodology approach adopted for each MEC differs based on availability of the data and research studies on the impact measurement and valuation. The summary of the methodologies used for each MEC is presented in Table 66.

Table 66: Summary of MEC methodologies

MEC category	Adopted methodology
MEC Infrastructure	Extended cost allocation method. MEC values calculated through aggregation of LA level data by road type, artic/ rigid and regional split, using updated variable cost weightings or standardized axle weight only.
MEC Accidents	Marginal cost approach (current TAG methodology). MEC values calculated by taking the risk elasticity multiplied by accident costs and the accident risk rate.
MEC Noise	Bottom up approach for calculating noise emissions and reception. MEC values calculated by estimating the noise level in over 400 scenarios corresponding to the permutation of six variables (year, road type, area type, congestion, vehicle type and time of the day).
MEC Behaviour	Travel time uplift (bottom up approach). MEC values calculated by estimating a travel time uplift for drivers encountering one additional HGV entering the road network. This multiplier is applied to a weighted average of the value of time of the road users (as defined in transport appraisal).
MEC Environment	Dose response function and a penalty factor. MEC values calculated by measuring the restoration cost as a function of HGV vehicular emissions. Additionally, a penalty mechanism accounting for HGV traffic through National Parks and AONB is applied.
MEC Up and Downstream processes	Bespoke model to estimate energy up and downstream emissions of energy and fuel production and distribution. Based on the conversion of Tailpipe emissions (NTM output emissions aggregated by area and road type) to Well-to-Tank CO2 emissions, using DEFRA's conversion factors.

Based on these methodologies, the MEC values were calculated. The summary of MEC values for rigid and articulated vehicles (2025 impact in 2020 prices) is presented in Table 67 and Table 68.

Table 67: MEC values for Artics by road type and MEC component (pence per vehicle kilometre, 2025 values in 2020 prices)

	MEC-B	MEC-I	MEC-A	MEC-UD	MEC-N	MEC-E
Inner and Outer Conurbations						
Motorways	0.13	4.62	0.51	1.16	2.07	0.04
A Roads	1.00	21.67	2.24	1.25	15.10	0.08
Other Roads	0.31	90.14	4.26	1.25	70.98	0.08
London						
Motorways	0.09	4.17	0.58	1.14	3.05	0.05
A Roads	2.54	40.52	4.67	1.33	20.95	0.14
Other Roads	0.51	201.60	10.37	1.48	147.61	0.11
Other Urban						
A Roads	0.91	15.55	3.33	1.21	19.59	0.06
Other Roads	0.22	56.84	5.31	1.22	86.61	0.07
Rural						
Motorways	0.07	4.59	0.48	1.16	0.44	0.06
A Roads	0.08	14.62	2.20	1.08	2.86	0.08
Other Roads	0.01	82.86	2.85	0.96	12.44	0.19

Table 68 - MEC values for Rigids by road type and MEC component (pence per vehicle kilometre, 2025 values in 2020 prices)

	MEC-B	MEC-I	MEC-A	MEC-UD	MEC-N	MEC-E
Inner and Outer Conurbations						
Motorways	0.13	1.36	0.51	1.16	0.96	0.04
A Roads	0.76	6.34	2.24	1.19	5.32	0.08
Other Roads	0.23	26.23	4.26	1.24	25.65	0.08
London						
Motorways	0.08	1.23	0.58	1.16	1.47	0.05
A Roads	2.17	11.86	4.67	1.30	8.13	0.13
Other Roads	0.33	58.65	10.37	1.49	55.59	0.11
Other Urban						
A Roads	0.59	4.55	3.33	1.13	7.18	0.06
Other Roads	0.16	16.62	5.31	1.18	31.13	0.07
Rural						
Motorways	0.07	1.35	0.48	1.16	0.20	0.06
A Roads	0.05	4.28	2.20	1.05	1.15	0.09
Other Roads	0.00	24.27	2.85	0.95	4.69	0.19

The analysis represented in this report revealed that in some areas the current state of the art in research on marginal external costs of heavy vehicles is limited and further research could be conducted in the future to further improve calculation methodologies. Several areas were identified where further research could bring additional value.

- **MEC Accidents**. Future research opportunities for more robust results include re-estimating the risk elasticities, the level of internalisation and disaggregate accident data by articulated and rigid vehicles and congestion bands.
- **MEC Up and Downstream processes**. Further research is recommended to assess the net value of the externalities related to embedded emissions such as emissions related to the production of HGV's raw materials (e.g. metal and plastic) and disposal or re-using of vehicle's components. Also, there is a need to evaluate the impact of maintenance and servicing of

vehicles on the emissions produced by freight vehicles which has been excluded from this study.

- **MEC Noise**. It may be desirable to adapt future rounds of strategic noise mapping, to allow for more detailed MEC-N studies to be conducted at a national level. However, this would require the underlying calculation methods, as well as the physical road network and classification, to be aligned with the preferred MEC-N methodology.
- **MEC Behaviour.** Further research is recommended on community severance aspect of HGV traffic impacts, as well as differences in stress and frustration generated by different HGV types (rigid and articulated vehicles), and stress impacts related to different driving patterns in relation to HGVs (e.g. there's no available research on driving along an HGV).
- **MEC Environment.** Further research is recommended in the area of ecosystem services valuation and natural capital (e.g. the valuation of landscape impacts associated with transport interventions using an ecosystem services approach). Currently available research is not suitable for calculating the MEC values, but as the science evolves there may be scope to reconsider such approaches.

Abbreviations

Acronym	Description
AADT	Annual Average Daily Traffic
AASHO	American Association of State Highway and Transportation Officials
AAWT (traffic flow rate)	Annual Average Weekly Traffic
ACM	Average Cost Methodology
Advanced DDD	Advanced Driver Drowsiness Detection Systems
AEB	Automatic Emergency Breaking
AONB	Areas of Outstanding Natural Beauty
APCUK	Advanced Propulsion Centre UK
BEIS	Department for Business, Energy & Industrial Strategy
CAV	Connected and autonomous vehicle
CBA	Cost benefit analysis
CCC	Committee on Climate Change
CH4	Methane
CLC	CORINE Land Cover
CO2	Carbon dioxide
CO2e	Carbon dioxide equivalent
CORINE	coordination of information on the environment
CRTN	Calculation of Road Traffic Noise
CSV	Comma Separated Value (.CSV file type)
ct/vkm	Cent per vehicle kilometre
dB	Decibel
DEFRA	Department for Environment, Food & Rural Affairs
DfT	Department for Transport
DG	Directorate General
DI	Distributional Impact
DMRB	Design Manual for Roads and Bridges
Eftec	Economics for the Environment Consultancy
ESA	Environmentally sensitive area
ESAL	Equivalent standard axel loading
EU	European Union
FY	Financial year
GB	Great Britain
GDP	Gross Domestic Products
GHG	Greenhouse gas
GIS	Graphic information system
GVW	Gross vehicle weight
gwt-km	Average gross vehicle weight-km
HGV	Heavy Goods Vehicle
HV	Heavy vehicle
HZ	Hertz
ICE	Internal combustion engine
IMPACT	Internalisation Measures and Policies for All external Cost of Transport
kHZ	Kilohertz
km	Kilometre
LA	Local authority
LAeq	A-weighted equivalent continuous sound pressure level

LAeq	A-weighted sound power level for a single vehicle
LDV	Light duty vehicle
LDW	Lane Departure Warning System
LowCVP	The Low Carbon Vehicle Partnership
LSOA	Lower Layer Super Output Area
m^2	Square Metre
MC	Marginal Cost
MCM	Marginal Cost Methodology
MDU	Maintenance delivery unit
MEC	Marginal External Cost
MEC-A	Marginal External Cost-Accidents
MEC-B	Marginal External Cost-Behaviour
MEC-E	Marginal External Cost-Environment
MEC-N	Marginal External Cost-Noise
MEC-O	Marginal External Cost-Other
MEC-UD	Marginal External Cost-Up and downstream
MEG	Maintenance Expenditure Group
MHCLG	Ministry of Housing Communities and Local Government
MMU	Minimum mapping unit
MSB	Modal Shift Benefit
MSRS	Mode Shift Revenue Support
N	Nitrogen
NOx	Nitrogen oxides
NPV	Net present value
NTM	National Transport Model
ONS	Office for National Statistics
OS	Ordinary Survey
PAH	Polycyclic aromatic hydrocarbons
PCU	Passenger Car Unit
PDF	Potentially disappeared function
PFI	Private Finance Initiative
PIM	Perpetual Inventory Method
pkm	Passenger-kilometre
PM10	Particle Matter (<= 10 µm in diameter)
PM2.5	Particle Matter (<= 2.5 µm in diameter)
PSV	Public service vehicle
RO	Revenue Outturn
RO2	General Fund Revenue Account Outturn Highways and Transport Services
Scot-TAG	Transport-Scotland Transport Appraisal Guidance
SLM	Sensitive Lorry Miles
SO2	Sulphur dioxide
SRN	Strategic Road Network
SSP	Shared Socioeconomic Pathway
TAG	Transport Analysis Guidance
tCO2e	Tonnes of carbon dioxide equivalent
TfGM	Transport for Greater Manchester
TfL	Transport for London
tkm	Tonne-kilometre
TTW	Tank-to-Wheel
UK GOV	UK Government
vkm	Vehicle kilometre

VOC	Volatile organic compounds
VOT	Value of travel time
VSL	Value for Statistical Life
WTA	Willing to Accept
WTP	Willing to Pay
WTT	Well-to-Tank
WTW	Well-to-Wheel

References

Adler, D. M. (2004). Fear Assessment: Cost benefit analysis and the pricing of fear and anxiety

AECOM and Transport Scotland (2016). Experimental study of the factors that influence driver frustration – a stated preference approach – an update

Anciaes, P. R. et al (2016). Community severance: where is it found and at what cost? Transport Reviews, 36(3), 293-317

Atkins and Jacobs (2019). Task 1-705 Road Layout and Information

Atkins and Jacobs (2019). Task 1-798 TSTR0009 Updating Marginal External Costs of road freight. Methodology review report

Bannon, E. (2017) Electric vehicle life cycle analysis and raw material availability. Transport & Environment

BEIS (2019) Updated short-term traded carbon values used for UK public policy appraisal 2018 (updated April 2019)

Brown, J., Rhodes, C. (2018). The motor industry: statistics and policy. House of Commons Library

CE-Delft (2015). External and infrastructure costs of HGVs in the Eu28 in 2013: Update of the total cost figures from 'Are trucks taking their toll?'

CE-Delft (2016). Infrastructure and external cost coverage of road freight transport on EU28 motorways

CE-Delft; INFRAS and Fraunhofer (2011). External Cost of Transport in Europe. Update study for 2008

CEH (2017). Critical load exceedance maps. Accessed online 02/10/2019 (http://www.cldm.ceh.ac.uk/exceedances/maps)

Cluzel, C., Hope-Morley, A. (2015). Transport energy infrastructure roadmap to 2050. Element Energy for LowCVP

Danish Ministry of Transport (2004). External Costs of Transport: 1st Report – Review of European Studies

Defra (2007). An introductory guide to valuing ecosystem services

Defra (2019a). Clean air strategy 2019

Defra (2019b). Emissions of air pollutants in the UK, 1970 to 2017

Defra (2019c). Impact pathways approach. Guidance for air quality appraisal

Delft (2004). Marginal costs of infrastructure use – towards a simplified approach: Final report

Delft (2008). Handbook on estimations of external costs in the transport sector: Produced within the study Internalisation Measures and Policies for all external Cost of Transport (IMPACT) Version1.1

Department for Transport, Road Condition Statistics - Table RDC0120 - Principal and non-principal classified roads where maintenance should be considered (categorised as red), by local authority in England, 2007/08 to 2018/19

Department of Transport and the Welsh Office (1988). Calculation of Road Traffic Noise. London: HMSO

DfT (2009). Mode Shift Benefit values: Technical report

DfT (2013). TAG Unit A3

DfT (2014). Mode Shift Benefit Values: Refresh Technical report

DfT (2017). TAG Unit A4-1 Social Impact Appraisal

DfT (2018). TAG Unit A5.4

DfT(2019). TAG Data Book

DIW Econ, CAU, Ricardo-AEA, (2014) Update of the Handbook on External Costs of Transport. European Commission – DG Mobility and Transport, January 2014.

Eftec (2019). Valuation of landscape impacts of transport interventions & mitigations using an ecosystem services approach. Landscape in WebTAG methodology report

Environment Agency (2015). Cost summary of habitat creation – summary of evidence

Eriksen, K.S. (2000). Calculating External Costs of Transportation in Norway Principles and Results

European Commission (2003). Sensitive areas and transport – progress towards an operational definition at the European level

European Environment Agency (2017). Copernicus land service – Pan-European Component: Corine Land Cover

Fridstrøm, L. (2011), "A Framework for Assessing the Marginal External Accident Cost of Road Use and its Implications for Insurance Ratemaking", International Transport Forum Discussion Papers, No. 2011/22, OECD Publishing, Paris, https://doi.org/10.1787/5kg29s6x0vd8-en
Guidelines for the Standardisation of Surfaces of Road Traffic Areas (Germany), 2012 Edition (RStO 12)

Haraldsson, M., Jonsson, L. and Ögren, M. (2012). Marginalkostnadsskattningar för buss och lätt lastbil–buller, trafiksäkerhet och vägslitage. VTI:s egen serie, VTI, Linköping, SE

Highways Agency (1993). Design Manual for Roads and Bridges, Vol.11, Section 3, Part 9

Highways Agency (1993). Design Manual for Roads and Bridges, Vol.5, Section 1, Part 3

Highways Agency (2011). Design Manual for Roads and Bridges, Vol.11, Section 3, Part 9

Highways Agency, Transport Scotland, Welsh Assembly Government and The Department for Regional Development Northern Ireland (2011). Design Manual for Roads and Bridges Volume 11, Section 3, Part 7, HD213/11: Noise and Vibration

Highways England (2017). Customer experience of changes in speed limits within roadworks, Unpublished Report

Highways England (2018a). Customer Insight Programme - Smart vs Standard Motorways Research, Unpublished Report

Highways England (2018b). Behavioural insight programme - negative driving behaviours research, Unpublished Report

Hine, J. (1996). Pedestrian travel experiences—Assessing the impact of traffic on behaviour and perceptions of safety using an in-depth interview technique. Journal of Transport Geography, 4, 179–199

International Networks Analysis and Support (INAS) and Freight and Logistics Division (FLD), Department for Transport (2009). Mode Shift Benefit Values: Technical report

Janson, J.O. Lindberg, G. (1998).”Accident externality charges - with emphasis on urban transport problems” in 1st Asia Pacific Conference on Transportation and Environment 13 - 15 May 1998, Proceedings Volume 1, p 401 - 410.

Jonasson, H. (2004). Harmonoise Work Package 1.1: Source modelling of road vehicles. Technical Report HAR11TR-041210-SP10

Jonasson, H.G. (2006). Acoustic Source Modelling of Nordic Road Vehicles. SP Rapport 2006:12

Jones, L. Mills, G. and Milne, A. (2014). Assessment of impacts of air pollution on ecosystem services

– gap filling and research recommendations. Defra project AQ0827

Lindberg, G (2002) Deliverable 9, Marginal accident costs – case studies. UNITE (UNIfication of accounts and marginal costs for Transport Efficiency) Deliverable 9. Funded by 5th Framework RTD Programme. ITS, University ofLeeds, Leeds, July 2002
Lindberg, G. (2001). External Accident Cost of Heavy Goods Vehicles. Swedish National Road and Transport Research Institute

Link (2006). "An econometric analysis of motorway renewal costs in Germany," Transportation Research Part A: Policy and Practice, Elsevier, vol. 40(1), pages 19-34, January.

Link, H. et al. (2007). Monitoring Pricing Policy Using Transport Accounts, Deliverable D5 of GRACE Project
Maibach et al (2008). Handbook on estimation of external costs in the transport sector

Maibach et al (2008). Handbook on estimation of external costs in the transport sector

Manaugh, K., El-Geneidy, A. (2011). Validating walkability indices: How do different households respond to the walkability of their neighborhood? Transportation research part D: transport and environment, 16(4), 309-315

Mehler, B., Reimer, B., Wang, Y. (2011). A comparison of heart rate and heart rate variability indices in distinguishing single task driving and driving under secondary cognitive workload. Proceedings of the 6th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design

Messagie, M. (2017). Life Cycle Analysis of the Climate Impact of Electric Vehicles. Brussels: Vrije Universiteit Brussel, Research Group MOBI

MTRU (2014). Heavy Goods Vehicles- do they pay for the damage they cause? Report prepared for Campaign for Better Transport

Murphy, P., Casey, J., McDonald, J. (2014). Experimental study of the factors that influence driver frustration on the A9. Proceedings of the European Transport Conference 2014

Murphy, P., Casey, J., McDonald, J. (2016). Experimental study of the factors that influence driver frustration - a Stated Preference approach - an update. Proceedings of the European Transport Conference 2016

Nash, C. & Sansom, T. (1999). Calculating transport congestion and scarcity cost. Final Report of the Expert Advisors on the High Level Group on Infrastructure Charging (Working Group 2)

Natural England (2016). The ecological effects of air pollution from road transport: an updated review

New Zealand Transport Authority (2017). Economic Evaluation Manual Economic Evaluation Manual, NZTA

Nikolas, H. et al (2019). Zero Emission HGV Infrastructure Requirements. Ricardo for the CCC

Odeh, N. et al (2013) Current and Future Lifecycle Emissions of Key ‘Low Carbon’ Technologies and Alternatives. Ricardo-AEA

Ordinance Survey (2019). OS Highways Road Link (ABM) data

Ott, Baur and Kaufmann (2006). New Energy Externalities Developments for Sustainability (NEEDS). Assessment of Biodiversity Losses.

Patterson, J. (2018) Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies. LowCVP

Peng, J. et al, N., A six-category heavy vehicle noise emission model in free-flowing condition, Applied Acoustics 143 (2019) 211–221

Peng, J. et al, N., A six-category heavy vehicle noise emission model in free-flowing condition, Applied Acoustics 143 (2019) 211–221

Pursula, M., Enberg, A. (2000). Characteristics and Level-of-Service Estimation of Traffic Flow on

Two-Lane Rural Roads in Finland

Ricardo (2018). Understanding the life cycle GHG emissions for different vehicle types and powertrain technologies. Final report for LowCVP.

Ricardo (2019). Air quality damage cost update 2019. Report for Defra AQ0650

Ricardo-AEA (for EC) (2014). Update of the Handbook on External Costs of Transport, London: Ricardo-AEA

Rowe E. et al (2019). Trends Report 2019: Trends in critical load and critical level exceedances in the UK. Report to Defra under Contract AQ0843. CEH Project NEC05708

Sakamoto, S (2015). Road traffic noise prediction model “ASJ RTN Model 2013”: Report of the Research Committee on Road Traffic Noise. The Acoustical Society of Japan, 36 (2) p49-108

Sansom et al. (2001). Surface Transport Costs and Charges: Final Report. For the Department of the Environment, Transport and the Regions. Institute for Transport Studies, University of Leeds, Leeds, July 2001

Schroten, A., Hoen, M. (2016). Infrastructure and external cost coverage of road freight on EU28 motorways. CE Delft

Schuller, A., Stuart, C. (2018) From cradle to grave: e-mobility and the energy transition. European Climate Foundation.

Sommer, H., Marti, M. and Suter, S. (Ecoplan), Deliverable 9: Accident Cost Case Studies, Case Study 8a: Marginal external accident costs in Switzerland (UNIfication of accounts and marginal costs for Transport Efficiency) Deliverable 9. Funded by 5th Framework RTD Programme. ITS, University of Leeds, Leeds, 2002

Tagliaferr et al. (2016). Life cycle assessment of future electric and hybrid vehicles: A cradle-to-grave systems engineering approach. Chemical Engineering Research and Design

THE ROADMAP REPORT TOWARDS 2040: A GUIDE TO AUTOMOTIVE PROPULSION TECHNOLOGIES. APCUK.

Tomlinson, P., James, E. (2005). Understanding community severance part 2: Monetisation of severance impacts (Report for the UK Department of Transport)

Transport Scotland (2018). Scottish Transport Appraisal Guidance Technical Database. The Scottish Government, Edinburgh

Wang, C., Quddus, M.A. and Ison, S.G, (2009). Impact of traffic congestion on road accidents: A spatial analysis of the M25 motorway in England. Accident Analysis & Prevention, vol. 41, no. 4, pp. 798–808

Weinreich, et al. (1998). Discussion paper No.98-06: External Costs of Road, Rail and Air transport – a bottom-up approach

Welsh Government (2008). Welsh Transport Planning and Appraisal Guidance (WelTAG). The Welsh Assembly Government, Cardiff

Wixey, S. et al (2005). Measuring accessibility as experienced by different socially disadvantaged groups. London, Transit Studies Group, University of Westminster

Yarmukhamedov, S., Swardh, J. (2016) Marginal cost of road maintenance and operation: Swedish estimates based on data from 2004 to 2014

Zeidner, M., Shechter, M. (1994). Reduction of test anxiety: a first attempt at economic Evaluation, 7 Anxiety, Stress & Copiting 1

Appendices

Appendix 1 Behaviour - Model assumptions - tables

Table A-1: Capacity calculation parameters

Lane capacity parameters	Parameter A	Parameter B
Motorways	2300	25
A Roads	2100	20
Other Roads	1380	15

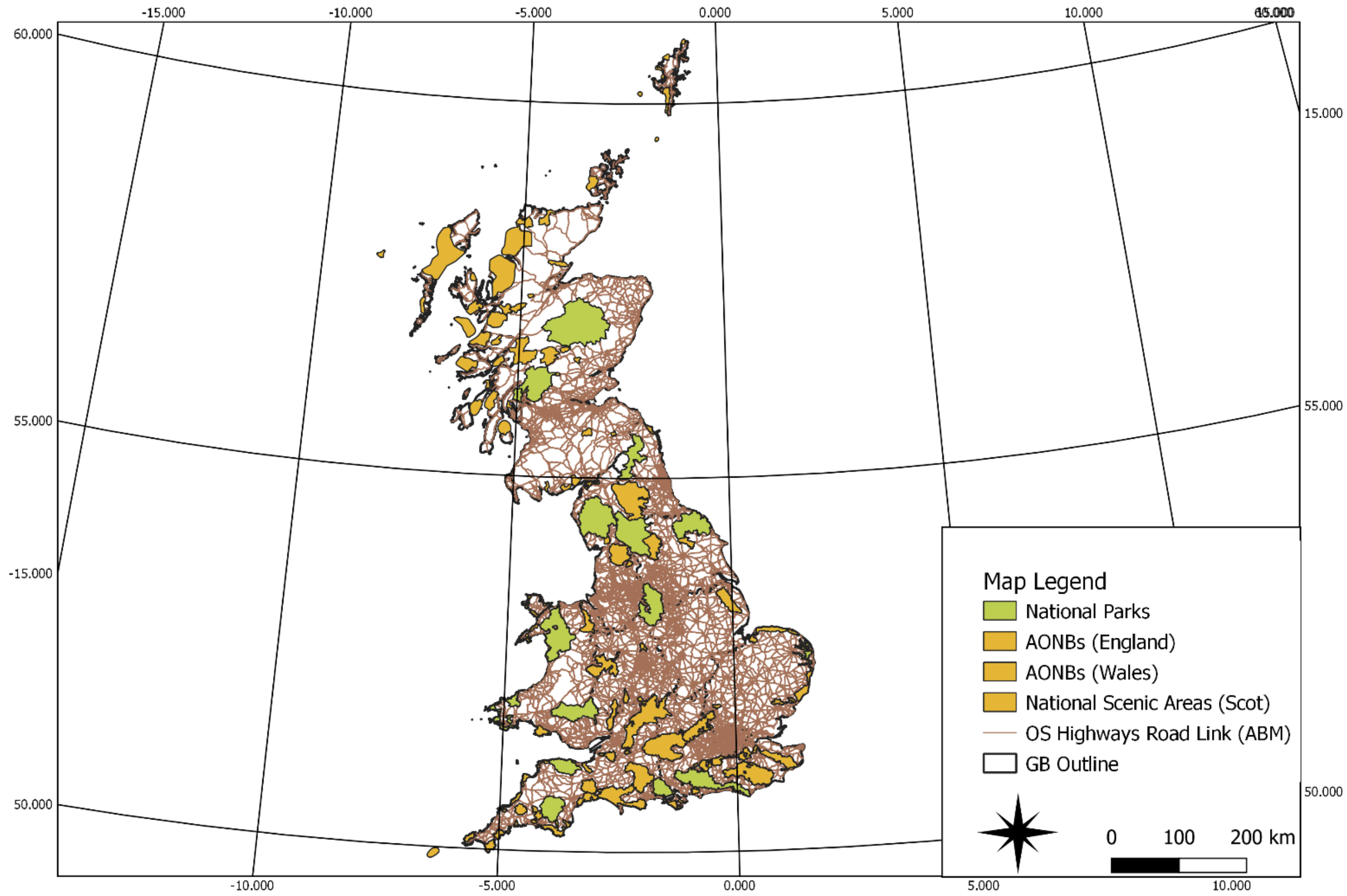
Table A-2: Capacity utilisation assumptions

Average Capacity Utilisation			
Motorways	Free flow (congestion bands 1-3)	London	25%
		Inner and Outer Conurbations	20%
		Other Urban	15%
		Rural	10%
	Congested (congestion bands 4-5) – flowing at 75% or more capacity	London	85%
		Inner and Outer Conurbations	80%
		Other Urban	75%
		Rural	75%
A Roads	Free flow (congestion bands 1-3)	London	20%
		Inner and Outer Conurbations	15%
		Other Urban	10%
		Rural	5%
	Congested (congestion bands 4-5) – flowing at 75% or more capacity	London	80%
		Inner and Outer Conurbations	75%
		Other Urban	75%
		Rural	75%
Other roads	Free flow (congestion bands 1-3)	London	3%
		Inner and Outer Conurbations	3%
		Other Urban	2%
		Rural	1%
	Congested (congestion bands 4-5) – flowing at 75% or more capacity	London	75%
		Inner and Outer Conurbations	75%
		Other Urban	75%
		Rural	75%

Table A-3: Percentage of distance travelled by vehicles for different trip purposes (all week average)

		Percentage of Distance Travelled by Vehicles (all week average)		
Mode		Work	Commuting	Other
Car		12.1%	25.5%	62.5%

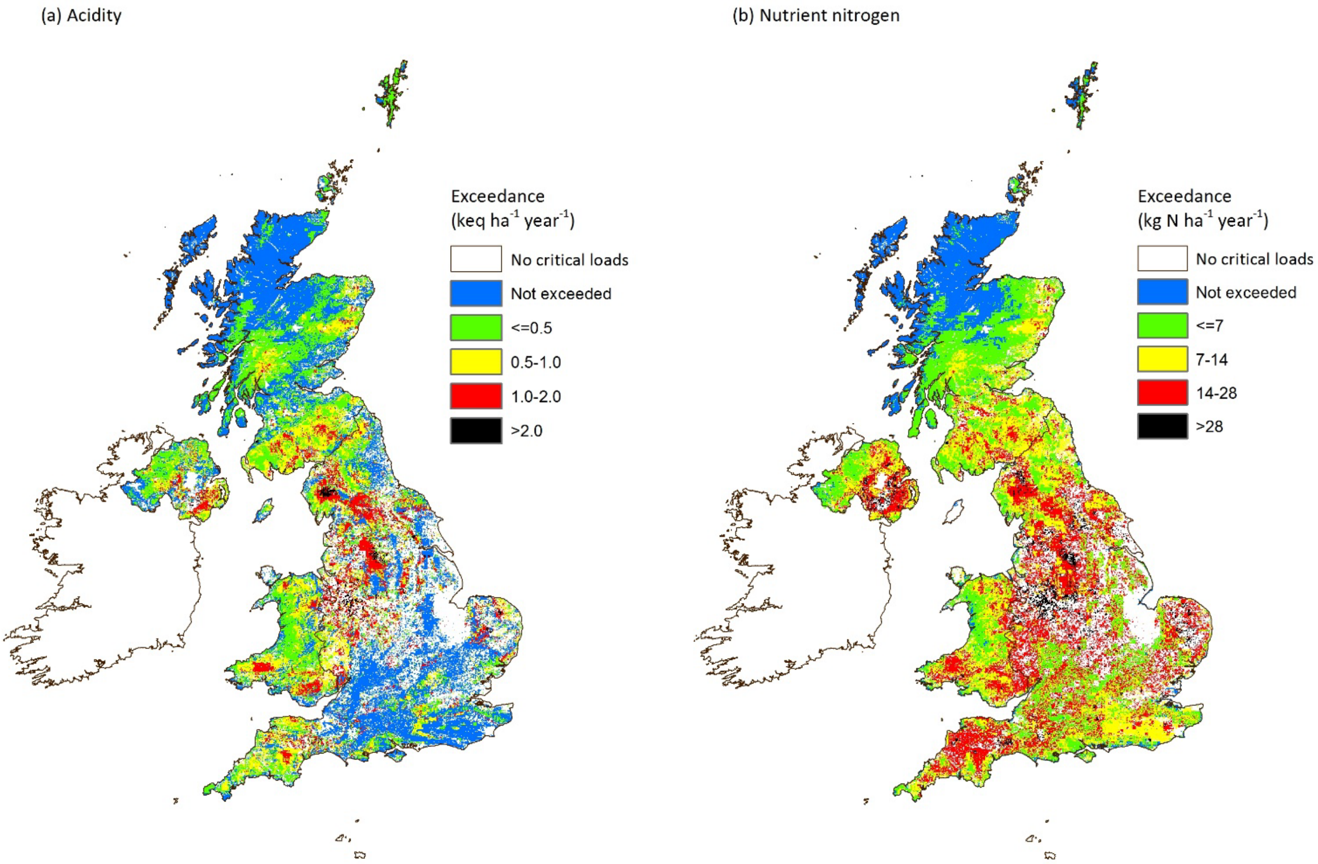
Appendix 2 Environment - Map of sensitive environmental areas



Appendix 3 Environment - Appraisal summary table for statutory designations in GB

Designation	Description	Designation type	Inclusion	Justification
Areas of Outstanding Natural Beauty (AONBs)	In England, Wales and Northern Ireland, the primary purpose of the AONB designation is to conserve natural beauty – which by statute includes wildlife, physiographic features and cultural heritage as well as the more conventional concepts of landscape and scenery. Account is taken of the need to safeguard agriculture, forestry and other rural industries and the economic and social needs of local communities. AONBs have equivalent status to National Parks as far as conservation is concerned. AONBs are designated under the National Parks and Access to the Countryside Act 1949, amended in the Environment Act 1995. The Countryside and Rights of Way Act 2000 clarifies the procedure and purpose of designating AONBs. In Scotland, National Scenic Areas are broadly equivalent to AONBs.	**National designation**. AONBs are designated under the National Parks and Access to the Countryside Act 1949, amended in the Environment Act 1995.	Yes	AONB's afford the same protection as national parks, though tend to be smaller than national parks. They are multi-functionality landscapes where protection focuses on landscape scale conservation for areas of natural beauty.
National Scenic Areas (in Scotland)	National Scenic Areas (NSAs) are designated by Scottish Ministers as the best of Scotland's landscapes, deserving special protection in the nation's interest. Scottish Ministers in 2010 confirmed 40 NSA under the provisions of The Town and Country Planning (Scotland) Act 1997 (as amended in 2006)(s.263) NSAs are broadly equivalent to AONBs in England and Wales.	**National designation**. National Scenic Areas under the provisions of The Town and Country Planning (Scotland) Act 1997 (as amended in 2006).	Yes	National Scenic Areas afford the same protection as national parks, though tend to be smaller than national parks. They are multi-functionality landscapes where protection focuses on landscape scale conservation for areas of natural beauty.
National Parks	In England and Wales, the purpose of National Parks is to conserve and enhance landscapes within the countryside whilst promoting public enjoyment of them and having regard for the social and economic well being of those living within them. The National Parks and Access to the Countryside Act 1949 established the National Park designation in England and Wales. In addition, the Environment Act 1995 requires relevant authorities to have regard for nature conservation. Special Acts of Parliament may be used to establish statutory authorities for their management (e.g. the Broads Authority was set up through the Norfolk and Suffolk Broads Act 1988). The National Parks (Scotland) Act 2000 enabled the establishment of National Parks in Scotland. In addition to the two purposes described above, National Parks in Scotland are designated to promote the sustainable use of the natural resources of the area and the sustainable social and economic development of its communities. These purposes have equal weight and are to be pursued collectively unless conservation interests are threatened.	**National designation**. The National Parks and Access to the Countryside Act 1949 established the National Park designation in England and Wales. The National Parks (Scotland) Act 2000 enabled the establishment of National Parks in Scotland.	Yes	National parks are large, multi-functional landscapes where protection focuses on landscape scale conservation for areas of national significance both environmentally, socially and historically.
Ramsar Convention	Ramsar sites are designated under the Convention on Wetlands of International Importance, agreed in Ramsar, Iran, in 1971. Originally intended to protect sites of importance especially as waterfowl habitat, the Convention has broadened its scope over the years to cover all aspects of wetland conservation and wise use, recognizing wetlands as ecosystems that are extremely important for biodiversity conservation in general and for the well-being of human communities. The Convention adopts a broad definition of wetland, namely "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres". Wetlands "may incorporate riparian and coastal zones adjacent to the wetlands, and islands or bodies of marine water deeper than six metres at low tide lying within the wetlands". Ramsar sites will be one of six designations contributing to our ecologically coherent network of marine protected areas.	**International convention**. Receive statutory protection under the Wildlife & Countryside Act 1981 (as amended), the Nature Conservation (Scotland) Act 2004 (as amended) and the Nature Conservation and Amenity Lands (Northern Ireland) Order 1985 (as amended).	No	Ramsar convention sites focus almost exclusively on ecology, with the primary aim to conserve important wetland habitats. The scope of protection is therefore too limited for the MEC-E penalty factor to consider.
Special Areas of Conservation (SAC)	SACs are designated under the EC Habitats Directive. The Directive applies to the UK and the overseas territory of Gibraltar. SACs are areas which have been identified as best representing the range and variety within the European Union of habitats and (non-bird) species listed on Annexes I and II to the Directive. SACs in terrestrial areas and territorial marine waters out to 12 nautical miles are designated under the Conservation (Natural Habitats, &c.) Regulations 1994 (as amended). Beyond 12 nautical miles they are designated under the Offshore Marine Conservation (Natural Habitats &c.) Regulations 2007 (as amended). SACs will be one of six designations contributing to our ecologically coherent network of marine protected areas. In the UK, designation of SACs is devolved to the relevant administration within each country. SACs, together with SPAs, form the Natura 2000 network.	Designated under the **EC Habitats Directive**.	No	SAC's focus on conserving important habitats for nature and are based on terrestrial and marine sites. Their focus is constrained to ecology and is often not at the landscape scale which makes them unsitable for MEC-E to consider.
Special Protection Areas (SPA)	SPAs are classified by the UK Government under the EC Birds Directive. The Directive applies to the UK and the overseas territory of Gibraltar. SPAs are areas of the most important habitat for rare (listed on Annex I to the Directive) and migratory birds within the European Union. SPAs in terrestrial areas and territorial marine waters out to 12 nautical miles are classified under the Wildlife and Countryside Act 1981 and beyond 12 nautical miles are designated under the Offshore Marine Conservation (Natural Habitats &c.) Regulations 2007 (as amended). SPAs, together with SACs, form the Natura 2000 network.	Designated under the **EC Birds Directive**.	No	SPAs are similar to SACs but with an explocity focus on important habitats/sites for birds. The sites are both terrestrial and marine. Again, the terrestrial sites are often conserved at the site-scale making them unsitable for MEC-E to consider.

Appendix 4 Environment - Average accumulated exceedance (AAE) of critical loads (2013-2015)



Source: CEH (2017)

Appendix 5 Sample Noise Calculation

Consider the following scenario to calculate MEC-N at night for one additional no. of HGV2 (articulated) in pence per km of road per day.

Use the following traffic flows for the base scenario.

Table A-4: Input parameters for MEC-N calculations

Year	Road type	Area Type	Congestion type	8-hr night-time traffic	Speed kph	LV	HGV1 Rigid	HGV2 Artic.
2015	A Roads	Inner and Outer Conurbations	CB13 (non-congested)	1745	53.9	1665	47	32

Calculate sound power level for each vehicle category: Light (LV), HGV1 and HGV2. Please note the logarithmic addition of rolling noise and propulsion noise terms to obtain the total sound power level for each vehicle category.

Table A-5: Sound Power Level Contributions

Sound Power Level	LV	HGV1	HGV2
Rolling Noise	95.0	99.0	102.0
Propulsion Noise	102.1	110.4	114.4
Total	102.9	110.7	114.6

Convert sound power levels to noise level in dB L_{Aeq} at a reference distance of 10m.

Table A-6: Sound Power conversion to noise

	LV	HGV1	HGV2	Total
dB L_{Aeq} at 10m	63.9	56.3	58.6	65.6
+3dB increase	63.9	56.3	L(HGV2)	68.6

In order for the overall noise levels to increase to 68.6 dB L_{Aeq} at 10m, and assuming contributions from LV and HGV1 remain the same, the new noise contribution from HGV2 is calculated as follows. Please note the logarithmic nature of the subtraction of levels;

$$L\ (HGV2) = 10\text{Log}\ [10^{(68.6/10)} - 10^{(56.3/10)} - 10^{(63.9/10)}] = 66.4\ \text{dB(A)} \qquad (7)$$

It is noted that to obtain a 3dB(A) increase in overall noise, above represents a 7.8 dB(A) increase in contribution from HGV2, all else remaining the same.

Adjust the total noise level for distance and assign population. Use WebTAG to obtain 1-year NPV at night. In this example this was calculated to be -£35,321.93 NPV per km of road (annual). Normalise to 1 day: -£96.77 per km of road per day.

Use the following relationship to determine HGVs required for a 3dB change:

$$L_{Aeq,T,D} = L_{wA} + 10\log_{10} D - 10\log_{10} V + 10\log_{10} N_t + 10\log_{10}\left(\frac{3.6}{2T}\right) \qquad (6)$$

Assuming the following parameters remain constant between the scenarios

- L_{wA} = the A-weighted sound power level for the individual vehicle,
- D = distance from road,
- V = speed in km/h,
- T = time in seconds for the calculation period.

The relationship can be expressed as follows:

$$L_{Aeq,T,D(1)} - 10\log_{10} N_{t(1)} = L_{Aeq,T,D\,(2)} - 10\log_{10} N_{t(2)} \qquad (7)$$

- (1) and (2) denote the base scenario and adjusted scenario which gives a +3dB increase
- L_{Aeq} = the A-weighted equivalent continuous sound pressure level,
- N_t = traffic flow for the vehicle category,

The number of HGV2 required to provide a noise contribution of 66.4 dB(A) is 193.

This represents an additional 161 HGV2s (=193 – 32) in the scenarios considered and is a significant increase in the number of HGV2s (approximately six-fold).

Dividing the monetary value calculated above by the number of additional vehicles gives;

-£96.77 per km of road per day x 100 / 161 = -59.92p per km of road per day

Appendix 6 Additional HGVs Required for a 3dB Change

				Daytime		Night	
Year	Road Type	Area Type	Congestion type	Change in HGV1 required for 3dB increase	Change in HGV2 required for 3dB increase	Change in HGV1 required for 3dB increase	Change in HGV2 required for 3dB increase
2015	A Roads	Inner and Outer Conurbations	CB13	3803	1535	400	162
2015	A Roads	Inner and Outer Conurbations	CB45	4270	1592	701	268
2015	A Roads	London	CB13	4629	1825	802	323
2015	A Roads	London	CB45	5523	2059	770	287
2015	A Roads	Other Urban	CB13	4215	1712	469	194
2015	A Roads	Other Urban	CB45	5271	2067	877	354
2015	A Roads	Rural	CB13	2711	1209	305	133
2015	A Roads	Rural	CB45	3044	1203	480	189
2015	Motorways	Inner and Outer Conurbations	CB13	27783	12927	6193	2825
2015	Motorways	Inner and Outer Conurbations	CB45	27669	11760	6392	2715
2015	Motorways	London	CB13	30307	14375	8080	3831
2015	Motorways	London	CB45	40046	17431	8947	3821
2015	Motorways	Rural	CB13	25405	12050	6072	2825
2015	Motorways	Rural	CB45	25942	11059	5675	2413
2015	Other Roads	Inner and Outer Conurbations	CB13	349	134	26	10
2015	Other Roads	Inner and Outer Conurbations	CB45	355	132	28	10
2015	Other Roads	London	CB13	355	133	50	19
2015	Other Roads	London	CB45	369	137	54	20
2015	Other Roads	Other Urban	CB13	410	157	31	12
2015	Other Roads	Other Urban	CB45	432	161	31	11
2015	Other Roads	Rural	CB13	171	71	10	4
2015	Other Roads	Rural	CB45	197	73	*N/A*	*N/A*
2020	A Roads	Inner and Outer Conurbations	CB13	3924	1584	417	168
2020	A Roads	Inner and Outer Conurbations	CB45	4338	1618	663	248

				Daytime		Night	
Year	**Road Type**	**Area Type**	**Congestion type**	**Change in HGV1 required for 3dB increase**	**Change in HGV2 required for 3dB increase**	**Change in HGV1 required for 3dB increase**	**Change in HGV2 required for 3dB increase**
2020	A Roads	London	CB13	4811	1896	873	344
2020	A Roads	London	CB45	5725	2134	835	311
2020	A Roads	Other Urban	CB13	4347	1765	485	201
2020	A Roads	Other Urban	CB45	5466	2097	916	370
2020	A Roads	Rural	CB13	2832	1263	316	138
2020	A Roads	Rural	CB45	2991	1182	445	180
2020	Motorways	Inner and Outer Conurbations	CB13	28883	13440	6299	2874
2020	Motorways	Inner and Outer Conurbations	CB45	28523	12143	6413	2729
2020	Motorways	London	CB13	34261	15952	8557	3983
2020	Motorways	London	CB45	33032	14389	7587	3229
2020	Motorways	Rural	CB13	26383	12514	6265	2915
2020	Motorways	Rural	CB45	27355	11677	5974	2539
2020	Other Roads	Inner and Outer Conurbations	CB13	366	140	27	10
2020	Other Roads	Inner and Outer Conurbations	CB45	371	138	29	11
2020	Other Roads	London	CB13	381	142	55	20
2020	Other Roads	London	CB45	395	147	59	22
2020	Other Roads	Other Urban	CB13	430	165	33	12
2020	Other Roads	Other Urban	CB45	452	168	32	12
2020	Other Roads	Rural	CB13	179	74	11	4
2020	Other Roads	Rural	CB45	202	75	*N/A*	*N/A*
2030	A Roads	Inner and Outer Conurbations	CB13	4177	1685	453	183
2030	A Roads	Inner and Outer Conurbations	CB45	4578	1707	741	283
2030	A Roads	London	CB13	5120	2016	972	383
2030	A Roads	London	CB45	5988	2232	953	355
2030	A Roads	Other Urban	CB13	4594	1904	534	217
2030	A Roads	Other Urban	CB45	5716	2192	924	364

				Daytime		Night	
Year	Road Type	Area Type	Congestion type	Change in HGV1 required for 3dB increase	Change in HGV2 required for 3dB increase	Change in HGV1 required for 3dB increase	Change in HGV2 required for 3dB increase
2030	A Roads	Rural	CB13	3034	1353	337	147
2030	A Roads	Rural	CB45	3042	1229	469	185
2030	Motorways	Inner and Outer Conurbations	CB13	29725	14089	6425	2987
2030	Motorways	Inner and Outer Conurbations	CB45	30726	13076	6916	2939
2030	Motorways	London	CB13	36238	17184	9170	4268
2030	Motorways	London	CB45	39945	17423	9331	4161
2030	Motorways	Rural	CB13	28235	13392	6517	3090
2030	Motorways	Rural	CB45	30239	13167	6662	2834
2030	Other Roads	Inner and Outer Conurbations	CB13	401	153	31	12
2030	Other Roads	Inner and Outer Conurbations	CB45	407	152	32	12
2030	Other Roads	London	CB13	427	159	62	23
2030	Other Roads	London	CB45	441	164	65	24
2030	Other Roads	Other Urban	CB13	471	180	36	14
2030	Other Roads	Other Urban	CB45	495	184	37	14
2030	Other Roads	Rural	CB13	196	81	12	5
2030	Other Roads	Rural	CB45	206	79	*N/A*	*N/A*
2040	A Roads	Inner and Outer Conurbations	CB13	4522	1785	493	199
2040	A Roads	Inner and Outer Conurbations	CB45	4847	1807	678	259
2040	A Roads	London	CB13	5390	2121	1060	417
2040	A Roads	London	CB45	6376	2376	1054	392
2040	A Roads	Other Urban	CB13	4849	2010	576	234
2040	A Roads	Other Urban	CB45	5889	2258	858	337
2040	A Roads	Rural	CB13	3255	1451	362	158
2040	A Roads	Rural	CB45	3281	1326	543	209
2040	Motorways	Inner and Outer Conurbations	CB13	31980	14880	6800	3161
2040	Motorways	Inner and Outer Conurbations	CB45	33538	13973	7499	3119

				Daytime		Night	
Year	**Road Type**	**Area Type**	**Congestion type**	**Change in HGV1 required for 3dB increase**	**Change in HGV2 required for 3dB increase**	**Change in HGV1 required for 3dB increase**	**Change in HGV2 required for 3dB increase**
2040	Motorways	London	CB13	37695	17875	9765	4630
2040	Motorways	London	CB45	48463	20688	11337	4948
2040	Motorways	Rural	CB13	30285	14361	6989	3313
2040	Motorways	Rural	CB45	32702	13941	7164	3051
2040	Other Roads	Inner and Outer Conurbations	CB13	433	166	34	13
2040	Other Roads	Inner and Outer Conurbations	CB45	440	164	36	13
2040	Other Roads	London	CB13	464	173	68	25
2040	Other Roads	London	CB45	478	178	70	26
2040	Other Roads	Other Urban	CB13	509	195	39	15
2040	Other Roads	Other Urban	CB45	535	199	40	15
2040	Other Roads	Rural	CB13	212	88	13	5
2040	Other Roads	Rural	CB45	220	84	*N/A*	*N/A*
2050	A Roads	Inner and Outer Conurbations	CB13	4737	1869	542	214
2050	A Roads	Inner and Outer Conurbations	CB45	4973	1853	616	230
2050	A Roads	London	CB13	5651	2175	1117	440
2050	A Roads	London	CB45	6561	2445	1123	418
2050	A Roads	Other Urban	CB13	5061	2097	610	247
2050	A Roads	Other Urban	CB45	6088	2334	875	336
2050	A Roads	Rural	CB13	3490	1526	381	167
2050	A Roads	Rural	CB45	3514	1422	567	223
2050	Motorways	Inner and Outer Conurbations	CB13	33233	15458	7118	3310
2050	Motorways	Inner and Outer Conurbations	CB45	34389	14628	7430	3159
2050	Motorways	London	CB13	38991	18495	10468	4872
2050	Motorways	London	CB45	51393	22360	12394	5291
2050	Motorways	Rural	CB13	32091	15217	7406	3511
2050	Motorways	Rural	CB45	34469	14694	7823	3261

				Daytime		Night	
Year	**Road Type**	**Area Type**	**Congestion type**	**Change in HGV1 required for 3dB increase**	**Change in HGV2 required for 3dB increase**	**Change in HGV1 required for 3dB increase**	**Change in HGV2 required for 3dB increase**
2050	Other Roads	Inner and Outer Conurbations	CB13	462	177	36	14
2050	Other Roads	Inner and Outer Conurbations	CB45	469	175	38	14
2050	Other Roads	London	CB13	489	182	73	27
2050	Other Roads	London	CB45	503	187	75	28
2050	Other Roads	Other Urban	CB13	543	208	42	16
2050	Other Roads	Other Urban	CB45	570	213	43	16
2050	Other Roads	Rural	CB13	224	93	14	6
2050	Other Roads	Rural	CB45	227	87	*N/A*	*N/A*