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Review of the

European Commission study "Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities" (STICITE) and the "Handbook on the external costs of transport version 2019" compiled by CE Delft

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This review has been compiled in a scientific and objective manner, consistent with the principles and practices of the consortium members. Its findings are directed towards informing and contributing to the client's ongoing policy work, by completing the assignments specified in the Call for Tender. We are open at any time, before or after final publication, to feedback, new data and alternative insights. Where possible, we endeavour to respond to contributions and account for them in the final report. All background data, sources and calculations are available on request.

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EXECUTIVE SUMMARY

This expert review assesses the study “Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities” (STICITE). It scrutinises the evidence in detail, including the methodologies, assumptions, data, results and conclusions, presents additional insights and research, and considers alternative approaches. Based on our review, we make recommendations for further study (Annex X).

General observations

The STICITE study is comprehensive, well-researched and thorough. It clearly identifies uncertainties in characterising and evaluating external costs, and where limitations to internalisation exist.

The publicly available documentation from the study includes a large amount of detailed data showing the results of analysis and numerical calculations. However, certain critical data and calculations, necessary to understand fully and reproduce the analytical steps, and investigate alternative scenarios, are not available for review. We acknowledge legitimate concerns regarding intellectual property. However, without access to this information, precise sensitivity analysis and full scrutiny of evidence were not possible.

The underlying approach of this review, when determining the nature and magnitude of external costs, is the “individual user perspective”. This perspective is consistent with well-established definitions of external costs, that are generated by people or groups that make decisions, and are imposed on other people or groups. The individual decisions to enter and utilise the transport system using a chosen means has an impact on other parties, that can be evaluated. The “system perspective” can provide additional insights under certain circumstances, for example when considering predictable congestion.

The objectives quoted by STICITE, which are 1: “influencing behaviour” (to reduce external costs), 2: “generating revenues” and 3: “increasing fairness”, are the key boundary conditions in assessing the implications of internalisation. Fairness involves applying the “polluter pays” principle, referring to the party generating the external cost. A strict interpretation of this principle would additionally involve the party bearing the external cost, where this party is identifiable, receiving a payment in compensation for the damage caused. In practice, identifying that party and executing payment can be complex and needs to be investigated for each external cost category.

The STICITE study is not a cost-benefit analysis, but does acknowledge that transport delivers benefits to society. The available literature around the benefits of transport suggests there are indeed a number of direct, indirect and wider economic benefits of transport. These derive from employment and value added within the transport sectors, the contribution of transport to the economic performance of other sectors, increased labour supply, induced property development, dynamic clustering and increased competition. However, the literature indicates that the wider benefits cannot be considered as external.

External and infrastructure cost and revenue: evaluation and internalisation

Our review has assessed STICITE’s evaluation of each external cost category and of infrastructure costs and revenues. The methodologies used by STICITE are appropriate, but the results are subject to uncertainties due to limitations in the best-available data and methods.

External cost categories: the following summarises the conclusions on evaluation of each external cost category and the implications for internalisation.

- Accidents: applying the responsibility approach, consistent with the individual user perspective, allocates costs to the causers of accidents and accounts for risk anticipation by internalising insurance premiums. This results in a value for external accident costs for road 44% lower than reported by STICITE when using the same value of statistical life (VSL). Significant uncertainty in the external accident cost figures exists due to the best-available methods and data for the determination of VSL.

  → Internalisation: contribution to behavioural change and fairness (internalisation objectives 1 and 3) can be achieved by internalisation of accident costs through insurance premiums. This represents full internalisation of the value of life/injury recognised by the insurance, or a partial internalisation if the VSL as reported by STICITE is applied. This highlights the wide range of valuations of VSL according to different assumptions. The impact of road pricing on accidents is highly situation-dependent and it is not clear that pricing would lead to reduction in accidents and their external costs. Addressing accidents through command and control and other measures can provide a comprehensive response to external accident costs, as acknowledged by STICITE.

- Congestion: STICITE's use of delay cost to calculate total external costs is not consistent with its statements that delay cost includes both internal and external components. From our analysis, the deadweight loss, used by STICITE when comparing costs to revenues and calculating cost coverage ratios, is the external congestion cost consistent with the individual user perspective. According to the STICITE figures, deadweight loss is approximately on sixth of delay cost. External congestion costs in non-road modes were addressed in STICITE but comparable figures were not generated. One estimate for average external delay costs of passenger rail indicates they may be similar to deadweight loss external costs in road transport, per pkm.

  → Internalisation: comprehensive application of the individual user perspective would preferentially apply pricing between the parties generating the congestion costs and those bearing the costs, implying mainly system-internal transfers. There are practical and technical challenges in designing effective congestion pricing mechanisms, for example through marginal social cost pricing (MSCP), that in practice inevitably includes an average pricing element. These factors hinder the full achievement of the behavioural and fairness objectives of internalisation through congestion pricing.

- Pollution and climate costs:

  Pollution: the STICITE methodology appears to be appropriate and the input data are reputable. The individual processing steps in the calculation of impact on human health are not fully available for scrutiny. Also considering the value of life year, derived in a similar way to VSL, some uncertainty in the final values results.

  Well-to-wheel climate: the key variable in the external cost determination is the cost of carbon. STICITE acknowledges a wide range of possible values.

  → Internalisation: using STICITE values for external costs, for almost all passenger cars and for other road vehicles certified to recent emissions standards, internalisation through fuel duties represents full MSCP of climate costs and approximate MSCP for pollution. For diesel rail in 13 EU28 Member States it represents full MSCP of climate costs and partial MSCP in the other 15.

- Noise and habitat costs:

  Noise: the STICITE methodology is reasonable, but the analytical steps and data sources introduce uncertainties that, when aggregated, diminish the robustness of the figures.

  Habitat: the STICITE analysis is less well-developed than other cost categories. The scaling up from a single country study to EU level introduces a high level of uncertainty.

  → Internalisation: for external noise costs, there are significant barriers to achieving the objectives of internalisation through pricing. For external habitat costs, the objectives of internalisation can be partially achieved through fixed or variable revenues.

- Other: STICITE identified additional external cost categories, with only qualitative description of the potential impacts. Additionally, embedded vehicle emissions increase well-to-wheel climate costs by up to 15% for some vehicle types (a 2-3% increase in their total external costs).
- General comments on cost evaluation: STICITE has advanced the state of knowledge in evaluation of external costs. However, for each cost category there are significant inherent uncertainties in one or more of methodology, source data and parameters, in addition to lack of access to some of the detailed calculations. The resulting figures should be seen as one possible estimate for external costs, under the stated assumptions and conditions.
- MSCP: for climate and pollution costs, MSCP through proportional revenues from fuel duties can contribute effectively to meeting the objectives of internalisation. Due to the difficulties of devising practicable pricing schemes, MSCP for congestion and noise can contribute to the objectives to a limited extent. Marginal external habitat costs are zero and MSCP does not apply. The impact of pricing on accident costs is unclear and MSCP does not appear to be an option that meets the objectives.

Alternatives to pricing: In some cases, regulation may be a more suitable method for reducing external costs than pricing. Total or near elimination of externalities will inevitably require regulation and innovation in addition to pricing. This is to a certain extent addressed in STICITE.

Government funding: non-infrastructure subsidies and public service obligations can be considered as additional costs, that support a functioning transport system. Our estimate indicates that these amount to approximately €30bn per year for rail.

Infrastructure costs: the methodologies appear to be robust although the allocation to vehicle types is dependent on assessments of road damage due to load factors. Different assumptions could affect infrastructure cost allocation to some road vehicle types by up to 25%.

Revenues: the values appear to be generally robust but in contrast to the treatment by STICITE, vehicle registration and circulation charges can be considered as partly variable.

<u>Sensitivity analysis</u>

Acknowledging the uncertainties, we have applied the above assessments in a sensitivity analysis to test the impact of alternative assumptions. Due to the different values for external accident and embedded emissions costs, the total external costs for passenger cars, buses/coaches, HGVs and LCVs are lower by up to 20% compared to the STICITE values. For motorcycles they are lower by about 45%. As with the STICITE results, each can be considered as one possible value for external costs, under the stated assumptions.

Applying the above-mentioned changes to accident costs and embedded emissions, as well as the deadweight loss instead of delay cost for congestion, results in a value for total external costs of transport of €652bn, compared to the figure reported by STICITE of €987bn. Of this, €448bn represents those external cost categories whose costs are borne mainly outside the transport system, for which pricing through taxes and charges can be considered most relevant. The remainder (accidents and congestion) are borne mainly inside the system, for which pricing that comprehensively meets the objectives would preferentially involve transactions between those parties inside the system. Again, these are possible values for external costs, under the stated assumptions and conditions.

Anticipated future technology, driven by known and expected regulations, is likely to reduce the external costs of all transport modes and vehicle categories substantially by 2030 and potentially towards zero by 2050.

The changes in the external cost values from the sensitivity analysis influence the cost coverage ratios. The variable cost coverage ratio is the key indicator as it provides an approximate measure of the extent of internalisation of marginal costs. For example, the marginal cost coverage ratio for passenger cars increases from 48% to 71%. Accounting for government subsidies as an additional cost, the variable cost coverage ratio for rail decreases, for example for high-speed rail from 208% to 91% and for electric passenger rail from 70% to 46%.

Risks of internalisation

An assessment of the risks of internalisation is a defined element of this review. Potential risks of internalisation include the following:

- Whilst in theory MSCP of congestion can contribute to meeting the objectives of internalisation, the average charging element of congestion pricing in practice and the variability of traffic flows diminish its effectiveness.
- The low price elasticity of transport can limit the effectiveness of pricing measures in reducing externalities.
- The distributional effects of pricing require further consideration, as under some circumstances pricing could also result in adverse outcomes for those on low incomes.
- The uncertainties inherent in the evaluation of external costs can create a risk of inaccurate price signals of internalisation, impairing the achievement of the objectives of internalisation.

Alongside the risks, from our analysis the main potential opportunity to contribute to the objectives of internalisation would be full MSCP of climate and pollution costs. These are the categories in which internalisation by proportional revenues can accurately apply MSCP in practice.

Assessment of STICITE conclusions

Based on our sensitivity analysis and the resulting cost coverage ratios as well as our assessment of MSCP, we make the following inferences on the three general conclusions reached in the STICITE Study Summary:

- The conclusion that *"External and infrastructure costs are only partly internalised by current taxes and charges"* is consistent with our findings, also after our revaluation of the external cost values. This finding is valid for all modes and vehicle categories, with partial internalisation achieved to different extents for each, as evidenced by the values for the total cost coverage ratio.

- Partly in contrast to the STICITE conclusion, the evidence indicates that MSCP is applied in a number of cases. STICITE's marginal cost coverage ratios indicate that MSCP is fully applied to cost categories excluding congestion for passenger cars and high-speed rail and partially to other modes and vehicle types. Our complementary analysis of the characteristics of individual cost categories indicates that MSCP is applied where it can effectively contribute in practice to meeting the objectives of internalisation: climate and pollution. MSCP fully applies to external well-to-wheel climate costs in road transport and, in 13 of the EU28 Member States, to diesel rail, due to full internalisation by fuel duties. For the majority of passenger cars and for other road vehicle types certified to the most recent emission standards, MSCP applies approximately to external pollution costs. In total, MSCP applies in this way fully or approximately to about 80% of the total well-to-wheel climate and pollution costs across all modes.
- Cost coverage ratio 4 compares infrastructure income to infrastructure costs. Evidenced by its low values (between 3% and 35%) except for aviation and maritime, *"Limited use of the 'user-pays' principle in the EU28"* appears to be valid for most vehicle types, to differing extents. However, variable infrastructure cost coverage is above 100% for most modes and vehicle types.

STICITE also presents options for further internalisation for all modes, proposing distance-based charges differentiated by vehicle characteristics, covering marginal climate, pollution, noise and congestion costs. The MSCP already applied to climate and pollution costs, as described above, suggests that the marginal benefits of further application of MSCP for these cost categories are limited. Due to the difficulties in achieving a fully differentiated pricing scheme in practice for congestion and noise, the proposal would introduce quasi-average charging for these categories. It could contribute to the behavioural objectives of internalisation to a limited extent. For congestion, however, a strict interpretation of the polluter-pays principle would require the pricing to generate transactions between users inside the transport system. For noise, it would require a mechanism for those affected by the costs to be compensated by the pricing revenues.

STICITE makes a number of recommendations for further assessment that would enhance knowledge of external costs and internalisation. In addition, we recommend the following:

- Further detailed investigation of the nature and extent of external congestion costs and the impacts of internalisation
- Including urban transport fully in the scope of future study
- Comprehensive evaluation of transport subsidies and their relevance to internalisation

NOMENCLATURE

ACEA: European Automobile Manufacturers' Association

BEV: Battery electric vehicle

CARE: Community Road Accident Database

CAV: Connected and autonomous vehicle

CBA: Cost-benefit analysis

CCS: Carbon Capture and Storage

CEEC: Central and Eastern European Countries

CH_4: Methane

CO_2: Carbon dioxide

dB: Decibel

DWL: Deadweight loss

ECMT: European Conference of Ministers of Transport

EEA: European Environmental Agency

EPA: European Parking Association

ETS: Emissions Trading System

EU: European Union

EV: Electric vehicle

FC: Fuel cell

GHG: Greenhouse gas

GDP: Gross domestic product

GVA: Gross value added

HGV: Heavy goods vehicle

ICAO: International Civil Aviation Organisation

ICE: Internal combustion engine

IO: Input-output

ITF: International Transport Forum

IWT: Inland waterway transport

JRC: European Joint Research Centre

kW: Kilowatt

LCV: Light commercial vehicle

LTO: Landing-and-take-off

MS: Member State

MSCP: Marginal Social Cost Pricing

NACE: Statistical classification of economic activities in the European Community

N_2O: Nitrous oxide

NO_X: Nitrogen-oxides

OECD: Organisation for Economic Co-operation and Development

O&M: Operational and maintenance

PCE: Passenger Car Equivalent

PHEV: Plug-in hybrid electric vehicle

PIM: Perpetual Inventory Method

PSO: Public service obligation

pkm: Passenger-kilometre

Ppm: Parts per million

PTW: Powered two-wheeler

SAF: Sustainable aviation fuel

SMC: Social marginal cost

STICITE: Sustainable Transport Infrastructure and Charging and Internalisation of Transport Externalities

tCO2e: Tonne of CO2 equivalent

TEU: Twenty-foot equivalent unit

tkm: Tonne-kilometre

TtW: Tank-to-wheel

UK: United Kingdom

VAT: Value added tax

vkm: Vehicle-kilometre

UNECE: United Nations Economic Commission for Europe

VRU: Vulnerable road user

VSL: Value of statistical life

WEC: Western European Countries

WHO	World Health Organisation
WTP:	Willingness-to-pay
WtT:	Well-to-tank
WtW:	Well-to-wheel
ZE:	Zero emissions

1 INTRODUCTION

The consortium comprising the Impact Assessment Institute (IAI), Element Energy (EE) and Cambridge Economics (CE) was engaged by the Fédération Internationale de l'Automobile (FIA) to compile an expert review of the study "Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities" (STICITE). The following are the main aspects in focus of the review:

1. Assess the overall analysis made in the study as well as the underlying methodological approach, also in view of the previous most relevant studies
2. Review the assumptions made and parameter values defined in the study, and analyse the sensitivity, variability of assumptions and parameter values and their impact on the level of the calculated income and external costs of transport
3. Identify and evaluate the benefits of transport to society
4. Analyse the conclusions drawn in the STICITE study with regard to its objectives

The objectives and specifications included in the call for tender are shown in Annex I.

The consortium committed to conducting an objective review, based on scientific analysis and available evidence. The resulting written report is to contribute to FIA's ongoing policy development and to their response to the STICITE study.

In our analysis, we have concentrated on "material" impacts, defined as those which either individually or aggregated could lead to a different conclusion.

In each of the Chapters 2 to 7 containing the main analytical content, we have included a summary of the findings. Recommendations for future study are presented in Annex X. Our analysis, data and calculations are open to feedback, comments and additional insights.

1.1 Overall results of STICITE study

The main results of the STICITE study are included in its "Study Summary", with main sections on external costs, infrastructure costs, revenues and state of play of internalisation. Additional detail is provided in a number of background documents and annexes (listed in the Bibliography), notably the "Handbook on External Costs" and "Internalisation State of Play". The Study Summary includes the table below showing the cost coverage ratios for each mode and vehicle type (see also Section 2.4 below).

	Overall cost coverage	Overall cost coverage excluding fixed infra costs	Variable infrastructure and external cost coverage	Total infrastructure cost coverage	Variable infrastructure cost coverage
Passenger transport					
Passenger car	51%	63%	48%	27%	417%
Bus	17%	24%	21%	3%	6%
Coach	18%	26%	23%	3%	6%
Motorcycle	19%	20%	15%	35%	576%
High speed train	26%	145%	208%	28%	394%
Electric pax train	16%	61%	70%	19%	160%
Diesel pax train	22%	91%	101%	16%	122%
Aircraft	34%	45%	46%	82%	247%
Freight transport					
LCV	43%	53%	48%	11%	153%
HGV	26%	37%	33%	14%	44%
Elec. freight train	12%	30%	35%	16%	86%
Diesel freight train	26%	55%	61%	25%	138%
IWT vessel	6%	12%	13%	12%	176%
Maritime vessel	4%	4%	4%	127%	4571%

Table 1: Cost coverage ratios reported in the STICITE study summary

These ratios have significant impact, since their evaluation leads directly to a number of main conclusions and policy implications. Additional summary information is provided by a number of charts for the respective sections (reproduced in Annex II of this review). These figures and their sources are therefore a primary object of our scrutiny.

The main conclusions drawn in the STICITE study are the following, which refer to the EU28 Member States:

- External and infrastructure costs are only partly internalised
- Little evidence of using marginal social cost pricing (MSCP)
- Limited application of the user pays' principle

The Study Summary also proposes policy applications for each mode:

- Road: the introduction of distance-based road charges differentiated to vehicle characteristics, location and/or time, complementing other policy instruments. Specific urban charging schemes.
- For rail transport, mark-ups on rail access charges to cover the fixed infrastructure costs and the introduction of noise differentiations in the rail access charges.
- IWT: appliance of fairway dues on a larger share of the EU inland waterways, differentiated by air pollutant emissions, complementing existing emission standards for new vessels.
- Maritime: environmentally differentiated port charges or fairway dues, complementing the IMO emission standards set for new vessels. Global policy instruments for GHG emissions.
- Aviation: GHG emissions in cooperation with global partners. Environmentally differentiated airport charges or aviation taxes for pollution and noise.

The Study Summary adds recommendations for further research.

Our review will also comment on the robustness of these conclusions, based on our detailed analysis. We focus our analysis and conclusion on the EU level impacts.

2 REVIEW OF OVERALL METHODOLOGICAL APPROACH

Summary

The methodological approach applied in the STICITE study is appropriate and the study is comprehensive and evidence-based.

Some of the detailed data and calculations necessary to understand and analyse fully the STICITE study have not been made available. This prevents comprehensive scrutiny of the study's results and conclusions by external stakeholders.

The European Commission Terms of Reference define a framework for an objective study.

The available definitions of external costs are consistent and can be used as a framework for analysis.

The "individual user perspective" is the appropriate approach for determining external costs, as it accounts for the impacts of actions taken by those able to take decisions. The "system perspective" can complement this approach, providing relevant insight under certain circumstances. STICITE itself employs the individual user perspective (without explicitly naming it), but there are material differences in its application compared to our approach.

The objectives of internalisation, as defined by the STICITE study, are "influencing behaviour" "generating revenues" and "increasing fairness". The STICITE conclusions derive from these objectives.

To be consistent with the STICITE analysis, the objective "influencing behaviour" should include the optimisation of traffic flows and congestion.

A strict interpretation of the concept of compensation would involve payment by the "polluter" to the "injures parties" bearing the costs, where this is possible. This requires accurate identification of the parties bearing the costs, the parties generating the costs, and a method to direct payment towards them.

Cost coverage ratios are an important primary result of the study, since they provide information about the extent to which the objectives are met. In some cases their evaluation is not unique and depends on the author's decisions on apportionment of costs and revenues, as acknowledged in the STICITE study.

The basic methodological approach described in the STICITE study (Handbook Chapter 2) is relevant and consistent. The study is thorough and well-researched. It clearly identifies uncertainties in identifying and evaluating external costs and the limitations of internalisation especially for certain cost categories. It specifically assesses the robustness of the cost and revenue categories within the relevant sections. The publicly available documentation from the study includes a large amount of detailed data showing the results of analysis and numerical calculations. However, certain critical data and calculations, that would be necessary to understand fully the analytical steps, reproduce the analysis and perform alternative calculations, are not available for review. We acknowledge that some of this information represents private intellectual property. However, without access to this information, reconstruction of the results, sensitivity analysis and full scrutiny were not possible.

2.1 European Commission terms of reference

As the European Commission's tender specification document provides the framework for the STICITE study, scrutinising its content is an integral part of the review. We have reviewed it to determine whether any of its provisions constrain or guide the contractor in a way that would be relevant to the outcome.

The document is explicit about the structure of the study. It also defines the external cost categories to be assessed. In this respect, flexibility to consider external costs in a broader sense, without an apparent constraint on the categories, would have been helpful.

Notwithstanding the above comment, the tender specifications appear to provide a framework for a scientific and objective study.

2.2 Definition and concept of external costs / externalities

The following definitions of externalities can be considered as an orientation:

- OECD: *"Externalities refers to situations when the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided"* (Glossary of Industrial Organisation Economics and Competition Law, 1993)
- Pigou: *"...one person A, in the course of rendering some service, for which payment is made, to a second person B, incidentally also renders services or disservices to other persons, of such a sort that payment cannot be extracted from the benefited parties or compensation enforced on behalf of the injured parties."* (The Economics of Welfare, 1932)

External costs are a subset of externalities. The following are the definitions of external costs that are included in the STICITE study summary (p43) and the 2019 Handbook (p24):

- *"Costs that arise when the social or economic activities of one (group of) person(s) have an impact on another (group of) person(s) and when that impact is not fully accounted, or compensated for, by the first (group of) person(s)"*

The following are complementary definitions used in the current Handbook and in previous versions of the Handbook:

- Handbook 2014: *"Costs imposed upon society by the side effects of a certain activity"* (p. 1)
- Handbook 2008: *"Costs to society… not taken into account by the transport users"* (p. 11)
- All Handbooks: *"Difference between social costs and private costs"*

All the above appear to be consistent with each other, whilst each describes the phenomenon in a slightly different way. They leave some room for interpretation. For example, the term "accounted for or compensated for" is not specifically defined. There are two possible interpretations of accounted for: paid for or anticipated/considered. This term may therefore not be sufficiently well-defined to differentiate between internal and external costs in some cases.

For the purposes of this review, the definition of external costs in the 2019 Handbook will be referenced.

When considering the implications of the definition, some reflections on the transport "perspective" are relevant. In particular, this is introduced in the UNITE study (2002) Deliverable 5 Annex 2 in relation to accident costs. The "transport system perspective" considers the transport system as a "group" in the context of the definition above. The "individual perspective" considers the individual (or groups of individuals) to be the "person" or "group".

The individual perspective is the appropriate approach when determining values for all categories of external costs according to the accepted definition. The decision by an individual to enter the transport system using a chosen method of transport leads to impacts borne by other individuals/groups both inside and outside the transport system. These are interpreted as external costs.

As a complement to the individual perspective, we also discuss the system perspective where it can provide additional insight. It is mostly relevant to the discussion of accident and congestion costs, since for these categories the parties bearing the majority of the costs are actors inside the system. The system perspective can be relevant when considering the system as an entity in itself, delineated from the rest of society. It does not however represent an alternative to the individual perspective for calculating external costs, since the system does not make decisions or take actions that have impacts on other groups/persons. This concept is further discussed in Section 3 in which the cost categories are characterised according to their nature.

2.3 The objectives of internalisation

The STICITE State of Play report sets out the objectives of internalisation (numbering added):

1. Influencing behaviour, to improve the efficiency of the transport system by:
   - reducing environmental impacts of traffic and enhancing traffic safety;
   - allowing an improved flow of traffic (i.e. reducing congestion).
2. Generating revenues, to:
   - finance new, extended or modernised infrastructure (which may in turn be related to the aim of improving freer flow of traffic);
   - cover costs of infrastructure management, operation and maintenance;
   - finance mitigation measures and/or alternatives for road transport;
   - finance the general budget (or reduce other taxes such as labour taxes).
3. Increasing fairness, to:
   - make the polluter/user pay (polluter/user-pays principle);
   - level the playing field for the competition between transport modes;
   - level out changes in income distribution or avoid overburdening socially vulnerable groups.

Table 2: Objectives of internalisation from the STICITE State of Play report

Objective 1 relates primarily to the impact of internalisation on the external costs. This objective is expressed in other parts of the study (Study Summary p16) as the "reduction of the external costs of transport". To be comprehensive "allowing an improved flow of traffic" should aim at the optimisation of the economic and social benefits of the flow (creating balance between reducing congestion and maintaining the benefits of the transport activity).

Objective 2 relates mainly to financing of infrastructure, but could partly relate to external costs when referring to mitigation measures. This objective is directly linked to objective 1, when relevant to investments that act to reduce external costs. It is also linked to objective 3 when considering whether the investments act to compensate those parties bearing the external costs.

Objective 3 relates to external costs (polluter pays) and infrastructure (user pays). In this context, “polluter” is taken to refer to the person or group generating the external costs (regardless of whether they are pollution or other cost categories).

A key aspect that requires attention is the identity of the person or group to which the payment is made. This is indirectly implied in the STICITE definition of external costs above, referring to “…when the impact is not fully accounted, or compensated for…”. It is more explicitly addressed in Pigou’s definition of (negative) externalities, stating that they occur when “…compensation [cannot be] enforced on behalf of the injured parties”. The Pigou definition refers to compensation “on behalf” of the injures parties, which could either mean any compensation would be paid directly to them or paid on behalf of them (for example as a tax).

This indicates that a contribution to the objective of fairness can be achieved by the polluter pays principle alone, regardless of the recipient of the payment. It further indicates that a strict interpretation of the concept of compensation and full contribution to the fairness principle would involve payment by the “polluter” to the “injures parties” bearing the costs, where this is possible. For a consistent treatment, this in turn requires accurate identification of the parties bearing the costs, the parties generating the costs, and a method to direct payment towards them. This is likely to present different challenges for each external cost category. It is addressed in the sections of Chapter 4 focussing on each cost category.

Fairness is also expressed using the term “equity” in the Handbook (p25) and is taken to have the same meaning in this context. In order to achieve fairness and a level playing field, consistent indicators are necessary for making comparisons.

One of the aims of this review is to analyse the conclusions drawn in the STICITE study with regard to the above objectives. We will therefore assess each cost category and any internalisation options in the context of the relevant stated objectives.

2.4 Cost coverage ratios

A number of different cost coverage ratios are calculated as one of the primary results of the STICITE study. They are informative indicators regarding the extent of internalisation of infrastructure and external costs and the achievement of the objectives of internalisation, calculated using average, not marginal, costs. Our analysis and calculations in the following sections of this review have an impact on cost coverage ratios, after which we reach conclusions. An understanding and initial assessment of the ratios is therefore of value, to put the analysis into context.

The following is an overview of the five ratios used and the reasoning given for each in the STICITE Internalisation State of Play or Handbook.

Cost coverage ratio	Explanation	Reasoning
1. Overall cost coverage ratio	Comparison of revenues from all taxes/charges with all external and infrastructure costs.	Good indication of the extent to which transport user pays for the average external and infrastructure costs caused.
2. Overall cost coverage ratio excluding fixed infrastructure costs	Comparison of revenues from all taxes/charges with all external and variable infrastructure costs (i.e. excluding fixed infrastructure costs).	This indicator is in line with the policy of the Commission to realise full internalisation of external costs, including wear and tear costs. It recognises that fixed infrastructure costs are sunk costs and that paying for these costs may result in (further) underutilisation of existing infrastructure (e.g. rail).
3. Variable external and infrastructure cost coverage ratio	Comparison of revenues from variable taxes/charges with variable external and infrastructure costs.	This indicator is measuring MSCP, in a simplified way (as proposed by the Communication of the Strategy for the internalisation of external costs). However, fixed taxes (and costs) are not considered at all, while they have an important role in many countries.
4. Overall infrastructure cost coverage ratio	Comparison of revenues from infrastructure charges with all infrastructure costs.	This indicator may provide an indicator of the extent by which the user pays principle is met. However, it should be noted that infrastructure charges are also used to cover external costs and that other taxes and charges can be used to fund infrastructures.
5. Variable infrastructure cost coverage ratio	Comparison of revenues from infrastructure charges with variable infrastructure costs.	As discussed above, there may be reasons to consider the level of internalisation without fixed infrastructure costs.

Table 3: STICITE explanations and justifications of cost coverage ratios

All ratios provide an indication of the extent to which the transport user pays for their costs. The relevance of each depends on the specific objective and pricing method that is being considered.

Ratio 1 considers all costs and revenues and is the most comprehensive when addressing the extent to which costs are covered by transport users. It is also the most accurate since it does not require judgement on differentiation between fixed and variable costs and revenues. It can be used as an overall measure of the objective to achieve fairness between modes.

Ratio 2: see below (derived from ratio 3)

Ratio 3 (variable external and infrastructure cost coverage) is most relevant to marginal external costs and STICITE introduces it as a simplified measure of MSCP. It is a measure of whether the principle of polluter pays is being fulfilled. Some sensitivity to interpretation of fixed and variable costs may exist, affecting the valuation of this ratio. It is relevant to the objective of influencing behaviour, since it is marginal behaviour that can be affected by internalisation. It is also relevant to fairness in term of the polluter pays principle, again due to the marginal impact on external costs.

> Ratio 2, according to the Study Summary, is consistent with the policy to realise full internalisation of external costs, by recognising that fixed infrastructure costs are sunk costs and are therefore excluded. For full consistency, fixed external costs (habitat costs) would be excluded from the external costs, since these are also “sunk costs”.

Ratio 4 relates to the coverage of infrastructure costs by related revenues. As indicated in the table above, the value of ratio 4 is open to interpretation, since it depends on which charges and revenues are deemed to cover infrastructure costs. This determination can be subjective and be dependent on the specific parameters of the costs and revenues in question. It therefore does not have a unique value in all cases. This ratio is relevant to the objective to generate revenues and also to fairness when comparing modes.

Ratio 5 (the variable infrastructure cost coverage) is relevant to marginal infrastructure pricing, consistent with the user pays principle. Similar to ratio 4, its value is not unique since it depends on partly subjective determinations about which charges are deemed to cover infrastructure costs. This ratio is relevant to generating revenues and also to the application of the user pays principle.

2.5 Conclusions on methodological approach

The concepts addressed in this chapter are important for understanding the framework of the STICITE study and setting the scene for our review. The European Commission Terms of Reference for the STICITE study and the available definitions of external costs provide a consistent background for the analysis. They lead to the definition of the individual user perspective as the appropriate one for calculating the magnitude of external costs. They also point to the system perspective as an informative concept that creates additional context.

The objectives link external costs to the practical implication of their internalisation. Complementing the objectives quoted by STICITE, improving traffic flow and reducing congestion should be considered in the context of optimising welfare from transport use. When considering the fairness objective, a consistent method to measure different modes comparably is essential. A strict interpretation of the concept of compensation and full contribution to the fairness principle would involve payment by the “polluter” to the “injures parties” bearing the costs, where this is possible.

The cost coverage ratios are the primary results of the STICITE study, since they are used to inform its main conclusions. Their values can be used to measure the achievement of the objectives.

3 OVERALL CONTEXT OF INTERNALISATION OF EXTERNAL COSTS

Summary

Transport delivers benefits to its users and operators. The use of transport also creates economic activity and employment in vehicle manufacturing, transport services and a range of supporting supply chain sectors.

Beyond these benefits, transport generates wider economic benefits, by linking labour, producers and markets, but these are difficult to quantify. The available literature indicates that these cannot be considered as external benefits, however.

In welfare economics theory, the purpose of taxes and charges is to ensure that infrastructure and external costs are internalised, through pricing signals and behavioural responses. The first-best approach from a theoretical point of view is marginal social cost pricing (MSCP).

However, applying MSCP poses considerable challenges in practice, since its fully accurate application requires monitoring of transport data in real-time with associated infrastructure. These are addressed in STICITE.

The theory is also formulated assuming idealised market conditions. The economic impact of taxes and charges that are calculated and allocated in the real world is more uncertain. It is therefore important that measures are tested on a case-by-case basis through robust assessment of the social, environmental and economic impacts.

Different pricing methods can be applied according to the policy objective that is to be achieved. This is addressed in STICITE.

In some cases, regulation can be a more suitable method for reducing external costs than pricing. Total elimination of externalities will inevitably require regulation and innovation in addition to internalisation. This is to a certain extent addressed in STICITE.

A number of additional elements were explicitly included in the call for tender of this review:

- identify benefits of transport to society,
- provide an overview of existing analysis on direct and indirect benefits of transport to society,
- discuss the risk of undermining the social benefits of transport through hampering mobility in an attempt to internalise external costs;

These are addressed in the following sections.

3.1 The benefits of transport to society

An objective of the STICITE study is to produce estimates of the external costs of transport in the EU and to assess to what extent external and infrastructure costs are internalised by current taxes and charges (cost-coverage ratios). STICITE states that *"transport is a precondition for a proper functioning of our modern society, for the well-being of people and for the economy"* (State of play of Internalisation in the European Transport Sector, p. 12). However, it is not the objective of STICITE to address the benefits of transport to society, or how these benefits would be impacted by the internalisation of external costs, whether through taxes and charges or command-and-control measures.

Nonetheless, it is widely acknowledged that there are both direct and indirect benefits to transport, which are considered to varying extent by investors and policymakers when assessing the impact of changes to the transport system. Furthermore, transport plays an important role in the modern economy and the economic development process.

At microeconomic level, direct benefits of transport refer to those benefits experienced by the users and operators associated with being able to move from one place to the other, and doing this faster, safer and cheaper as a result of incremental improvements to the transport system over time. At macroeconomic level, transport generates economic value, expressed by the economic activity within the transport sectors, i.e. the gross value added (GVA) and jobs linked to the movement of passengers and freight (e.g. train operators), as well as economic activity in those sectors providing goods and professional services associated with transport, such as vehicle manufacture insurance of freight for transport companies, or transport of feed and livestock for agriculture (Rodrigue and Notteboom, 2017).

Beyond these direct benefits, the transport system produces wider economic benefits such as more productive jobs (e.g. through better skills matching), accessibility (i.e. increased labour supply), induced property development, dynamic clustering, increased competition and business/supply chain redesign, etc. While these are only indirectly linked to transport, and transport improvements over time in particular, they are wider economic effects on employment, prices and economic development at the local, national, and international level. The fact that these are wider benefits does not mean that they are external though (the benefits are fully reflected by market transactions). This has been discussed by, for example, Rothengatter (1994), Lakshmanan et. al. (2001) and Blauwens et. Al. (2006).

It is through delivering these various benefits to the economy that transport contributes to economic development. In its simplest form, transport moves people and products to different locations. It has improved accessibility between workers and the workplace (El-Geneidy A. M. & Levinson D. M., 2006), generated new opportunities for jobs, and shortened travel times. It has allowed companies to sell goods in new markets and allowed them to exploit geographical comparative advantages (Rodrigue J-P. & Notteboom T., 2017). Therefore, the economic literature provides good indications that improvements in the transport system over time have generally brought about positive economic net-effects. However, the magnitude of these effects is highly context dependant. Nations and regions respond differently based on their current level of economic and market development as well as their institutional setup (Lakshmanan & Chatterjee, 2005).

In the short-term, better transport infrastructure tends to increase output and competitiveness while bringing about improvements in travel time and a reduction in congestion. The long-term effects include access to new markets which allow firms to exploit economies of scale and scope through the promotion of globalisation as well as technological improvements due to better accessibility and dissemination opportunities (Lakshmanan & Chatterjee, 2005). Better access to transport services can also be an important factor in lifting poorer segments of the population out of poverty by providing them with reliable access to employment, education, health, and social services (Jaber, 2017) as well as regional development (Goodbody Economic Consultants, 2003).

After many years of investing in and improving transport systems around the world, transport thus plays a vital role in the modern economy. Transport and its related sectors account for a considerable share of GDP in many economies, including the European Union. EU level macroeconomic analyses of this contribution transport plays is scarce, but includes for example a study of the economic footprint of European railway transport (ECORYS, 2014) and an EU-wide labour supply and demand analysis which estimates the future employment effect of the EU transport sector (Christidis, et al., 2014). Using Input-Output analysis, ECORYS (2014) find that the direct and indirect impacts of railway transport add up to 2.3 million jobs and 142 billion Euros gross value added in 2012.

In the absence of similar estimates for all transport modes, we have compiled data from Structural Business Statistics (SBS) (Eurostat) on GVA and employment in associated sectors to provide a basic assessment of the economic footprint of transport in the EU. First, a list of sectors associated with transport was identified, covering all modes considered in the STICITE study. Second, data on GVA and employment for each sector was extracted from the 2016 SBS. The SBS are detailed statistics on the structure, conduct and performance of businesses across the European Union (EU). Third, this data was aggregated to produce estimates of total GVA and employment related to transport in the EU, as presented Annex VI.

	GVA	Jobs
Units	€ billions (current prices)	Millions of jobs
Total	**1,110**	**18.0**

Source: Structural Business Statistics

Table 4: GVA and jobs in sectors related to transport

Based on the SBS and selection of sectors, transport contributed €1.1 trillion to the EU28 economy in terms of GVA and provided 18 million jobs. This represents almost 8% of the EU28's GVA and total employment. Of the subsectors included, road transport contributed the highest GVA. This was also the subsector which contributed the most to the increase over 2011-16.

The precise NACE Rev. 2 sectors underpinning each of the relevant subsectors are listed in Annex VI. At this level of granularity of sector classification (3/4-digit codes) data are missing. Where necessary methods have been applied to estimate these, these methods are also included in Annex VI.

The above calculation could also be attempted for each individual mode and vehicle type, but is not carried out here. A more accurate assessment of the economic footprint would require more detailed and comprehensive Input-Output modelling, capturing all sector-linkages within the economy, as well as counterfactual analysis.

3.2 The purpose of internalisation

In welfare economics theory, optimum resource allocation within a market takes place when the marginal cost equals the marginal benefit. In many instances though, negative externalities (the costs faced by those other than the individual consumer) are not reflected in the price faced by that individual, which leads to overconsumption of that good or service and thus welfare losses. To reach the point at which total marginal costs (faced by society and the individual) match total marginal benefits, the externalities need to be internalised into the price the user pays for the use of the good or service. This is typically done through taxes or charges, ideally set at levels that correspond with the marginal social cost caused by the additional user of that good or service.

The fundamental theoretical justification for the internalisation of externalities is therefore that doing so increases economic efficiency. Internalisation shifts the private demand curve (in the case of an externality linked to consumption, e.g. traffic congestion) or the private supply curve (in the case of a production externality, e.g. air pollution) to be consistent with the social equivalent, and so that an equilibrium is arrived at where social costs equal social benefits (i.e. the benefits and costs summed across the whole population are equal), rather than the point at which private costs equal private benefits (where benefits and costs to the individual are equal).

The British economist Arthur C. Pigou was the first to suggest that externalities were a justification for government action. In *The Economics of Welfare* (1920), he argues that firms are seeking to maximise their own interests; and where social interests vary from private interests (i.e. there are externalities), the unfettered market does not provide incentives to act to maximise social interests. He argues that this leads to the over-provision of goods where private benefits are higher than social benefits, and an under-provision where social benefits are greater (since the firm is not taking account of the social aspect). He proposed a range of policy options for dealing with goods and services which were subject to externalities, including regulation and bans, but is most well-known for what has since become known as a 'Pigovian tax' on production to shift production in such a way as to align private and social costs. Through the application of such a tax, the market conditions faced by the firm (or individual) can be made to mirror the overall societal costs and benefits.

Ronald Coase, in his 1960 Paper *The Problem of Social Cost*, set out the case for alternatives to government intervention; he argued that, when transaction costs between agents are zero, the issue of externalities can be better resolved through bilateral bargaining - that is, rather than imposing blanket regulations, the causers of externalities should enter directly into negotiation with those that suffer them, and that an agreement between these parties would represent a more efficient outcome than government regulation. However, it should be noted that Coase still considered externalities an issue which needed to be dealt with through some form of compensation – he argued rather that micro-level agreements would provide a more optimal outcome than a broader set of regulations.

In the case of transport, the cost paid by the user of a certain transport mode is lower than the full cost to society of the transport system, because the external costs associated with the use of that transport mode (climate costs, pollution costs, etc) are not reflected in the price that users pay for the use of the transport mode. Taxes and charges can therefore be used to influence the behaviour of transport users in order to bring the market to the level of transport use that is considered more efficient from a welfare perspective. At this point, transport users take the full costs into account when they decide to make a trip. Full efficiency is reached when all costs, including the private costs and social costs, are fully borne by the users of the transport system, possibly with lower use overall. This is called the 'optimal' size of the transport system, with transport volumes in a situation where transport users pay the full costs (plus a more optimal split between the different modes).

The European Commission 'Greening transport package' from 2008 first sought to establish the principle of internalising externalities in the field of transport; explicitly, it aimed to 'ensure that the prices of transport better reflect their real cost to society in terms of environmental damage and congestion'. The 'Strategy for the internalisation of external costs' (COM(2008) 435) stresses the need to account for external costs, and that transport prices should more accurately reflect all the costs generated by transport and that a number of appropriate pricing instruments can be used to achieve this. The 2011 EU White Paper on Transport emphasises that market-based instruments (i.e. taxes, charges and trading) should be developed in line with the user-pays principle.

The authors of the STICITE study rightly acknowledge, however, that the position of economic efficiency is merely a theoretical position that can only be achieved through a very accurate application of marginal social cost pricing (MSCP). In the real world, applying MSCP may pose considerable challenges:

- To be economically efficient, accurate estimates of the marginal cost would be needed for each transport user at any point in time
- Applying MSCP may be impractical and incur operational costs that outweigh the benefits

Therefore, other pricing methods may be more feasible, such as charging vehicles at their average cost or Baumol pricing, by which taxes and charges are simply introduced to reach a certain objective (reduce congestion at peak hours). In other words, users do not necessarily have to be charged the marginal social cost of their decision to join the transport system and different pricing methods for taxes and charges (MSCP, average social cost pricing, Baumol pricing and Ramsey pricing) can be applied according to the objective that is trying to be achieved. On these objectives, the STICITE study further points out that besides the primary objective to improve the efficiency of the transport system, there may be other motives for applying internalisation measures, such as raising government revenues for new infrastructure projects or designing mitigation measures. These issues are revisited when assessing internalisation in the context of each external cost category.

3.3 The economic impact of internalisation through taxes and charges

While welfare economics theory helps economists think about private costs versus the costs to society and the purpose of internalisation, there are several reasons why the impact of internalisation through taxes and charges in the real world is more uncertain and might not match what economic theory suggests (e.g. may not lead to higher welfare overall):

- A key uncertainty, for example, exists around the price elasticities of transport use, how these may differ between transport modes and over time, depending on the purpose of the trip and the factors driving decisions of transport users. In other words, whether and to what extent taxes and charges would lead to the desired behavioural changes is uncertain.
- The theory is formulated assuming idealised economic conditions of perfect competition, market stability, rational behaviour, complete information, etc. In the real world, this is rarely the case. There is a lot of heterogeneity in the transport market and between transport modes, oligopolistic market structures are common, some submarkets are more regulated than others, and economies of scales may exist in some cases (e.g. in the railway sector).
- The choice of policy instrument and its design does matter: both average cost pricing and marginal cost pricing are assumed to be in line with the user-pays principle, but different pricing methods will have different distributional and economic effects, also depending on the way any revenues are used.
- Effects are dependent on existing national policy and economic circumstances, and therefore valuation of these effects cannot be done in a general way. Impacts will differ between countries and regions, depending on institutional setup, existing taxes and regulations, etc.

The net impact on welfare (i.e. the sum of all negative and positive effects) of taxes and charges in the real world is therefore unclear and depends upon many different factors. The extent of these effects and their relative importance depend on – in a given context - whether and to what extent consumers react to changing prices, how producers react to the changes, what the market structure is, how the government revenues are used etc. More detail on these is provided below;

- The extent to which users and operators react to the measure: in reaction to a tax or charge, the consumer can decide whether to make use of the transport system or not, shift between different modes of transport, or to spend that money on other goods and services.
- Supply-chain effects: sustained changes in consumer spending will in the medium to long-term affect producer and investor behaviour, shifting resources from some supply chains to others. Depending on the employment intensity of the respective supply chains, this can lead to higher or lower employment overall.
- Revenue use: government revenues from the taxes and charges can be used to finance new or improved infrastructure, mitigation measures, invest in other transport modes, reduce other taxes, or for any other government expenditure. However, taxes and charges may also bring about higher administrative costs.
- Distributional effects: Depending on the design of the tax/charge, the employment impacts and the allocation of revenues, taxes and charges can also have distributional effects, potentially affecting aggregate demand in an economy (positively or negatively)
- Induced price effects: effects on consumption through potential effects on prices of goods and services outside the transport system

It would thus be inaccurate to interpret economic theory as saying that any tax or charge to internalise the external costs of transport is always economically efficient or welfare increasing (note though that nowhere in the STICITE study is this interpretation presented). In order to come to a reliable assessment of the welfare impact of a change in the system, it is important that policies are tested against real world conditions and on a case-by-case basis through well-performed assessment of the direct, indirect and induced social, environmental and economic impacts alongside each other.

An extensive literature review of existing impact assessments of transport pricing was carried out for this review, but little empirical analysis on the impact of transport pricing is available. Most of the assessments focus on the economic effects of investments in transport infrastructure rather than on the economic effects of transport pricing. A few interesting case studies were identified, for which the main conclusions are described below.

3.3.1 Economic effect of an aviation tax in the Netherlands

Using the AEOLUS-model, Faber and van Wijngaarden (2019) study the economic impact of different variations of an aviation tax which the Netherlands is considering implementing in the year 2021. All variations of the aviation tax produce a net positive effect on the economy. This mainly comes from higher revenues collected by government through the tax itself, and the multiplier effect of changes to consumption tax as a result of the policy. The authors estimate losses to the consumer surplus for air travellers who decide not to travel or to change their mode of transport. They estimate losses to the producer surplus due to changes in export patterns and domestic spending (Faber & van Wijngaarden, 2019). They estimate that the positive effects outweigh these losses. In general, the paper finds that there would be a positive impact on the Dutch GDP under all tax variations and under both macroeconomic baselines in 2021 (Faber & van Wijngaarden, 2019). Furthermore, the authors project a short-term effect of the aviation taxation on employment but no significant effect in the long-term. The short-term effect is either marginally positive or marginally negative depending on macroeconomic baseline chosen (Faber & van Wijngaarden, 2019).

3.3.2 Economic effect of road freight transport taxation in the UK

Piecyk and McKinnon (2007) review the impact of taxation aimed at internalising the external costs of UK freight transport to fully cover environmental costs, congestion costs, and infrastructure costs. The authors compare the duties, taxes, and road tolls paid by heavy goods vehicles to government estimates of their external costs and found that approximately 67% of external costs were internalised by taxes and charges at the time of writing. The authors estimate that 40% of all external costs can be associated to congestion. When these are excluded, taxation covered 112% of external costs. Although the authors argue that heavy-duty vehicle taxation should increase, they explain that this may create competitive disadvantages to UK freight firms operating in an open European Union market. In fact, foreign-registered heavy-duty vehicles impose an external cost when they use UK roads but do not pay UK vehicle excise duties. Moreover, foreign-registered freight vehicles likely pay little in the way of UK fuel duties as they purchase most of the fuel used in cheaper neighbouring countries (Piecyk & McKinnon, 2007).

3.3.3 Economic effects of congestion charging in Stockholm

Anderstig et al. (2012) analyse the effect of a congestion charge, specifically the congestion charge implemented in Stockholm, on the labour market under labour market imperfections. They test the hypothesis that welfare losses, such as lost income, may outweigh the welfare benefits of internalising external transport congestion. Using the results of a transport model and of travel survey data, the authors investigate the relationship between income and workplace accessibility and find that the congestion charge, in fact, brings about a net positive effect on labour income in Stockholm. This is attributed to accessibility improvements for the segments of the population with the highest time value of money, which outweighs the negative effect of lower accessibility of people with a lower time value money (Anderstig, et al, 2012). The authors explain that this should not be perceived as a general finding and that it depends on geographical and economic conditions. Although the net effect is positive for the case of Stockholm, aggregating the income effects in monetary terms may hide the fact that socially disadvantaged people, who coincidentally have lower time values of money, have decreased accessibility options.

3.4 Relative efficiency of prevention vs internalisation

It is important to note that the internalisation of external costs through taxes and charges does not seek to entirely eliminate these costs; its explicit aim is only to ensure that the 'user-pays' / 'polluter pays' – that is, that the causer of the externalities is paying a price which reflects the impacts on society at large as well as to the individual. It does so in order to maximise 'economic efficiency', i.e. to ensure that an equilibrium is reached at the point where costs and benefits are equal, and - according to economic theory - using transport taxes and charges are the most efficient way to achieve this. However, as noted already, the extent to which this affects transport volumes also depends on the elasticities of demand. In other words, the extent to which transport users change their behaviour in response to higher prices.

This is particularly relevant when considering the policy implications of externalities. It is clear that there are substantial externalities associated with different transport modes across the EU. Internalising these will increase the costs of transport across the different modes (compared to a situation where such externalities were not accounted for). However, it is also well established that demand for transport is relatively price-inelastic (e.g. Goodwin, 1992), i.e. there are not typically substantial changes in demand as a result of price changes. As such, 'pricing in' external costs will ensure that the polluter pays but can be expected to still lead to the generation of costs.

Therefore, at the same time as adhering to the 'user-pays' / 'polluter pays' principle and internalising externalities through taxes and charges, the European Commission has stated ambitions to encourage the take-up of low-emission mobility, and has introduced specific policies seeking to reduce emissions from transport (such as the CO_2 standards for light duty vehicles and HGVs), which can be expected to have a much more pronounced impact on emissions from the transport system. The fact that the Commission has pursued such policies demonstrates a recognition that market-based instruments cannot by themselves be expected to lead to the systematic reduction or elimination of externalities.

In the STICITE study, several reasons are identified for applying regulation and/or subsidies to reduce externalities in addition to or instead of taxes and charges, as follows:

> In general, several reasons have been identified for applying command-and-control measures and/or subsidies to reduce externalities in addition to or instead of taxes and charges:
>
> – *The international dimension of some of the external costs*; some of the external costs have transboundary impacts (e.g. climate change, air pollution) and therefore addressing them at the EU level has added value. As transport taxes and charges are under Member States competence, they cannot be easily harmonised at the EU level. Using alternative EU-wide instrument may be preferred in such cases.
> – *To avoid distortions of the internal market*; as transport taxes and charges differ widely between EU Member States, they may distort the internal market, leading to higher administrative costs. Using EU-wide harmonised instruments may therefore be preferred (in some cases).
> – *Better conditions to invest in technologies reducing external costs;* closely related to the previous issue is the fact that EU harmonised policies may provide a broad level playing field, providing vehicle manufacturers (and other industry) the same specifications that should be met by externality reducing technologies/actions at the entire EU. This improves the investment climate for these types of technologies/ actions. Furthermore, command-and-control measures may provide some more long-term certainty to investors as they are (perceived) less volatile than tax/charge measures.
> – *The energy paradox*; vehicle owners do not always invest in fuel-reducing technologies, even if the higher investment costs are fully compensated by lower energy costs. This 'so-called' energy paradox may be explained by several factors, including consumer myopia, imperfect information and split incentives (see Section 4.5 for more details). Instruments like fuel-efficiency standards are better equipped to solve the energy paradox than tax/charge measures.
> – *Improving information provision to consumers/companies:* instruments like labelling may improve the knowledge of consumers/companies and may indirectly change their behaviour.

- *To address externalities that are not targeted by taxes and charges*: accident costs are currently not (directly) addressed by transport taxes/charges, mainly because it is not straightforward to internalise these costs by tax/charge measures[22] (CE Delft et al., (2008)). Therefore, other policy instruments (mainly command-and-control measures) are used to improve transport safety.

Lack of social and political support for taxes and charges: the lack of social and political support for implementing or raising taxes and charges[23] may also be a reason to choose other policy instruments.

Table 5: STICITE State of Play - Reasons for applying command-and-control measures and/or subsidies to reduce externalities

While it is impossible to make a detailed assessment of the relative efficiency of internalisation versus prevention without conducting an empirical analysis, it can be inferred from the STICITE study that in some cases policy measures can be more efficient than pricing methods, that internalising external costs through pricing methods will by itself not eliminate the external costs of transport and that several reasons may exist, including social objectives, to use regulation instead of pricing methods. How, for each of the transport modes considered in the STICITE study, non-pricing instruments (e.g. CO_2 standards) can help reduce externalities is also addressed in the STICITE study (see: STICITE 'State of Play').

A related question is whether the cost of complying with regulation that reduces externalities can be considered as an internalisation of part of the related external costs. For example, the effect of road vehicle exhaust emissions regulations (currently Euro 6/Euro VI) is a cost for the user that is applied due to the existence of the external costs of pollution, which also reduces the level of the external cost. This in itself is compatible with the definition of internalisation, although its main action is not to reduce the level of externality by reducing traffic demand (although it may partially have that effect), but rather to reduce the externality by direct means. The costs are shared between consumers and vehicle manufacturers, depending on the extent to which they can be recouped through vehicle pricing. However, these costs vary inversely with the external costs, since those vehicles with more expensive equipment are those which consequently emit less and generate lower external costs. In this sense it cannot be considered as internalisation.

Similar considerations could be undertaken for the cost of safety equipment, greenhouse gas reduction technology and noise reduction technology on vehicles and cost of related technology such as low carbon fuels.

3.5 Conclusions

Many of the benefits of transport derive from the dynamics of supply and demand, and can therefore be measured by the value of related economic transactions. Associated benefits from manufacturing, services and related employment can also be measured. The estimated economic footprint of transport is €1.1trn. Wider benefits of transport can also be identified, from its enabling of more productive jobs, increased accessibility of labour, induced property development, increased competition etc.

Economic theory states that under idealised market conditions the optimum situation for transport use can be reached through internalisation of external costs by MSCP. In practice MSCP poses considerable challenges, since the economic impact in the real world is subject to uncertain parameters. Each potential pricing measure requires assessment of its specific impacts, depending on the policy objective.

Regulation can be more effective than pricing in reducing external costs, especially if the objective is reducing the costs to (near) zero.

4 REVIEW OF EXTERNAL COST TYPES – ASSUMPTIONS, DATA, ANALYSIS AND RESULTS

Summary

STICITE has advanced the state of knowledge in evaluation of external costs. However, there are inherent uncertainties in the assumptions and best-available data that preclude full confidence in some specific resulting figures. Additional uncertainty arises due to the unavailability of detailed data and analysis.

STICITE introduces the concept of responsibility in determining external accident costs, but does not follow up this approach, quoting the lack of detailed data. Its chosen approach accounts for the cost of all accident victims as external. It also introduces the concept of risk anticipation but excludes it from the further analysis.

The implied value of statistical life (VSL) differs significantly between national jurisdictions, insurance systems and willingness-to-pay assessments such as that used by STICITE. Each of these values is subject to significant uncertainties.

The responsibility approach, taking into account risk anticipation, is a consistent method for determining external accident costs. It allocates costs to the causers of accidents and accounts for internalisation of risk anticipation through insurance payments. This method results in a value for total external accident costs of road transport 44% lower than calculated by STICITE (if still applying STICITE's value for VSL).

The impact of pricing on accidents is highly situation-dependent and it is not clear that measures that reduce demand would lead to reduction in accidents and their external costs. Contribution to the objectives of internalisation can be achieved by risk-differentiated insurances, subject to the value of life and injury attributed. Methods other than internalisation, including command and control measures, can provide a comprehensive response to external accident costs, as acknowledged in the STICITE Handbook.

STICITE uses delay cost, representing loss of time compared to the free-flow situation, as the measure of external congestion cost for calculating total external costs of transport. However, delay cost is not a measure of external cost, as acknowledged in the STICITE handbook. According to the STICITE figures, deadweight loss is approximately on sixth of delay cost.

STICITE uses deadweight loss as the measure of external congestion cost when comparing costs to revenues and calculating cost coverage ratios. This measure represents the total welfare gain if all transport users considered the impact of their decisions. Deadweight loss is a consistent interpretation of external congestion cost, as it acknowledges the optimum balance between reducing congestion and maintaining the benefit of the transport activity.

Due to the absence of new sources of data, STICITE does not generate comparable figures for congestion costs of non-road modes. These may be material and STICITE acknowledges this by omitting congestion costs from the direct modal comparisons of external costs.

Internalisation of external congestion costs fully consistent with the individual user perspective would apply pricing between users within the system. There are practical and technical challenges in designing effective and predictable congestion pricing mechanisms, that hinder the achievement of the objectives of internalisation.

The calculation methods for external pollution and well-to-wheel climate costs appear robust. Marginal social cost pricing for these cost categories through fuel duties can contribute to the achievement of the objectives of internalisation.

There are barriers to meeting the objectives of internalisation of external noise costs through pricing, due to spatial, exposure and behavioural parameters. In practice, pricing can contribute to a limited extent to the objectives, which can also be met through other means such as regulation and behavioural measures.

Due to inconsistencies in the analysis and scaling up to European level, the results for external cost of habitat loss cannot be considered as robust, although it is not possible to conclude whether the estimates are too high or too low. The objectives of internalisation can partially be met through fixed or variable revenues.

The uncertainties identified in the external cost values for all categories reduce confidence in the effective and efficient achievement of the objectives of internalisation.

This section of the review assesses external costs in conceptual terms and fully assesses each individual external cost category. For each category we assess the methodology applied by STICITE, the data sources used, the results generated and, where relevant, the conclusions regarding internalisation.

Full detail of the background data and analysis for the cost categories evaluated by STICITE is not available for external review. This prevented understanding and further assessment of some elements of the cost categories, which is a source of uncertainty in the results.

4.1 Characterisation of external cost types

In order to evaluate external costs in an informative manner, it is relevant to compare their characteristics and determine how these may influence their further implications.

The following table categorises external costs according to a number of attributes, followed by a discussion of the relevance. These assessments reflect statements in the STICITE documents:

		Accident	Congestion	Pollution	TtW climate*	WtT	Noise	Habitat
Fixed/ variable		Var	Var	Var	Var	Var	Var	Fixed
Primary impacted parties		Affected users in system	Affected users in system	People in dispersion zone	Global society / environment	Global society / environment	People within earshot	Local environment
Marginal costs	Correlation to average costs	Low	Part (above threshold)	Strong	~100%	~100%	Part	~100%
Marginal costs	Context specific	Highly	Highly	Partly	-	-	Mostly	-
Timing of cost – individual		Subsequent to accident events	While in congested system	Long lasting (days/ weeks)	Very long lasting	Very long lasting	While in system	Very long lasting
Timing of cost - system		Subsequent to accident events	During event (mins / hours)	Long lasting (days/ weeks)	Very long lasting	Very long lasting	While traffic present	Very long lasting
*Climate costs as defined in the STICITE study are tank-to-wheel and are denoted as “TtW climate” in this review								

Table 6: Characteristics of external cost categories

Fixed/variable: the fixed or variable nature of the costs determines in which cost coverage ratios the costs are included in the STICITE study documents. This is a valid differentiation, since variable and fixed revenues can be directly associated with variable and fixed costs respectively, whether those costs are infrastructure or external.

Impacted party: the identification of those groups primarily suffering the external cost may help to put the question of internalisation into context. This is relevant due to the concepts of fairness and equity quoted in the STICITE documents. For example, the Handbook (p25) refers to equity, *"ensuring that the transport sector or vehicle categories pay for the costs they impose on society"*. Those costs imposed on people and the environment (see table) are almost fully external to both the transport user and transport system. Accidents and congestion external costs are not imposed on society as a whole but to a great extent to those who choose to enter the system.

That choice also recognises the concept of risk anticipation, which implies that road users are aware of the risk of accidents and congestion that they may suffer when entering the transport system. For congestion, this factor is stronger in predictable traffic situations, where the choice for some users could be considered explicit in accepting the congestion and thereby its costs. It could be considered as "accounted for" by one interpretation of the definition of external costs. Costs are still imposed by one person/group on another, but according to these considerations, there can be different interpretations of the extent to which they are external. These considerations also affect the implications of the concept of equity.

External pollution costs impact that part of society within the local dispersion zone, which could be an urban area or potentially a much larger region depending a complex set of factors including meteorological conditions. External noise costs are imposed on members of society within earshot of the noise source, which is relatively localised. These observations can also influence considerations of equity when considering the appropriate nature of internalisation and related measures.

Marginal costs average part: this attribute identifies the extent to which average costs approximate to marginal costs. Its characterisation for TtW climate, well-to-tank and pollution reflects the Handbook p25 as identifying average and marginal costs as approximately equal. Accident, congestion and noise costs are more context-specific (see next point). Noise costs have some correlation to transport activity. Congestion varies non-linearly with transport activity above the maximum free-flow point. The relationship between accidents and transport activity is more complicated. This assessment has implications for how efficiently the costs can be reduced by average pricing schemes.

Marginal costs context-specific part: this identifies the extent to which marginal costs are different from average costs and therefore the extent to which an effective pricing scheme would require accurately differentiated application of marginal pricing to maximise efficiency.

Timing: the attributes related to timing of the costs are related to the question of differentiation of average and marginal cost parts and may be informative in that context.

The above considerations are revisited in later sections.

4.2 Accident costs

Accidents are the largest external cost block reported by the STICITE study, representing 29% of total reported external costs.

4.2.1 Methodology:

Selecting the "individual perspective" as the appropriate one for determining external costs (Section 2 above) implies a clear identification of individual decision and responsibility as the driving factor. For accident costs, this approach implies that the risk value of the non-causer of the accident is external, since the payment of damages to victims (by insurance companies or individuals) is interpreted as compensation for costs borne. The "(group of) person(s)" generating the costs is the causer of the accident. In this case liability insurance payments, which represent a (partial) internalisation, are subtracted from the total social costs to determine net social costs. Social security payments by governments are additional external costs added to the resulting figure to determine total net external costs. This approach is presented by UNITE (2001) Deliverable 5 Appendix 2 as the relevant approach for pricing related to *"…whether the causer of the accident has to bear the consequences of his misconduct."* This translates into an approach for calculating external costs according to the individual user perspective.

In the STICITE Handbook General Methodological Framework, the text in the table on p26 states that the external costs are *"Part of the social costs that is not considered in own and collective risk anticipation and not covered by (third party) insurance."* P31 further states *"…part of the total accident costs is already internalised, for example through insurance premiums or through accounting for risks that are well anticipated."* These indicate that some internalisation through risk anticipation should be taken into account when calculating the external costs. In practical terms, the concept of risk anticipation is applied through the payment of insurance premiums, since they represent an explicit internalisation of that risk.

The STICITE approach to external accident costs is explained in the Handbook Annex B by stating (p168) *"we define them as the social costs of traffic accidents that are not covered by risk-oriented insurance premiums."* It also states *"Economic theory suggests that for true internalisation of external costs to happen, the marginal costs should be paid for by the causer of those external costs."* It follows this up with a discussion on internalisation through insurances. A consistent inference of the quoted theory would be that, over and above paying for accident costs imposed on other parties (directly or through insurance), the causer should pay his/her own external costs, which would be a form of internalisation.

Risk anticipation and internalisation through insurance is a relevant line of inquiry but is not explicitly developed in the later parts of the Handbook. The STICITE authors have taken an alternative approach, which appears to exclude these considerations.

On p169, the STICITE concept is discussed with a comparison of different approaches. It states that the "Responsibility approach" (allocating costs to the responsible party) is *"…arguably the fairest way to allocate the accident costs. Unfortunately, accident statistics at the EU level do not contain information on responsibility."* It provides the following arguments for using the "Damage Potential" approach (allocating all victims in a certain vehicle to the other vehicle involved in the accident):

- *"Firstly, the accident statistics with differentiations on responsibility are not available for all countries within the scope of this study."* This argument appears reasonable, but due to the highly material difference between external costs calculated by the Responsibility and Damage Potential approaches, it would be appropriate to identify ways at least to estimate the impact.

- *"Secondly, as argued by (CE Delft & VU Amsterdam, 2004) the 'responsibility' for an accident in a moral and causative sense does not only lie with the party 'in error', but may also lie with the party that, legally speaking, did not commit an error at all. After all, certain activities undertaken by society are accompanied by a certain intrinsic risk, even if no 'error' was made."* This argument also appears reasonable, but its implication is that there may be more than one party at fault, or potentially none. One consequence could be that in a single accident, the human costs of more than one at-fault driver would be considered internal, partially or potentially fully.

The Handbook does not explicitly address the issue of self-accidents, in which only one vehicle is involved. Assuming responsibility lies with the driver in such cases, the human costs of the driver can be considered internal, with those of passengers external. This is partially consistent with the Handbook (p35), which states *"Drivers consider all human costs of individuals inside their vehicle as fully internal, but the human costs of individuals in other vehicles as fully external."* However, our approach additionally considers the human costs of passengers in the vehicle of the causer of the accident to be external. The Handbook (p35) also explains that external accident costs are calculated by deducting the compensation transfers from liability insurance systems and gratification payments.

Without access to the background data and calculations of the STICITE study, it is not possible to verify the exact method used for determining the costs. The STICITE approach is summarised in the table below (approach #1).

From the above discussion, a comprehensive approach, consistent with the individual user perspective, would treat the external costs of at-fault drivers, drivers of individual vehicles and the transfers from liability insurance systems and gratification payments as internalised. This corresponds to the UNITE approach using the individual user perspective (approach #2 in the table below). Referencing the discussion in Section 2.2 above, this approach recognises that road users take decisions and carry out actions that have impacts on other users (groups/persons). In the case of accidents, the decision is the (usually involuntary) one that leads to an action causing an accident. The road user taking that decision and carrying out that action is the responsible person/group, that is therefore generating the external cost borne by another person/group. This is the "responsibility approach" mentioned but not pursued in the STICITE Handbook, and is the basis for the calculation of external cost (see below Section 4.2.3 and Annex III). Using the responsibility approach, the concept of risk anticipation is manifested in practice through insurances, which internalise the anticipation of risk in tangible monetary terms.

The "transport (system) perspective" (approach #3) argues that all users of the transport system have internalised the risk of accidents and therefore the full human cost in their decision to participate in it. It represents the concept that external costs are those imposed by users on those outside the transport system. Only social security transfers are considered as external costs. We have not followed this approach, since it does not consider the effects of individual decision making on other parties, regardless of their participation in the transport system. This is an example of the system perspective and may nevertheless be an informative consideration for discussions on internalisation.

The approach (#4 in the table) used by Baum (2008) assumes that external costs of the non-causers of the accident are covered by compensation payments. It is a further example of the system perspective. It recognises the value of life or injury as that enshrined in the relevant national law or determined by court proceedings, and only when actually applied in practice to extract payment. By definition in this case, all costs are deemed to be internal. We also do not follow this approach, but the legal and judicial valuations of life are relevant parameters for further discussion.

To enable comparison in context, the approaches discussed above and their attributes are tabulated below.

Approach	**1. STICITE**	**2. UNITE Individual user perspective**	**3. UNITE Transport perspective**	**4. Baum**
Risk anticipation	Mentioned but not further assessed	Risk value of non-causer is external	Considered as transport system internal except for social security transfer payments	Not explicitly considered
Cost coverage	Liability insurance payments and gratification payments (unclear if accounted for)	Auto liability payments less social security	Auto liability insurance considered but not evaluated (only social security relevant)	Fully internalised by compensative payments
Individual accidents	Not explicitly stated	Not explicitly stated	Not specifically addressed	Fully internal
Fault	Considered but not applied	Causer has to bear consequences	Not considered	Relevant to who pays compensative payments
Relevance argued in source study	Calculating external costs	Pricing	Total costs and benefits of system	Calculating external costs

Table 7: Comparison of four approaches for the evaluation of external accident costs of transport

Applying the individual user perspective as indicated in the introduction to this review leads to amended values for the external accident costs.

The partial internalisation of accident costs through compensation by insurance liability and gratification payments is referred to in the Handbook but it does not appear to have been taken into account in the STICITE calculations.

The methodology for calculating value of statistical life (VSL) for determining human costs is legitimate but generally subject to a high level of uncertainty due to its general reliance on the willingness-to-pay method. It is generated from an OECD (2012) meta-study based on a large number of underlying studies with a very high range of VSL. The scientific approach on VSL from this study is improved compared to the 2014 Handbook version, which was based on a single study. However, the high range of values underlying the value generated from the OECD study demonstrates the inherent uncertainty. This is discussed in greater detail in Annex III.

The VSL method can be compared to alternative valuations of life that derive from actual compensative payments. These can be defined in law or negotiated in court settlements, also involving a degree of subjectivity. In most cases the values are significantly lower than the VSL. For example in the UK, the legal compensation rate for bereavement is £12,980 (Fatal Accidents Act 1976). This indicates a wide divergence between valuation by the law and by personal preference in this respect. At the same time, also in the UK, Judicial College Guidelines for the Assessment of General Damage in Personal Injury Cases 14th Edition (2017) (not fatalities) attribute values of the order of £200,000 to £400,000 for severe injuries, similar to the value for serious injuries derived from VSL. Since the valuations of life defined in law or in court differ greatly between Member States and within Member States, they cannot be applied as standard values relevant to policy. These are legitimate values generated according to very different assumptions, processes and conditions. It is an objective of VSL to generate a legitimate standardised value. Each method has merits, uncertainties and disadvantages.

The STICITE methodology for calculating damage costs is consistent. Certain unreferenced assumptions are used to calculate the internalised part, but their impact is not material for the total evaluation, since total damage costs are projected to be approximately 10% of total external costs and any error would be a small fraction of this 10%.

4.2.2 Inputs

The data on road fatalities per vehicle type from the European Commission CARE database are expected to be robust, since they are based on reputable statistics from official agencies. Explicit data on injuries are not available and have to be deduced from ratios reported for 2014. More detailed data on which vehicles crashed with which vehicles when fatalities were caused is necessary to determine the internal portion of the accident costs. These data are referred to in the STICITE Handbook but are not publicly available.

The Handbook (p33) quotes correction factors for underreporting of accidents. The quoted studies are relatively old (HEATCO, 2006 and Ecoplan, 2002) and their conclusions could therefore be questioned, should there have been factors increasing the accuracy of official figures by 2016. The Handbook argues that there are no indications that the results of these studies are outdated. To support this it quotes more recent studies, specifically a 2008 study for Korea (and a 2016 OECD study quoting this 2008 study) and a 2016 study for Denmark. The relevance of the Korean study to the European situation is not clear and would require further in-depth analysis. The Danish study includes specific data for vulnerable road users including motorcyclists. This is relevant, but the applicability to the full range of vehicle types across Europe is also unclear.

The Handbook quotes Ecoplan & Infras (2014), that revealed there are no longer the 2% unreported fatalities in Switzerland reported in HEATCO (2006) and Ecoplan (2002). A possible interpretation could be that the underreporting of injuries had also improved during this time. The Handbook's conclusion, that "there are no indications that [the correction factors] are outdated", is a possible interpretation. It could also be the case that underreporting had diminished by 2016. This subject is a candidate for further in-depth study.

We made a base assumption for attributing fault between cars and larger vehicles, motorcycles (powered two-wheelers - PTWs) and vulnerable road users (VRUs = pedestrians and cyclists), with two sensitivity cases. These are presented in more detail in Annex III:

Case	PTW fault rate	VRU fault rate
Base case	50%	0
Sensitivity 1	25%	0
Sensitivity 2	50%	25%

Table 8: Different assumptions for fault rates of PTWs and VRUs for external accident costs

Data on insurance premiums associated with human cost of accidents is not available at the necessary level of detail. A proxy for insurance premiums is compensation payments made to victims by insurance companies. This is likely to underestimate the premiums, since they cover costs and profits in addition to payments. However, we identified no more accurate figure. Annex VII provides an estimate of the relevant figures, estimated from individual country data.

The data underlying the value for VSL in STICITE, determined by OECD (2012), indicated a more than 100-fold variation in individual values. The reported VSL figure is the median of these, which is a standard method to select a single result. The wide range indicates a high level of uncertainty in the value used, explicitly acknowledged in the Handbook by quoting the recommended range of €1.8m to €5.4m. This is discussed in greater detail in Annex III. The values of life derived from national law and court proceedings are significantly lower than VSL and represent non-standardised alternative values.

4.2.3 Accident cost results and conclusions

The above alternative assumptions result in a different value for the external costs of road transport (assuming the same VSL is used). Compared to the STICITE value of €279bn, the Base Case assumption results in €155bn (-44%). Sensitivity Case 1 results in €161bn (-42%) and Sensitivity Case 2 €135bn (-52%). A further breakdown of these figures is shown in Annex III. Although the EU-wide detailed figures on accidents were not available for review, we were given access to data from the UK (RAC Foundation, 2016), which includes information on which vehicle categories were involved in accidents with which vehicle categories. Using the same assumptions as in our calculations for EU, the share of the internalised accident costs is nearly identical, confirming the validity of our estimate based on those assumptions, that results in the figures summarised above.

Using the responsibility approach, we found accident costs for motorcycles to be 85% lower than reported by STICITE. This significant reduction occurs due to the accounting only for opposing fatalities and injuries caused by the motorcycle user in calculating its external cost. STICITE assesses accident costs for motorcycles but not for mopeds, quoting the lack of transport performance data for mopeds. Available data (CARE database) indicates that adding mopeds would increase the number of accidents and therefore the total external accident costs for PTWs by approximately 20% (in aggregate still about 80% lower than the STICITE value).

The numerical results of the STICITE study in terms of external accident costs are to be regarded in the context of the methodological choices made and the above-identified uncertainties in addition to the above alternative calculation. In particular, the disparity in the available VSL estimates generally results in high disparity in the external accident cost estimates, both on the up and down-side.

4.2.4 Conclusions regarding internalisation

The discussion of internalisation in the STICITE study and the above review lead to reflections on the extent to which internalisation of accident costs can be expected to meet the objectives of influencing behaviour and achieving fairness, referring to all modes. Behavioural change through market measures requires a price signal that acts to reduce the external costs. In the first instance, an effective signal would also require a robust estimate of the external costs, which are subject to uncertainties associated with best-available methods and data as identified above.

Regarding the effectiveness of internalisation, the Handbook (p179) quotes research *"…implying an increase in traffic leads to a reduction in the accident risk."* Page 40 provides estimated values of the elasticity of accidents to traffic volume that are negative, except in urban traffic, in which it estimates them to be zero. It implies that the impact of pricing on accident costs would be unpredictable, with no clear evidence whether pricing would lead to higher, lower or unchanged accident costs. Pricing, including MSCP, could therefore not be assumed to lead to any reduction in accidents and their costs. The Study Summary (p79) refers to *"…the difficulty of internalising accident costs through pricing measures."* On p83 it excludes accident costs from the external costs categories that could be internalised by its proposed option for road transport internalisation. These observations indicate an acknowledgement by STICITE that internalisation of external accident costs may not meet the objectives of internalisation.

Regarding the fairness objective of internalisation, the responsibility approach that we have applied to the calculation of the external costs provides the appropriate framework for consideration. The following references in Section 4.2.1 above to the STICITE Handbook illustrate the concept:

> *"Economic theory suggests that the marginal costs should be paid for by the causer of those external costs."*
>
> *"… the Responsibility approach"* (allocating costs to the responsible party) is *"…arguably the fairest way to allocate the accident costs."*

Charging the responsible party achieves "polluter pays" and makes a contribution to the fairness objective. In the case of accidents, identification of the party bearing the costs is usually straightforward. The strict interpretation of "polluter pays" in this case would involve the at-fault party being charged in order to compensate the victim. This also implies that a pricing mechanism to achieve the objectives fully would act preferentially between parties inside the transport system.

In practice this is partly achieved by the payment of insurance premiums, which can be seen as an indirect method of internalisation of accident costs. It internalises the risk rather than the cost. This is particularly the case when premiums are differentiated according to risk. For example, bonus-malus systems consider claim history whilst age-based premiums take into account higher risk for younger drivers. This type of internalisation can help to change behaviour (internalisation objective 1) by increasing the cost according to accident risk. It can also partly achieve fairness (objective 3), by making those more at risk of causing accidents pay more and creating a mechanism enabling the accident victim (or their family) to receive compensation. In principle, all accident costs can be internalised by insurances, if the payout in the event of an accident covers the costs. The discrepancy between the external costs according to STICITE (and the lower value according to our sensitivity analysis) and the much lower aggregate value of insurance premiums is due to the very different value of life or injury implied by each (see discussion on VSL above).

The alternatives to internalisation in meeting the objectives are measures that directly impact technology and behaviour, including regulation, guidelines, training and infrastructure. This point is also addressed in the STICITE Study Summary (p79) stating:

> *"Other policy instruments (mainly command and control measures) are used to improve transport safety. For example, road safety is regulated at the EU level by command-and-control measures, primarily through setting (minimum) safety standards or requirements. These EU-level measures, combined with national-level requirements (e.g. speed limits), provide a comprehensive response to external accident costs."*

Describing these existing measures as "comprehensive" implies that the objectives can be achieved through these other means. Those choosing to drive a vehicle bear the costs of technologies and measures (such as speed limits) that act to reduce the external accident costs in a direct manner.

<u>Final assessment</u>

Contribution to behavioural change and fairness (internalisation objectives 1 and 3) can be achieved by internalisation of accident costs through insurance premiums. The value of life used is the critical parameter in determining the extent of this internalisation. A response to accident costs that includes command and control and other measures can provide a comprehensive response to external accident costs.

4.3 Congestion costs

Congestion costs as reported by STICITE represent 27% of total external costs, although STICITE also quotes a significantly lower alternative value approximately 17% of this amount as a lower bound, which is used when calculating cost coverage ratios. The following observations were identified in STICITE's treatment of congestion costs as described in the Internalisation Handbook. Further detail is provided in Annex IV. Our analysis primarily addresses road transport, since STICITE identifies a value for congestion costs only for this mode. We also review STICITE's assessment of congestion in non-road modes.

4.3.1 Methodology

The individual user perspective (as explained in Section 2.2 above) leads to the deduction that part of the delay cost of congestion can be considered as external. This is also stated in the STICITE Handbook, but it does not present a unique designation of which part is external. Both "delay costs" and "deadweight loss" are reported in the results presented in the STICITE Study Summary, which states (p44) *"Two approaches have been developed to estimate congestion costs at urban and inter-urban level"*. These two approaches are explained below.

The Study Summary uses delay cost in the calculation of total external costs of transport (27% of the total, p11) and in the pie chart comparing the magnitude of different external cost categories (p49). It uses deadweight loss in the charts presenting total costs vs total revenues (pp65-73) and also for calculating cost coverage ratios for each mode. These charts are reproduced in Annex II to this review. The two approaches appear to be presented as upper and lower bounds for external congestion costs. The use of delay cost as a measure for external congestion costs is inconsistent with STICITE's explanation that delay cost includes both internal and external portions.

Taking into account all approaches, there is a range of treatments of congestion costs, with possible interpretations varying from all delay costs being external to all congestion costs being internal. Due to the absence of a single definition in the Handbook, it is relevant to look into other sources, in particular previous Handbooks, which contain more in-depth conceptual analysis.

The following table presents a number of methods of determining the external portion of delay costs from congestion, assessing the respective parameters of each:

External cost part	**1. Delay costs**	**2. Sum of marginal costs**	**3. Sum of marginal costs above optimum point**	**4. Deadweight loss**	**5. None (all internal)**
Concept for external cost part	All delay costs are counted as external	Aggregated marginal costs of all additional vehicles above free-flow state	Aggregated marginal costs of all additional vehicles above optimum point	Excess demand above optimum marginal cost point	Delay costs only suffered by parties inside system
Perspective	Individual	Individual	Individual	Individual	System

Where raised	STICITE Handbook / Study Summary	CE Delft 2011 update study	STICITE Handbook / our analysis	STICITE Handbook	e.g. Baum (2008)
Approximate magnitude	100% of delay costs	>50% of total delay costs	<33% of total delay costs	17% of total delay costs	Zero
Relevance	Total cost to society	Measure of total effect on system of marginal vehicles	Measure of total effect on system of marginal vehicles above the optimum	Measure of economic/ social inefficiency / welfare loss	View from the system perspective

Table 9: Different concepts for determining external portion of congestion costs

To illustrate conceptually, the cost curve graph from the Handbook (p88 & 217) is reproduced below, with areas indicated that represent methods 1 to 4 for calculating (non-zero) delay cost. It is apparent that the graph is not to scale, since the magnitude of the deadweight loss area (method 4) appears to be more than half the total delay costs (method 1), whereas in the STICITE results deadweight loss is 17% of the value of delay costs.

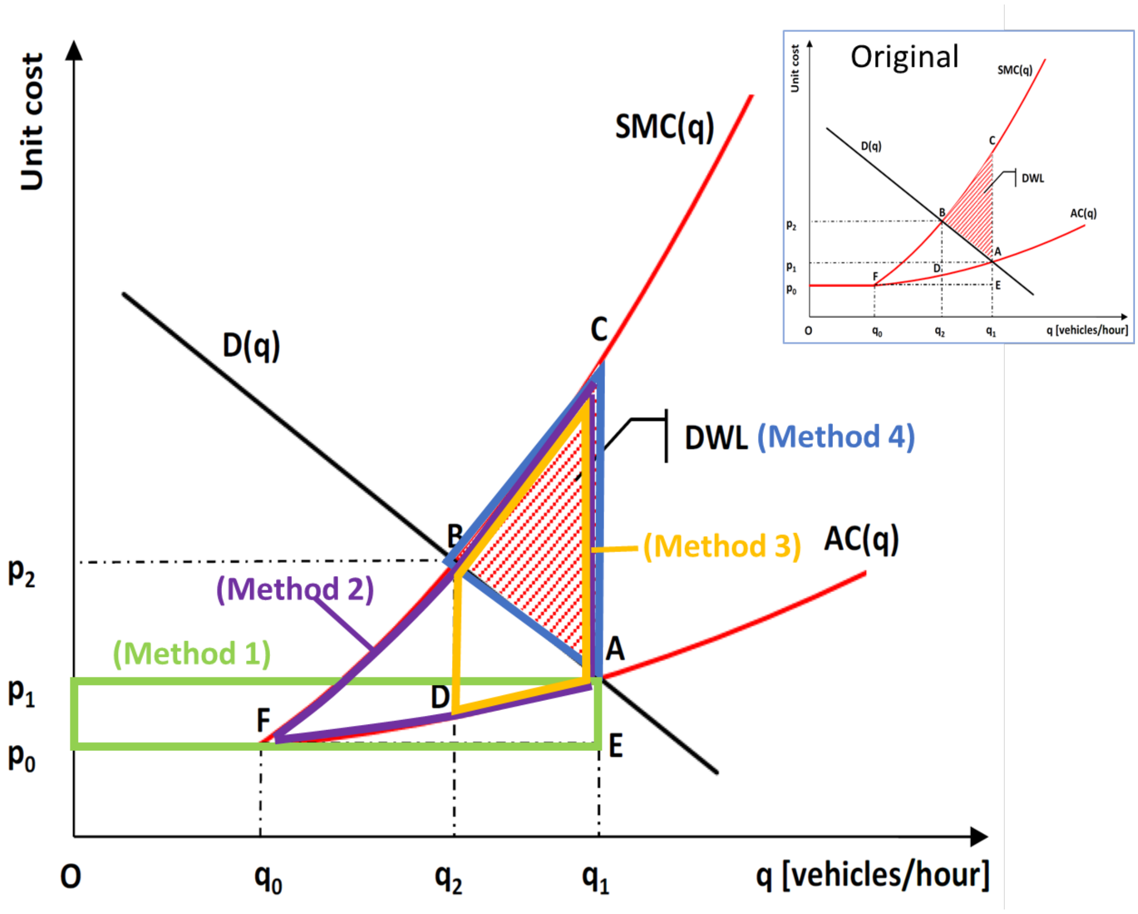


Figure 1: Road congestion chart from STICITE study showing methods for calculating congestion costs

<u>Method 1</u> is the total delay cost, representing the value of the total additional travel time compared to the theoretical free-flow situation. As stated in the STICITE Handbook, it includes both internal and external parts. It is therefore not consistent to use this value to represent external cost (as is for example done in charts on p49 of the Study Summary). Using total delay

cost is also inconsistent with the statement on p26 of the Handbook, *"own costs (e.g. additional travel time or fuel costs) are private costs and hence are not considered when estimating external congestion costs"*. The 2011 update study defined delay cost in comparison to 60% of the free-flow speed, based on the "users' expectation approach", referring to OECD research. The current Handbook has not persisted with this alternative approach and calculates delay cost compared to the free-flow situation.

Method 2 is described in the 2011 update study, calculated by *"summing up the marginal external cost-contributions of the individual road users"*. By definition this is significantly greater than the deadweight loss but less than the delay cost, since it represents the part of the delay costs (green box) represented by the area above the AC curve above. Figures in the 2011 handbook indicate that it is likely to be at least approximately half the total delay cost (although that estimate may be confounded by that paper's calculation of delay cost compared against 60% free flow speed). From the shape of typical cost and demand curves (see chart above), an upper limit appears likely to be approximately ⅔ of the delay cost. It represents the total additional travel cost generated by all marginal vehicles entering the traffic and is the equivalent method to that used for calculating other external cost categories. This could be termed "gross external congestion cost".

Method 3 is a variation of method 2, whereby only the marginal costs above the optimum marginal cost point, described in the Handbook as the "economically optimal solution" are counted as external. It reflects the comments in the footnote on p97 of the Handbook *"…the marginal congestion cost can be calculated for a traffic situation, beyond the economically optimal solution"*.

Method 4 (deadweight loss) is described as a measure of external congestion costs in the Handbook (p89): *"the external cost of congestion is given by the demand in excess with respect to q2 and the triangle ABC is the so-called 'deadweight loss' ."* (see chart above). Deadweight loss is a standard economic tool to calculate the net welfare loss due to taxes or system inefficiencies, in this case marginal costs of congestion. According to the 2011 update study, it *"…is identical to the additional social welfare all users competing for a scarce road capacity could gain, in case everyone considers her/his impact on other road users when taking travel decisions."* Deadweight loss is used in the STICITE study documents as the measure of external congestion costs when comparing the costs to revenues and calculating cost coverage ratios.

Method 5, which asserts that external congestion costs are zero, is not consistent with the individual perspective and is therefore cannot be considered a valid concept for determining external costs. However, it may have relevance for one type of congestion, that where congestion is known and anticipated by transport users. According to the STICITE Study Summary p42, *"…external costs of transport are generally not borne by the transport user and hence not taken into account when they make a transport decision"*. In the case of anticipated congestion, external costs are both borne by the user and taken into account in their decision making. The decisions made by transport users entering congested traffic under these predicted circumstances are fully informed about the delay impacts. By making those informed decisions they are implicitly accepting the consequent costs. Whether this implies that the costs are internalised depends on the interpretation of "taken into account". It is not possible to reach a definitive conclusion on this point. One possible interpretation is that external costs in predictable congestion situations are zero.

From the above descriptions there are cases for accepting methods 2, 3 or 4 as the external cost, with method 5 also having relevance. Method 2 represents the total external costs imposed upon the affected transport system participants by those entering the system. Methods 3 and 4 take into account the fact that even with congestion there is an optimum flow that is above the free-flow situation (and that the impact of ideal marginal social cost pricing -MSCP- would be to bring the flow to the optimum point).

Congestion is a special case regarding external costs, because for all other cost categories (except habitat) the situation can legitimately be compared to the case of zero transport activity, which leads to zero external costs. However, the action of reducing traffic both reduces the economic cost of congestion whilst reducing the overall level of transport activity, and therefore its economic and social benefits. Therefore the zero activity situation is not the correct counterfactual for congestion costs, nor is the free-flow situation. There is a theoretical optimum balance between these two opposing dynamics. In the concepts discussed above, this economic optimum is implied by the definition of the deadweight loss, which is equal to "*…the additional social welfare all users competing for a scarce road capacity could gain…*" That is, compared to the given congestion situation, the maximum welfare gain that can be achieved is the deadweight loss. It therefore appears to be consistent to use the deadweight loss as the external cost. The other methods are each valid as a measure of cost, but are not of practical relevance since their counterfactual is not applicable.

A further issue related to the above concepts considers efficient use of infrastructure. Outside of congested times of day (when the infrastructure is over-utilised) there are times of under-utilisation. The congested times, if not occupying an excessive portion of the day, could be considered as a price to be paid for greater efficiency of infrastructure use at uncongested times. A logical extension of the concept of MSCP, with the objective to maximise efficiency, is to set a wider gradient of pricing at different times, including a negative charge at uncongested times. The net intended effect would be to smooth out the peaks in traffic flow, reduce congestion, increase infrastructure utilisation and incentivise economically/socially beneficial road use. Whether such a scheme would meet the objectives overall would need to be investigated according to the practical details.

A relevant question is the extent to which congestion costs are borne by persons/groups outside the transport system. An impact can be inferred to business and social connections, whose own time or productivity is affected by the late arrival of the transport user. It could be argued that this is fully priced in by the user, and that any costs due to their lateness are borne by them through actions taken by their counterparties. In our further analysis of congestion, we assume that the external costs are "mainly" borne by the users inside the system.

The Handbook additionally introduces the differentiation between costs borne and costs generated, applying these to both delay costs and deadweight loss. Whilst the concept of costs generated being the external costs is coherent, an explanation of how each are calculated is not provided.

The methodology for calculating the delay cost and deadweight loss figures reported in the study is reasonable and consistent. The specific calculations are not publicly available for review, thereby preventing detailed scrutiny of the data and results.

<u>Non-road modes</u>

The STICITE Handbook addresses congestion in non-road modes, explaining the concept of congestion and scarcity costs. It devotes a number of pages to the methodology and calculation of these costs, but the available research is much less well developed than for road.

'Congestion cost' in scheduled transport services refers to the situation when one scheduled service delays another. This is the equivalent concept to congestion in road transport, since it is the presence of vehicles using the infrastructure that impedes other vehicles from travelling at the scheduled pace.

A 'scarcity cost' arises where the presence of a scheduled service prevents another scheduled service from operating. The Handbook states that the scarcity cost is the opportunity cost to service providers for the non-availability of the desired service times. The Handbook does not explore this further, quoting the large amount of information and complex elaborations necessary to generate estimates.

Another way of considering scarcity cost is through its consequences. Scarce supply, assuming no change in demand, normally leads to higher prices. This could be considered as internalisation of the scarcity cost for those who pay the higher prices. If price peaks are controlled, as may be the case in certain scheduled services, the consequence is overcrowding, which leads to discomfort, and could also be interpreted as an internal cost, although difficult to quantify financially. In either case, those discouraged from travelling would represent lost economic or social output, which is a cost to society. The Handbook addresses some of these issues and states that further work on this "requires due consideration". It would appear to be a candidate for a further study (see Annex X). The need for additional data on congestion and scarcity for non-road transport modes is also acknowledged in the STICITE Handbook (Chapter 11.4).

STICITE appears to have used a valid methodology for calculating congestion costs in rail freight from the reactionary delays of trains. It does not make an equivalent calculation for passenger rail. Delay costs for air transport are based on data on actual delays. For waterborne transport, scarcity costs at specific inland ports were calculated. It assumes congestion costs for maritime to be negligible.

This analysis of non-road modes is subject to high levels of uncertainty in interpretation and evaluation, which is acknowledged by the authors. Valid comparison to the methodology used for road transport does not appear to be possible with currently available data and analysis. Additional analysis is shown in Annex IV.

4.3.2 Inputs

The value of time data derives from reasonable sources and can be considered to be valid for this input parameter.

No detail is provided on the traffic flow data and how they are processed into values for congestion cost. A full scrutiny of the methodology, calculations and results is therefore not possible. In particular, the precise method for gathering congestion data and scaling this up to European level is unclear and subject to high uncertainty (on the up and down sides).

<u>Non-road modes</u>

Within the context of the much lower maturity of research for other modes compared to road, and the inherent uncertainties, the data quoted on delay costs in rail and aviation and scarcity costs in inland waterways appear to be appropriately sourced.

4.3.3 Congestion cost results

Subject to the uncertainties identified above, STICITE appears to have calculated both delay cost and deadweight loss for road vehicles in a robust fashion. The values reported for deadweight loss is approximately 17% of delay cost. For cars, the average external congestion cost calculated in this way is reported as €0.45/pkm.

Marginal congestion costs

STICITE presents figures for marginal congestion costs for a number of traffic situations in urban and non-urban areas. To calculate these it applies the difference between the private and marginal cost curves (as in the chart above). This is a legitimate measure of individual marginal cost, but it is not consistent with the deadweight loss approach to calculating external congestion costs. Integrating (summing) the marginal congestion costs across all traffic situation should equal the total external congestion costs. However, as indicated in the table above, integrated marginal costs are approximately three to four times the deadweight loss. The discrepancy, as indicated in Section 4.3.1 above, is that the deadweight loss takes into account the opposing dynamics of economic losses due to congestion and economic benefits of traffic. Marginal costs in isolation do not take this into account.

Whilst the STICITE figures for marginal congestion cost are valid, it is not consistent to use them when determining internalisation options and calculating marginal cost coverage ratios.

Non-road modes

Annex III includes a summary of the STICITE findings on congestion costs in non-road modes and some additional analysis.

Specifically for rail, Christidis and Brons (2016) quotes €0.43/1000tkm for average delay cost for the interurban rail freight network. An equivalent figure for the HGVs on the road can be calculated as €2.21/1000tkm, also for delay cost from STICITE. Comparing the figures, congestion costs for rail freight are approximately 20% those for road freight. A first approximation could apply this same fraction to passenger rail compared to passenger cars, but such an estimate is subject to high uncertainty.

A further orientation can be generated using example data from the UK. A report by Which? consumer magazine (2017) found that in the year to March 2017, 3.6m passenger hours were lost to trains delayed by more than 29 minutes. Using the STICITE data on cost per hour lost and total rail performance data, the average rail delay cost is between €0.35/pkm (personal travel) and €0.92/pkm (business travel). This tends to overestimate the costs attributable to congestion, since not all such delays are caused by congestion (e.g. breakdowns, lack of drivers, industrial action). Conversely it tends to underestimate the total delay cost, since delays under 30 minutes were not counted. These figures compare to average delay cost of passenger cars of €4.2/pkm.

Apart from rail, STICITE quotes non-road congestion costs only for inland waterways. It reports scarcity costs at specific inland ports in Germany of between €0.38 and €1.25 / TEU-km (twenty foot equivalent unit) are quoted. This converts to about €40/1000t-km assuming full capacity of transport units. This is not directly comparable to the significantly lower estimates for HGVs and rail referred to above.

The interpretation of these figures is difficult, and comparability cannot be assured. For example, as argued above, for road vehicles the external congestion cost is about 17% of the delay costs. It is not clear whether delay cost should be interpreted as the external cost for rail or if a different one would be more relevant. In theory the concept of deadweight loss can also be applied to rail, implying that the external rail congestion cost is a fraction of the above figure. Further, scarcity cost is not calculated by STICITE due to complexity and lack of evidence.

These observations point to the high levels of uncertainty involved and the lack of good comparability between road and rail in particular. This is acknowledged in the STICITE study, in which congestion costs are omitted from the direct modal comparisons of external costs. However, congestion costs of road (deadweight loss) are used in the STICITE charts of external plus infrastructure costs against revenues and in the cost coverage ratios. To be fully comparable, estimates of congestion cost of non-road modes should be available and included.

Whilst external congestion costs are tangible, there is some inconsistency in how they are presented and calculated. In particular, this can affect conclusions drawn from the comparison of cost coverage ratios between modes. However, the value of congestion cost applied to cost coverage ratios for road (deadweight loss) is low and the impact is not significant.

In our sensitivity analysis later in this review, we do not apply a specific figure for congestion costs of rail due to the high levels of uncertainty. In the sensitivity analysis (Chapter 7) we do separately discuss the potential impact of rail congestion/scarcity costs.

4.3.4 Conclusions regarding internalisation

According to the individual user perspective applied in this review, congestion costs are imposed by individual users on other users in traffic. This gives rise to the estimate for congestion costs discussed above. It implies that the appropriate perspective for internalisation is also the individual user one. From this perspective, external congestion costs are mainly being imposed upon other users of the system. As indicated above, the costs imposed on parties outside the system are (close to) zero.

The STICITE Handbook (p89) and State of Play (p18) state that deadweight loss *"is regarded as a proper basis for transport pricing"*. On p102 the Handbook explains that this approach involves congestion pricing according to the social marginal cost (MSCP). If MSCP is applied, the deadweight loss represents the *"additional social welfare all users competing for a scarce road capacity could gain, in case everyone considers her/his impact on other road users when taking travel decisions"* (2011 update study). This welfare gain, equal to the deadweight loss, would be the impact of MSCP.

Perfect MSCP would charge the marginal costs in real time, thereby bringing the traffic flow to the optimum point and eliminating the welfare loss as described above. Since the optimum point still represents a congested situation, congestion costs would be reduced but not eliminated (this is a feature of MSCP). The main effect of the congestion pricing would be a financial cost for the road users, equal to the aggregated marginal costs, and the increase in welfare equal to the deadweight loss due to reduced congestion. Using the estimated values from the analysis in section 4.3.1 above, the pricing charges would exceed the welfare gain by a factor of 3 to 4. The implications of the pricing depend on how the revenue is used:

- Revenue redistributed between road users: if technically feasible (see below), a dynamic redistribution of the marginal costs would represent a fully consistent application of MSCP. It would enable the optimum contribution to the behavioural and fairness objectives of internalisation. This corresponds to the strict interpretation of the polluter pays principle described in Section 2.3 above, if the parties generating and those bearing the costs can be accurately identified and payment executed.

- Revenue directed to government: as indicated above, the costs external to the system are a small proportion of the total. In this scenario, the "polluter pays" principle is observed and a contribution is made to achieving the fairness objective. If the funds were earmarked to improving infrastructure it could contribute to the objective of reducing the external cost, but without direct compensation between users generating and bearing the costs.

The STICITE analysis sets out very clear arguments regarding the difficulty of applying MSCP to congestion in practice. In particular, the State of Play report p30 refers to the need for spatially differentiated and dynamic "minute to minute" cost estimates for an ideal system. It also questions whether users could manage highly differentiated charges that are continuously fluctuating, and highlights the challenges of identifying technical solutions. On this point, on p194 it states *"There are also doubts that such differentiation would be technically feasible in the foreseeable future."* It would also mean absence of predictability for road users, preventing informed decision making.

STICITE State of Play p30 further states *"…a certain degree of simplification (i.e. averaging of marginal cost figures) is inevitable when implementing MSCP."* Due to the difficulties, congestion schemes in practice very roughly attempt to approximate MSCP by charging at times when congestion is expected. They have a significant element of average cost pricing, for example if they apply across large city areas and defined periods, which inevitably include uncongested zones and times of the day. This could be termed "quasi-average pricing". STICITE State of Play p31 refers to the disadvantage of average cost pricing for congestion, that the price incentives *"…do not perfectly reflect the costs of transport decisions of individuals"*. It further states, *"…transport users will not take the actual social cost into account when making a transport decision, resulting in 'sub-optimal' decisions."*

The impact of charging is also dependent on the demand curve. If the demand curve is highly inelastic, which as stated in Section 3.4 above can be the case in transport, the deadweight loss of congestion, and therefore the expected welfare gain from applying (social marginal cost) pricing, could be relatively small.

Anderson and Mohring (1997) modelled the effects of marginal congestion pricing in Minnesota-St Paul, USA. They concluded that most users would suffer a net loss (charges minus time gains) from such a system, the exception being those on highest incomes and those shifted to mass transit (for example buses). This indicates there can be a question of equity in deploying such schemes. They also discuss redistribution of the charging revenues and the difficulty of devising a scheme that ensures the lower income road users are compensated whilst maintaining the incentive to reduce road use. Whilst revenues can be used to improve mass transit options, this may still leave some of those on low incomes, for whom mass transit is not a convenient option, disadvantaged by the pricing.

The observations above lead to implications for the objectives of internalisation. The risk of "sub-optimal decisions", resulting from the application of congestion pricing in practice, implies that there are barriers to meeting objective 1 (influencing behaviour and reduction of the external costs).

The objective 3 (fairness) can be seen both from a system and an individual point of view. The costs of congestion are mainly borne by actors within the system. As indicated in Section 2.3 above, a strict interpretation of the polluter pays principle would require the identification of the parties generating and those bearing the external costs, to assess whether direct compensation between these is possible. In the case of congestion, revenue from charging would preferentially thus be redirected to users inside the system to meet the objectives fully. Individuals would compensate each other for the marginal delays they generate. In the practical case of quasi-average cost pricing (defined above), both those users responsible for congestion and those not responsible would be charged (and compensated). These arguments also link to objective 2 (generating revenues), whereby earmarking of revenues to be invested inside the system could work to reduce congestion costs and/or compensate those affected.

The relevance of internalisation can also be considered in the context of identified attributes of congestion. Congestion is often predictable, for example the traffic entering cities during rush hour. In these situations, a proportion of the road users are aware in advance of the likely congestion, and anticipate this risk when deciding to enter the system. They still bear the costs, but have chosen to do so with full knowledge of the consequences for their time. One interpretation is that, by making this decision, they have accounted for and internalised the costs generated and imposed on them by other users entering the system. In this case it is appropriate to consider the implications of the system perspective. However, the deadweight loss is also a relevant measure of external congestion cost in this case, since the potential overall welfare gain from all users considering their impact on other users still exists.

Final assessment of internalisation

There are significant difficulties and limitations in applying internalisation of congestion costs in practice in a way that meets the stated objectives of internalisation.

The complex discussions above indicate that additional theoretical and practical investigations of congestion and pricing would be beneficial. Some suggestions are made in Annex X.

4.4 Pollution costs

Air pollution represents a significant cost component in the STICITE study, making up 14% of the 2016 total external costs for the EU28. The most analysed aspect of air pollution costs is health impacts which is understandable given the increase in awareness over recent years of the air quality issues that exist in EU cities, and the improved knowledge of the health problems these can cause. The air pollution analysis has been assessed in terms of its robustness and reliability of the resulting figures. Below are the key findings from this assessment.

4.4.1 Methodology:

The overall methodology described by STICITE, in particular the Impact Pathway Approach used to convert an initial emission source into a cost value, based on the method used in NEEDS (2008), is appropriate. The key consideration when assessing the robustness of results is the availability, quality and accuracy of the inputs. The steps in the Impact Pathway Approach, as applied in STICITE, are explained in the Handbook Annex. The specific calculations are not available and it is therefore it is not feasible to undertake a fully detailed interrogation of each stage. The majority of input sources underlying the air pollution costs are reputable and consistent with what one would expect to be used in such a study.

The Handbook refers to epidemiological research, which underpins the NEEDS study. The need for epidemiology studies to be supported by additional lines of evidence (toxicology, controlled exposure studies) due to potential confounding factors have been well documented (HEI 2018, CONCAWE 2017). NEEDS refers to toxicology studies in its analysis of impact of particulate matter but not of other components. This indicates a material degree of uncertainty in the overall specific figures.

The method used is consistent with other well-known studies such as the Ricardo-AEA 2014 Update of the Handbook on External Costs of Transport (commissioned by the European Commission), the 2013 CE Delft report on External and Infrastructure Costs of HGVs in the EU28 (commissioned by Transport & Environment), and the CE Delft Environmental Prices Handbook (2018). In addition, the NEEDS model calculations are updated to better reflect the current situation and knowledge, and ultimately improve accuracy. This included updating assumptions around concentration response functions to reflect the more recent (2013) WHO study, and updating population size and structure using reputable Eurostat data. These steps help improve the air pollution cost input quality, but the lack of availability of the calculations and resultant uncertainty should be considered.

4.4.2 Inputs:

The main data source for road transport emissions is COPERT v5 which is an EU standard vehicle emissions calculator. It is an internationally recognised research tool, used by national governments and European Union agencies, to calculate emissions to a high level of spatial accuracy. The study applied the standard country-specific setting of COPERT for each member state, which contains an inherent set of assumptions around aspects such as speed profiles and vehicle stock composition. These assumptions and data are considered reliable and as such the inputs taken by STICITE from the model appear to be robust.

Much of the data necessary to understand the derivation of the results is presented in the STICITE Handbook Annex. The unavailability of all the specific calculations in each step of the Impact Pathway Approach prevents a comprehensive scrutiny of the figures.

The key transport data source is Eurostat which is the official European Statistical Office. Eurostat provides data on traffic volumes on European roads, enabling calculation of spatial emissions data. As an official EU source, inputs taken from Eurostat are considered reliable.

The maritime and aviation transport statistics are based on survey results for a selected number of ports and airports (34 and 33 respectively). This creates uncertainty in the inputs, as there may be variation in the quality of data collection across different facilities, and those included in the sample are not guaranteed to be representative. Factors representing emissions per craft, applied to these transport statistics to calculate total emissions, are from more reliable sources however, such as the TREMOD database.

An additional key input parameter is the value of life years lost (VOLY), which is derived from meta-analysis. As indicated in Annex III, there is a significant level of uncertainty in the applied figure of €70,000/year. This general point is acknowledged in the Handbook, but the extent of the uncertainty (both up and down side) may be greater than inferred.

4.4.3 Air pollution cost results

Air pollution costs associated with aviation and maritime are based on a selection of facilities. This includes the largest (air)port in each country and the next 5 largest across the EU that are not already included amongst the largest per country. This method ensures the biggest individual emitters are included but results in the emissions from a significant number of airports being omitted. Ultimately this will have a large impact on the total aviation and maritime air pollution cost figures, but when the average costs are calculated (e.g. c/pkm), the effect is minimised.

The marginal air pollution costs for road transport show trends that would be expected and as such seem reasonable. For example, the costs per pkm reduce as Euro emission standards improve, and the costs are higher in metropolitan areas than rural areas for an equivalent vehicle. Similarly, the general cost trends seen in the marginal cost tables for rail, maritime and aviation are in line with what one would expect. The results are subject to the uncertainties identified, in particular the value of life year (VOLY).

4.4.4 Conclusions regarding internalisation

The Handbook p51 states *"For air pollution costs, the marginal costs are virtually the same as the average costs."* quoting the linearity of dose-response relationships. There are however spatial and human exposure parameters that imply differences between average and marginal pollution costs. For individual vehicles, it would be consistent to state that average and marginal pollution costs are similar. For gasoline and diesel vehicles, fuel duties are generally approximately proportional to exhaust emissions. Internalisation by fuel duties could therefore be considered as a form of approximate MSCP.

However, vehicles have different emissions characteristics. Therefore, whilst the external pollution costs of newer vehicles (e.g. certified to Euro 6 emissions standards) may be low enough to be internalised by fuel duties, those of older vehicles (e.g. Euro 3) may not be. MSCP cannot therefore be assumed to be valid for all pollutant emissions.

If external pollution costs still in existence after such internalisation are still considered to be of concern for policy makers, this suggests that the further reduction / elimination of negative externalities would require more than just pricing instruments. In practice, this objective is targeted directly through regulations, which are identified for all relevant modes in Section 6 below. These act in addition to any internalisation. The efficacy of using pollution regulation at a European level, either instead of or in addition to taxes and charges, is discussed in the Study Summary p78 referring to rail, but could be equally applicable to all other relevant modes.

The internalisation through fuel duties can contribute to achievement of Objective 1, to reduce the external costs. This is enhanced by regulation and other direct measures.

Those bearing the external costs of pollution are those people present in the dispersion zone, in particular urban areas. Full consistency however would require the revenues to be targeted towards those on whom the pollution costs are imposed. In practice fuel duty revenues are directed towards general revenues could be considered to be compensating society in general. Part of the general revenues may however be used to cover relevant costs, such as health care. According to this discussion, internalisation through fuel duties contributes to meeting the fairness objective of internalisation (objective 3).

It can also be noted that in a number of countries, registration and/or annual vehicle taxes are modulated according to the pollutant emissions level. This is another form of internalisation of the external pollution costs.

Final assessment of internalisation

In the case of pollution, the existing pricing mechanism, which internalises marginal external pollution costs by fuel duties, can contribute to the behavioural and fairness objectives of internalisation. It is an approximate form of MSCP for individual vehicles. This is valid if the revenues are sufficient to cover the marginal costs of the vehicle in question, dependent on its emission characteristics. This is more likely to be the case for newer vehicles certified to the most recent pollutant emissions standards.

4.5 Tank-to-wheel (TtW) climate costs

TtW climate costs ("climate costs" in STICITE) are a significant external cost component and account for 14% of the 2016 total external costs calculated in the STICITE study. The calculations consider CO_2, N_2O and CH_4, and aviation-specific emissions such as water vapour, sulphate and soot aerosols. The climate cost analysis has been assessed in terms of its robustness and reliability of the resulting figures. Summarised below are the key findings from this assessment.

4.5.1 Methodology

The overall high-level methodology is sensible and appropriate, which means the key consideration is therefore the quality of the inputs. One aspect of the approach which has a significant impact on the results is the decision to base the climate analysis on avoidance costs rather than damage costs. There is no standard approach to climate costs in studies of this nature, and indeed some papers use damage costs which result in higher external costs. It should be noted however that the way in which the avoidance cost approach is applied in the STICITE study is sensible as it is based on the targets set in the Paris Agreement (1.5-2-degree temperature rise, equivalent to 450 ppm CO_2 in the atmosphere).

4.5.2 Inputs

The key source of uncertainty in the climate analysis derives from the inputs related to the external cost per tonne of carbon dioxide equivalent (tCO_2e). The climate change avoidance costs used in the study are based on analysis of relevant literature which includes reports from reputable institutions such as the Department for Energy & Climate Change (DECC) and International Energy Agency (IEA). However, there is a significant spread in cost values across the literature. For example, the projected central case cost per tCO_2e for 2025 ranges from ca. 50 to 150 €/tCO_2e, based on literature from IEA and Kuik et al respectively. The literature-based approach to deriving cost values is sensible and the range of values identified suggests that some level of uncertainty in these assumptions is unavoidable. Nonetheless, the uncertainty these inputs introduce should be considered when viewing external cost results.

Overall the emissions and transport data sources are of high quality. As per the air pollution analysis, one of the main emissions sources is COPERT v5 which is highly reputable. The study applied the standard country-specific setting of COPERT for each member state which contains an inherent set of assumptions around aspects such as speed profiles and vehicle stock composition. Another key data source used is TREMOD – the German Government Transport Emission Model. The emission factors used in TREMOD are taken from a number of European collaborations between leading groups and are considered a reliable source of data.

4.5.3 Climate cost results

TtW climate costs associated with aviation and maritime are based on a selection of facilities. This includes the largest (air)port in each country and the next 5 largest across the EU that are not already included. This method ensures the biggest individual emitters are included but results in the emissions from a significant number of airports being omitted. Ultimately this will have a large impact on the total aviation and maritime climate cost figures, but when the average costs are calculated (e.g. c/pkm) the effect is minimised.

The detailed marginal TtW climate cost breakdowns in the STICITE study show the trends one would expect for each transport mode. The accuracy and robustness of the absolute values is dependent on the input quality. As discussed above, there is significant uncertainty around the cost per tCO_2e assumptions due to the nature of these inputs, but the other input sources are reliable and of high quality.

4.5.4 Conclusions regarding internalisation

In the case of TtW climate costs, marginal and average costs are almost identical (Handbook p67). This occurs because each unit of greenhouse gas emitted has the same impact as any other, regardless of emission location, timing and level of local emissions. All emissions act to increase the concentration of greenhouse gases in the global atmosphere.

There is an almost exact correlation between gasoline/diesel consumption and their prevailing duties, and average/marginal TtW climate emissions from vehicles. Fuel duties are equivalent to €283/tCO2 on average (STICITE Annex D spreadsheet), compared to the external TtW climate cost applied by STICITE of €100/tCO2. The marginal social costs of TtW climate emissions are therefore internalised by fuel duties. MSCP applies fully for this category for road vehicles and diesel rail.

In this case, the parties bearing the external cost are the global population (though the impacts on some are likely to be different than others). Compensating those parties directly is not practicable. The closest practicably proxy is society, represented by governments. Therefore the fuel duties could be considered as compensating society in general for the external costs. The fairness objective 3 appears to be fulfilled by this existing internalisation. Since TtW climate costs are a global phenomenon, the directing of revenues from fuel duties to general budgets does in principle fairly compensate "society" for the costs.

Equivalent to the discussion for pollution costs above, policy makers are calling for reductions of the external TtW climate costs of transport over and above what is achieved by internalisation. To achieve objective 1 of internalisation and further reduce the external cost, additional measures such as regulation may be necessary. This reflects policy decisions in the EU, where CO_2 standards are in place or planned for many vehicle categories, complemented by a number of agreements and voluntary measures in some modes.

<u>Final assessment of internalisation</u>

For TtW climate costs, marginal external pollution costs can be internalised by fuel duties, contributing in an optimal manner to the behavioural and fairness objectives of internalisation. It represents almost ideal MSCP, if the revenues are greater than the cost, which is the case for road transport across the EU and, for other surface modes, in some EU Member States. This conclusion applies equally to well-to-tank costs.

4.6 Well-to-tank climate costs

Well-to-tank (WtT) costs are a relatively small external cost component, accounting for 5% of the 2016 total external costs for the EU28. There is overlap in the assumptions used for the WtT analysis and that of TtW climate and air pollution costs. As such, some of the points made in this section mirror those the respective sections for these cost components. Below is a summary of the assessment of the WtT analysis robustness and reliability. It should be emphasised that well-to-tank costs are closely connected to TtW climate costs and the two elements should ideally be considered together, especially when comparing the impacts of different propulsion technologies.

4.6.1 Methodology

The overall STICITE methodology used to calculate the WtT costs is simple and appropriate. It is the same general approach as is taken for both air pollution and climate costs. The key consideration when determining the robustness of outputs is therefore the quality and accuracy of the inputs to the methodology.

4.6.2 Inputs

The main data sources for WtT emission factors are TREMOD, the JRC report: Wheel to Tank Report Version 4.a, and national electricity grid carbon intensity figures. The emission factors used in TREMOD are taken from a number of European collaborations between leading groups working on transport emissions and are therefore expected to be a reliable source of data.

There is more uncertainty associated with the other two sources. The JRC report is a very comprehensive analysis that covers the WtT emissions along hundreds of fuel production pathways. Gaining representative WtT emission factors from this requires a careful selection of pathways to accurately represent the country or region of study. The STICITE report does not explain how pathways were selected and as such it is not possible to assess the representativeness of the results. This introduces a degree of uncertainty around the robustness of the WtT analysis.

The source of the carbon intensity assumptions for grid electricity are not provided in the report, but discussion with the authors revealed they are taken from the latest update of EcoTransIT World. This is a well-known calculation tool and is considered reliable.

The cost factors for WtT are taken from the climate and air pollution cost analyses. As a result, the sources of uncertainty identified in these values will also impact the WtT outputs. These are explained in the relevant cost sections of this report. For air pollution the key uncertainty lies in the process used to convert an initial emission source into a cost value. The lack of transparency in these calculations makes it difficult to assess their robustness, however it is important to note that steps were taken to improve the accuracy of the cost values generated.

The uncertainty in the cost per tCO_2e assumptions used to evaluate climate costs arises because of the spread in values found in the study's literature review. For example, the projected central case cost per tCO_2e for 2025 ranges from ca. 50 to 150 €/tCO_2e, giving an order of magnitude range. The literature review approach is sensible, but its results suggest that a high level of uncertainty in these inputs is unavoidable.

4.6.3 Well-to-tank cost outputs:

As is seen in the air pollution and TtW climate cost analyses, the WtT costs associated with aviation and maritime are based on a selection of facilities. This includes the largest (air)port in each country and the next 5 largest across the EU that are not already included. This method ensures the biggest individual emitters are included but results in the emissions from a significant number of airports being omitted. Ultimately this will have a large impact on the total aviation and maritime climate cost figures, but when the average costs are calculated (e.g. c/pkm) the effect is minimised.

The detailed marginal WtT cost breakdowns in the STICITE study generally show the trends one would expect for each transport mode. There is a small number of results which are not in line with anticipated trends but have been validated through discussions with the report authors. For example, high-speed electric trains have lower WtT costs than other electric trains, which is unexpected given the high-power demands of travelling at very high speeds. The reason provided for this is that high-speed trains are generally operated in countries with a lower grid electricity carbon intensity (e.g. France and Belgium), whereas more standard electric trains are used in a wide range of countries including those with particularly carbon intensive grid electricity.

The accuracy and robustness of the absolute cost values is dependent on the input quality. As discussed above and in sections 3.3 and 3.4, there is significant uncertainty around the cost per tCO_2e and a degree of uncertainty around the air pollution cost assumptions, as well as the way in which WtT emission inputs have been extracted from the JRC report. These should be considered when viewing the WtT external costs produced in the STICITE study.

4.6.4 Conclusions regarding internalisation

The conclusions on internalisation of climate costs (Section 4.5.4 above) are equally relevant to the WtT element of climate costs. Well-to-tank climate costs are approximately 33% of tank-to-wheel climate costs. As indicated in the STICITE Annex D spreadsheet, fuel duties represent 213% of well-to-tank plus tank-to-wheel climate costs for gasoline and 149% for diesel.

In parallel, internalisation of WtT costs through other mechanisms should be considered. This specifically relates to the EU Emissions Trading System (ETS), an EU-wide scheme that sets a market price on greenhouse gas emissions for large emitters, including oil refiners. Emitters are required to present allowances for each tonne of CO_2 equivalent emitted.

The average ETS market price in 2016 was approximately €5.50 per tonne. This compares to the central estimate for CO2 avoidance costs used by STICITE of €100/tonne. In that year, 60% of ETS allowances were allocated for free. These figures result in a WtT internalisation in 2016 through the ETS price of about 2.2% of the external WtT cost and approximately 0.1% of total external costs reported by STICITE.

For 2030, the 2016 EU reference scenario generated for policies including the Renewable Energy Directive (European Commission 2016 – p275) indicate an ETS carbon price of between €27 and €42. Accounting for this as internalisation, between 27% and 42% of the projected WtT cost is internalised by carbon pricing in 2030 (assuming the central STICITE avoidance cost estimate and no free allowances).

For 2050, the same reference (p231) indicates an ETS carbon price of approximately €90, implying that the WtT climate costs (using current STICITE avoidance cost estimate) would be almost fully internalised through the ETS in that year. Other projections have indicated ETS prices in 2050 well above €100 (European Commission 2014 – p81).

It is also relevant to note that a possible outcome is the inclusion of all or part of the transport sector in the ETS, as this has been suggested, for example, in the European Commission communication on the European Green Deal (2019). If this were to be adopted, it could potentially mean full internalisation of the climate costs of transport, depending on the extent of coverage of transport emissions and the price per tonne CO_2e.

Final assessment of internalisation

As for TtW climate costs, WtT costs can be internalised through fuel duties, applying MSCP and contributing to the behavioural and fairness objectives of internalisation.

4.7 Noise costs

Noise costs are a relatively small external cost component, accounting for just 7% of the 2016 total external costs for the EU28. The noise cost analysis has been assessed in terms of its robustness and the reliability of the outputs. Summarised below are the key findings from this assessment.

4.7.1 Methodology

The noise cost methodology requires key decisions around the scope of noise impacts to be considered. In the STICITE study, the noise related health impacts included are based on reports produced by reputable organisations including the WHO and the UK Government Department for Environment, Food and Rural Affairs (DEFRA). However, it should be noted that certain health impacts were not included, as the existing evidence was considered insufficient to reliably attach costs. This factor in isolation would result in an underestimation of the total external noise costs. The assumptions made on noise nuisance threshold do somewhat balance this and are explained in more detail later in this section.

Health impacts of noise captured in this study include ischaemic heart disease, stroke, dementia, hypertension and annoyance. The quality of the data supporting the link between noise and these health impacts varies. The Handbook Annex E presents WHO classifications of the evidence base for some of the health end points of noise. For some of these, including stroke, diabetes and noise, it is classified as "moderate quality", with additional statements that *"further research is likely to have an important impact on our confidence in the estimate…"*. For ischaemic heart disease it is classified as high quality.

The road and rail marginal noise costs have been calculated based on marginal cost estimates in CE/INFRAS/ISI (2011) and INFRAS/IWW (2004), but updated based on changes in the average costs associated with different modes and vehicle types between these two older studies and this STICITE report. The output quality is therefore dependent on the robustness of the methods used in the two referenced studies. The method used to update the marginal costs is sensible and will improve the suitability of cost outputs.

Some additional uncertainties can be identified regarding the costs for PTWs. The weighting factors for mopeds (9.8) and motorcycles (13.2) derive from an "expert guess" in a 2004 study, for which there is no specific reference or derivation. This increases the uncertainty of the methodology for this vehicle type.

4.7.2 Inputs

A key assumption for determining external noise costs is the noise nuisance threshold. To some extent, as is mentioned in the Handbook, the value used for this threshold is quite arbitrary. The study uses a relatively low threshold which ensures the results do not underpredict costs. This approach is sensible and is likely to slightly balance the fact that certain health impacts were not considered due to a lack of reliable evidence. The noise nuisance assumption of 50 dB was informed by review of reports from reliable bodies such as DEFRA and WHO. The conclusion was that noise annoyance can occur below 50 dB, but that there is a lack of robust evidence on dose-effect relationships at these volumes, hence this level was set as the threshold. This assumption is considered sensible but introduces a level of uncertainty in the results.

Input data used to determine the number of people exposed to road noise is based on the European Environment Agency (EEA) Noise Map. This appears to have relatively low resolution and is therefore a key source of uncertainty in the final results. However, no other database with Europe wide coverage is available to use and hence the source is considered to be the appropriate one. The low resolution of the noise map and its incomplete nature presents a significant barrier to accurately estimating noise costs. Given the importance of this source, the method used to estimate the missing data is very important to the quality of the final results. Missing data have been estimated by correcting upwards the number of people affected by noise by the ratio of the number of urban residents known to live in the country to the number of urban residents captured by the noise map. This is a sensible method given the data available and is an improvement over an uncorrected figure.

Annoyance cost inputs are taken from Bristow et al 2015. This is the most recent and up to date meta-analysis of noise cost studies. As a result, this is considered an appropriate and sensible data source, however it is clear that there is significant variation in the numbers between sources. This introduces a further degree of uncertainty which should be considered when viewing results.

Health cost inputs are taken from DEFRA sources and show agreement with the numbers presented by the WHO. These data sources are up to date and considered reliable.

The STICITE Handbook (p85) indicates uncertainties in the data for motorcycle kilometres driven, deducing that a proportion of these may be misreported moped kilometres. This would cause the STICITE values to be an overestimate of the noise costs, if the ratio between the weighting factors is correct (which imply mopeds generate less noise than motorcycles). Conversely, mopeds are not explicitly included in the analysis, potentially implying an underestimate of the noise costs. The data are not sufficient to enable an accurate estimate of the magnitude and direction of these potential errors.

4.7.3 Noise cost outputs

The quality of the noise cost output values is dependent on the input data. As discussed above, the input data suffer from a lack of detailed coverage and uncertainties around some of the cost values applied. This creates inherent uncertainty in the results themselves. It should be noted though that several suggestions are given as to how future work could improve upon these results if further data collection and analysis is completed.

The noise costs generated in this version of the Handbook are higher than in previous versions of the Environmental Prices Handbook. However, the methodological changes that have led to this appear to be sensible and so the increase may infer an undervaluing of noise costs in previous work. The major change from the previous handbook is that the annoyance costs increase at higher noise levels which matches the approach used in countries such as Denmark, UK and Sweden. As annoyance costs are the majority of total noise costs this has a large impact on the total noise cost values.

Overall the cost trends for road and rail follow those that would be expected. Two sets of aviation cost results are presented, and there are discrepancies between the different sources and methods. The first method provides costs for a series of different aircraft types on a landing/take-off (LTO) basis, whereas the second approach provides lower and upper bound marginal costs, as well as an average cost for aviation. Excluding the highest cost for a specific aircraft type (B 747-400: 266 €/LTO), there is reasonable consistency in the range of marginal costs derived through the two methods (52-122 €/LTO vs. 74-154 €/LTO).

The net impact of the factors identified in the previous section due to motorcycle and moped data is uncertain but appears likely to be less than 10% of the total noise costs of motorcycles.

4.7.4 Conclusions regarding internalisation

As indicated in the Handbook (p82), marginal noise costs are strongly context-specific and differ from average costs. They are partially correlated with traffic volume. Similar to accident and congestion costs, this indicates that there are likely to be difficulties in devising MSCP systems that would efficiently reduce the costs and fairly apply internalisation. Differentiation of pricing would accurately have to take into account the noise levels of individual vehicles, user behaviour, timing of driving and spatial / proximity parameters. This could be approximated, but the complex set of drivers could render an accurate MSCP very difficult in practice, as acknowledged in general by STICITE (State of Play p 193), resulting in quasi-average pricing. For example, individual behaviour (excessive acceleration) is one major driver of peak noise levels, but charges that differentiate for this parameter and disincentivise it would appear to be very difficult to devise.

The partial correlation with traffic volume implies also a partial correlation to fuel consumption and therefore fuel duties. To the extent that this is the case, MSCP could be considered to apply but this would likely represent only a minority of the external noise costs.

Other measures, including regulation on vehicles and driver behaviour, may be necessary to achieve the objective of lower external costs. In practice, noise levels of new vehicles are controlled by EU regulation since 2016. Exhaust systems of motorcycles must be constructed in a way that does not easily permit removal of baffles, that prevent excessive noise under acceleration, according to international regulation (UNECE regulation 41) adopted by the EU.

The fairness objective of internalisation (objective 3) could be achieved if its effect were to compensate those bearing the costs or applied to reducing the effects of noise (for example through enhanced infrastructure). Again, the barriers to applying this in practice would likely be extensive.

Final assessment of internalisation

For noise costs, the behavioural and fairness objectives of internalisation can be met to a limited extent through pricing. Specifically, internalisation of the limited proportional element of the marginal costs could considered to be possible through proportional revenues such as fuel duties. There are significant barriers to achieving the objectives of internalisation of total external noise costs through pricing due to their highly situation-dependent nature.

4.8 Habitat costs

Habitat cost is the only external cost category considered to be a fixed cost in the STICITE study. This reflects its nature as a cost of the standing infrastructure.

4.8.1 Methodology

The analysis of habitat costs is less well-developed than the other cost categories. Unlike the other categories, the relevant STICITE chapter does not include a review of robustness.

Cost factors for habitat loss and habitat fragmentation are derived from a study on Switzerland (INFRAS, Ecoplan, 2018), then applied to the whole EU transport infrastructure. This raises questions about the representativeness of the data and the validity of scaling up to European level, since local characteristics are likely to be very different depending on country and region.

The available data and analysis are not sophisticated enough to address deeper issues such as the value of the alternative habitat structures created due to compartmentalisation by transport infrastructure. Whilst a material external cost of habitat loss appears likely, the methodology does not appear to be robust enough to enable the magnitude to be stated with any confidence.

Habitat damages other than loss and fragmentation (e.g. light emissions, invasive plants, visual impairment of landscape scenery) were not considered and may in aggregate have a material impact on the total habitat costs.

4.8.2 Inputs

From the available data it is unclear whether cost factors are a simple conversion from CHF to EUR or if further calculations and assumptions have been made.

No details are provided on how costs have been allocated to vehicle categories, except mentioning that “transport demand” and “average vehicle length” are used.

There appear to be transposition errors in the Handbook in the figures for habitat loss and fragmentation impact on the total costs for motorways and rail. This does not, however, have any impact on the total external costs.

4.8.3 Habitat cost outputs and conclusions

The figures reported in the Handbook for habitat loss for high-speed and for other railways are significantly different from each other, but this cannot be found in the original underlying study, and no further details are provided.

Due to the concerns above, the results for external cost of habitat loss cannot be considered as robust, although it is not possible to conclude whether they are too high or too low.

4.8.4 Conclusions regarding internalisation

The achievement of the objective of internalisation to reduce external costs is difficult in the case of habitat costs since any effects are potentially irreversible. Full reversal of the habitat loss would require both the removal of the infrastructure and regeneration of the habitat to its original state. Even if such actions were undertaken, the nature of the resulting habitat cannot be predicted.

The internalisation of external habitat costs may be achieved by vehicle taxes or fuel duties (Section 7.2.). As fixed external costs, the marginal habitat costs are zero, so this does not represent MSCP. It would not influence transport behaviour (internalisation objective 1) in a way that would reduce the external cost.

Revenues from internalisation of habitat costs, for example from infrastructure charges, if spent on infrastructure in a relevant manner (objective 2 of internalisation), could act to reduce the habitat costs.

If internalisation is achieved in this way, it appears to be consistent with fairness (objective 3), since the costs are paid by road users into general budgets, compensating society as a whole for the impacts.

Final assessment of internalisation

The fairness and infrastructure objectives of internalisation of habitat costs could be partially achieved by pricing, through fixed or variable revenues (such as vehicle or fuel taxes, access charges).

4.9 Robustness of results and sources of uncertainty

For each of the external cost categories we have identified three main types of uncertainty in the STICITE results:

- Uncertainty arising from methodology.
- Uncertainty arising from robustness of input data.
- Uncertainty arising due to absence of access to detailed data and calculations.

These are summarised in the following table for each external cost category.

Category	Methodology	Published input data	Access to data
Accident	Substantial change from the sensitivity analysis.	VSL – significant uncertainty.	No access to interaction data – significant unknowns.
Congestion	Delay cost methodology inconsistent. Deadweight loss methodology appropriate.	Value of time is from reasonable sources.	No access to traffic flow data – significant unknowns.
Pollution	Consistent overall methodology. Reliance on epidemiology.	Reliable sources. Minor questions on emission data. Questions re ports and airports. VOLY – significant uncertainty.	Analytical path and calculations not available – significant unknowns.
TtW and WtT Climate	Consistent and reliable.	Mostly reputable and robust data, minor exceptions. Questions re ports and airports. Cost per tonne CO2e - significant uncertainty.	No issues.
Noise	Some questions on the quality of evidence for health end points.	Selection of noise nuisance threshold, resolution of noise map, annoyance costs – significant uncertainty. PTW weighting factors and statistics – significant uncertainty.	Calculations not available – not verifiable but assumed to be consistent with the methodology.
Habitat	Rudimentary methodology and scaling up – high uncertainty.	Some inconsistent figures quoted – significant uncertainty.	No detail on cost apportionment – significant uncertainty.

Table 10: Sources of uncertainty in external cost calculations

For most of the external cost categories, the level of robustness, in both the STICITE values and those resulting from our sensitivity analysis, reduces the degree of confidence in the resulting figures. When applied to internalisation, contributions to meeting the objectives of internalisation can be achieved, but if the resulting pricing signals are not representative of the external costs, it could diminish the level of effectiveness of meeting the objectives.

4.10 Other external costs

Chapter 10 of the Handbook assesses other external costs, with a mainly qualitative description complemented by some quantitative indications.

The main set of additional costs identified relate to soil and water pollution due to road, rail and waterborne transport, and to oil spills. The identification of these as external costs and the qualitative analysis appears to be consistent. The indications of the magnitude of these costs in the chapter and in the references indicate that they are not of material magnitude on average, although pollution due to oil spills has the nature of a catastrophic event and generates significant marginal costs in the local area.

Costs of upstream and downstream emissions of vehicles and infrastructure are also relevant. Upstream emissions are those generated by the manufacture and transport of the vehicles. Downstream emissions are those associated with the end-of-life dismantling, recycling and disposal of the vehicle/its parts. Together these represent "embedded" emissions. For passenger cars, for example, studies (UCS, 2015 and EEA, 2018) indicate that the embedded greenhouse gas emissions could be between 10% and 20% of the well-to-wheel emissions. (well-to-wheel considers all emissions associated with producing, distributing and dispensing a fuel as well as those produced at the tailpipe = tank-to-wheel plus well-to-tank climate). The magnitude is uncertain but the existence of the emissions and therefore the climate cost is well established. A 15% addition to well-to-wheel climate costs is a consistent and conservative assumption for passenger cars and light commercial vehicles.

For heavy goods vehicles, buses, coaches the data is less well developed. For them, the ratio of embedded climate costs to well-to-wheel costs is likely to be lower than for passenger cars. Such vehicles tend to be in continuous use, generating a significantly higher lifetime mileage and they also have higher per-vehicle fuel consumption/emissions. Their embedded emissions per vehicle are higher as they are larger. Compared to passenger cars, the higher emissions from vehicle operation overcompensate the higher embedded emissions per vehicle. The embedded emissions for heavy duty vehicles can be estimated to be of the order of 5%. For other modes, again the data are scarce, but the embedded emissions are likely to be lower than for road vehicles as a proportion of the total emissions due to the long lifetimes and frequent operation.

Part of these costs are internalised by other means. Specifically, the EU emissions trading system (ETS, see also Section 4.6.4 on WtT above) sets a carbon price for certain greenhouse gas emissions, including those from large manufacturing facilities. Estimating the embedded emissions covered by the ETS would be extremely difficult, due to the complex supply chains and many manufacturers involved in production of each vehicle. With a 2016 average ETS carbon price of €5.50/tonne compared to the STICITE central cost of €100/tonne, the internalisation fraction appears likely to be negligible. It can be expected to rise to partial internalisation in 2030 and potentially towards full internalisation in 2050.

Since embedded emissions of electric vehicles are higher than conventional, their future penetration will increase embedded emissions. This will partly offset the decrease they contribute to well-to-wheel emissions. If the share of low carbon electricity rises, the embedded climate emissions per vehicle would fall.

The STICITE section on external costs in mountainous regions refers to three specific studies. We do not scrutinise these in detail, but the reasoning for higher costs in these areas appears generally consistent. This is unlikely to bring a material impact on total and average costs, but clearly would have an impact on local average and marginal costs in those regions. These findings are subject to the identified uncertainties in the determination of external costs.

Further externalities are briefly described in the Handbook but not analysed in any detail due to lack of studies and data.

5 REVIEW OF INFRASTRUCTURE COSTS, REVENUES AND SUBSIDIES

Summary

STICITE's calculation of infrastructure costs and transport revenues appears to be generally robust, although some uncertainties arise for inland waterways and aviation.

We identified some sensitivity to the choices made on apportionment of costs, including the allocation factors for road vehicle categories and the non-transport share of inland waterways.

Vehicle taxes, defined in STICITE as fixed revenues, could be considered as partially variable, having an impact on the results for variable cost coverage.

Government support for transport through subsidies and other payments can be considered as an additional internal cost category. This has not been taken into account by STICITE. When accounted for in this way as an additional cost element, they result in a substantial reduction of the variable cost coverage ratio for rail categories.

Costs, revenues and subsidies of urban public transport are also relevant as it operates alongside road, but analysis of its costs and revenues was not included in the scope of STICITE. This results in a lack of comparability of the presented data and conclusions.

5.1 Infrastructure costs

Infrastructure costs include fixed and variable elements, whose valuation and apportionment to vehicle categories are the key factors for their assessment.

5.1.1 Methodology

The general STICITE methodology appears to be consistent and well-designed. The identified scope of transport infrastructure categories for the different modes of transport is comprehensive.

The allocation of infrastructure costs to vehicle categories for the road transport mode is performed according to assumptions on the appropriate allocation factors, including "passenger car equivalent" and "4th power axle load". This follows from decisions on which cost drivers to apply, which can materially "charge" or "reward" a specific vehicle category. The STICITE Overview of Transport Infrastructure Costs states, quoting Doll (2005), that road damages are proportional to 3rd or 4th power axle load. This factor is used to allocate a fixed part of infrastructure costs to vehicles. The extent to which this or other factors are used is determined according to literature review and STICITE's own assessment. There is therefore a subjective element to the cost allocation, potentially resulting in different values.

Parking-related infrastructure costs for open road parking spaces are accounted for, but not those for off-road parking.

5.1.2 Inputs

There is a good quality and scope of supporting data for road and rail. In the case of IWT and aviation, the data are not fully consistent with the identified categories, as acknowledged in the Handbook.

The allocation factors appear to be consistent and appropriately explained in general. For road vehicles, 4th power axle load is used as the allocation factor for 23% of costs. 3rd power axle (mentioned above) is a significantly different parameter and if applied, it can materially impact the input value.

The representativity, accuracy and consistency of available data for IWT, maritime and aviation is not as robust and comprehensive. For maritime and aviation, some of the data is sourced only from a single port/airport. These factors introduce a degree of uncertainty in the reported values for these modes. A default value of 20% is set for the non-navigational share of IWT infrastructure ("Transport Infrastructure Expenditure Costs" p71), estimated based on observations from a number of studies. The allocation of costs is sensitive to this figure.

There is a high variance of the value for road infrastructure depreciation period across different infrastructure works and different countries. The value used in the study (35 years) appears to be a realistic median. However, there is sensitivity to the length of this period, due to the mathematical effects of the perpetual inventory method (PIM). For example, from the available background data on infrastructure lifetime (Ecorys & CE Delft, 2005), 40 years could also have been selected as a reasonable median value. This change would increase the fixed infrastructure costs by 5%. The wide range of data is available only for road infrastructure. The same conclusion could however be reached for other modes, if there are similarly broad ranges of depreciation periods for relevant infrastructure.

5.1.3 Infrastructure cost outputs

The assumptions on allocation of infrastructure costs introduce material variations in the resulting values per road vehicle type. For example, a sensitivity analysis can be carried out using 3rd power axle load for allocating the portion of the costs currently using 4th power axle. With all other assumptions remaining the same, this results in 15 to 25% reduction in costs allocated to buses and coaches, 5-10% percentage points increase for HGVs and 1-1.5% increase for cars. These results indicate the level of sensitivity to the allocation factors applied.

For all modes, there is some uncertainty in the output values, which is potentially material depending on interpretation.

5.1.4 Conclusions regarding internalisation

The extent to which infrastructure costs are covered by revenues depends on how the revenues are categorised and whether they are considered to cover external costs. Infrastructure charges (tolls, access charges) are directly associated with infrastructure costs, as recognised by cost coverage ratio 4, which indicates the extent to which the cost of the infrastructure is covered by income related to infrastructure. Other revenues such as vehicle taxes could additionally be considered to cover infrastructure costs, as indicated in the description of ratio 4 (see p63 of the STICITE Study Summary for the full explanation). The decision whether a particular revenue stream covers external or infrastructure costs involves a degree of interpretation, depending on the specific circumstances. This question is mainly relevant for road, since for the other modes, infrastructure charges represent by far the largest portion of the revenues (except for diesel rail). It is further discussed in the section below on revenues.

5.2 Taxes, fees and charges (revenues)

Revenues are categorised as fixed or variable. The intention of this differentiation is to enable revenue streams to be allocated consistently to related costs. Fixed revenues can preferentially be used to cover fixed costs, variable revenues to cover variable costs.

The sources of the revenue figures are generally transparent and well-documented.

5.2.1 Methodology

Regarding the structure and level of taxes/charges, the overall conceptual framework is consistent.

Since 2016, the situation has evolved in several countries, in particular regarding road charging and registration taxes. However, this is not expected to have led to major impact on the overall picture.

5.2.2 Inputs

The calculations are supported by data from reliable sources (especially for road, rail, aviation).

5.2.3 Revenue outputs and conclusions

Parking-related taxes and charges have not been included in the analysis. On-street parking infrastructure is part of the public road infrastructure. Revenues in this sector are difficult to quantify. They could represent a few percentage points of total EU road infrastructure revenues.

The allocation of revenues to vehicle categories partly depends on the robustness of the transport performance data sources used. For road and rail the sources appear to be reliable.

5.2.4 Conclusions regarding internalisation

As indicated in the above section on infrastructure costs, the nature of revenues may have an influence on the extent to which they are relevant to different cost categories. Firstly, the identification of revenues relevant to infrastructure is open to interpretation. Both vehicle taxes and fuel duties could be considered as revenues either to internalise external costs or to pay for infrastructure. If fuel duties are apportioned to cover relevant external costs, as suggested in the above sections, vehicle taxes could be relevant to infrastructure costs. For passenger cars, for example, the total value of vehicle taxes in 2016 reported in STICITE was very close to the figure for fixed infrastructure costs. This is one possible apportionment method.

Secondly, the identification of revenues as fixed/variable is highly relevant. Rail access charges are identified as almost 100% variable according to the STICITE figures (Annex D). This corresponds to their calculation with respect to wear and tear, mark-ups to buy a path to run a train and the cost of power supply (STICITE Taxes and Charges p79). The designation as variable appears to be reasonable according to this explanation. It is not clear whether the footnote on p78 regarding Eurostar refers to a fixed charge or whether the fixed charge per transit is understood as a variable charge. However, any discrepancy in interpretation of this point appears unlikely to result in any material difference in results.

For road, vehicle taxes are identified in STICITE as fixed costs. An alternative interpretation is possible as vehicle registration taxes are charged per vehicle in service, and annual circulation taxes are charged for each year the vehicle is in service. These have the nature of charges that enable the vehicle to be driven and are somewhat correlated with vehicle use, which could be considered at least partly to be a variable charge. If this is the case, it would have an impact on cost coverage ratio 3. This is explored in the sensitivity analysis in Section 7.

5.3 Subsidies and cost of government support

An explicit component of this review is the investigation of public subsidies for transport, how to account for them and the implication for internalisation of external costs. The STICITE documentation (Taxes and Charges p116) states that collecting data on transport subsidies has been out of the scope of the study, due to the poor availability of data and the many schemes that exist. The key question is whether subsidies are relevant and material to the discussion on costs and revenues. If they are determined to be relevant and material, acquisition of data and its analysis is necessary to generate comprehensive results and conclusions, notwithstanding the levels of availability and complexity.

According to the OECD (2005), subsidies are *"a result of a government action that confers an advantage on consumers or producers, in order to supplement their income or lower their costs"*. It implies that there is no service in return. This definition includes infrastructure costs. It includes activities such as direct payments from government budgets, tax exemptions, rebates, subsidies stemming from regulatory preferences (preferential market access, soft loans, special exemptions from regulations for example).

The OECD provides a few additional examples of what could constitute a subsidy:

- Subsidies for purchasing vehicles/vessels
- Subsidies for vehicle adaptations or improvements
- Financing of recurrent losses of state-owned transport operators
- Debt clearance
- Direct support to operators
- Pensions contributions

A large proportion of the transport infrastructure is funded by government money. This is explicitly and fully taken into account in the calculation of infrastructure costs in the STICITE study. Tax rebates and deductions are also taken into account in the STICITE figures, since tax revenue figures are net of these deductions. Other subsidies incentivise the purchase of vehicles (for example with new technology) or are directed to supporting transport operations. Such payments are not taken into account in the STICITE calculations of infrastructure or external cost. These could be considered as additional costs that society (through governments) is willing to pay for the transport system in question.

A public service justification is often given for such payments. This in particular applies to public service obligations (PSOs), which are contract requirements on a transport operator to provide a particular service, compensated by government payments. They are often introduced to ensure a service that otherwise might not be provided, or to reduce fares for certain groups. The above OECD definition explicitly excludes PSOs from subsidies. The relevance to this review is whether they represent a cost of maintaining the transport system, rather than whether they conform to the definition of subsidies. Our analysis therefore attempts to evaluate and categorise any government financing schemes, in order to calculate their impact and reach conclusions. This therefore includes consideration of PSOs.

The most comprehensive single source for data on transport subsidies in the EU is a study by the EEA from 2007, assessing the year 2004. It covers all EU25 Member States, although data from the 10 new member states acceding to the EU in 2004 were assumed to be of lower accuracy than those from the existing Member States. Apart from infrastructure subsidies, it identifies on-budget subsidies for road vehicle purchase (€7bn) and non-infrastructure subsidies for rail services (€33bn). It also identifies off-budget tax breaks for all modes. How the data from the source studies was used to generate the results is not clear. It is therefore useful as an indicator of the type and magnitude of subsidies, to inform investigation of more recent data.

In order to determine equivalent figures for 2016 to be consistent with the STICITE target year, we have carried out additional research.

5.3.1 Vehicle incentives

Comprehensive data on vehicle incentives is not available. Reviewing the references for the €7bn figure in the EEA study does not result in a clear explanation for the source. It is described as *"Subsidies for production, distribution, use and disposal of vehicles"*.

In 2016, government subsidies for electric vehicles for example, of which 400,000 were sold, were likely to be less than €1bn in total. This figure may increase in future as more electric and alternative fuel vehicles penetrate the market, but this is also dependent on the ability and willingness of governments to provide such support. Other subsidies for buses and HGVs may also be relevant. As an approximation, the €7bn figure could be used for 2016, but without any data on the apportionment across vehicle categories, any conclusion would be a rough estimate. In general terms, application of such a figure as an increase in variable costs could decrease the cost coverage ratios of road transport vehicle categories by a few percentage points.

5.3.2 Operating losses, debt alleviation, public subsidies and concessionary fares

These four categories of subsidy are not distinct from each other. For example, public subsidies are often used to fund concessionary fares as part of a public service obligation contract. When accumulated operating losses are cleared by debt alleviation (as for example is planned for SNCF in 2020), this is a one-off accounting that represents the realisation of those annual losses, which should already been taken into consideration as subsidies in annual accounts. Restrictive or protective market regulation could also be considered a form of subsidy, if their effect is to confer an advantage on a particular market or company. However, identifying, characterising and quantifying the impact of such programmes robustly would be extremely difficult to achieve in an accurate manner.

A study from 2016 relating to the year 2012 quotes a figure of €35bn for total non-infrastructure rail subsidies (European Commission 2016). This is very close to the €33bn EEA figure above for 2004. In both cases the sources are unclear and an explicit verification is not feasible. For 2016, we have reviewed available figures for eight EU Member States representing 81% of GDP. The figures are shown in Annex V. The total estimated figure for 2016 is €30bn.

The data are difficult to identify and categorise and therefore subject to some uncertainty, in particular regarding their allocation to different rail service categories (high-speed plus electric and diesel passenger and freight). We have used the following assumptions to allocate the subsidies as costs:

- Subsidies explicitly identified as supporting passenger rail, for example PSOs and concessionary fares, are apportioned to the three passenger rail categories in proportion to their annual infrastructure costs.

- All other subsidies are apportioned to the five rail categories in proportion to their annual infrastructure costs.
- Subsidies for concessionary fares are considered as variable costs. Half of other subsidies are considered as variable, the other half as fixed.

Alternative assumptions could be considered and evaluated in sensitivity analysis.

In order to estimate the effect of the subsidies on each category, we first used the background figures to recreate the total cost coverage ratio for all rail. We then applied the estimated total subsidy figure as an additional cost alongside external costs to calculate new values for cost coverage ratios 1, 2 and 3. This is a simplification, representing the best estimate with the available data.

We account for these payments as a cost that is necessary to maintain a functioning rail service, according to the policy imperatives of the Member States. The cost of the service is an internal cost, but in this case it is one that is not paid for by the user, but by the subsidy. It is therefore counted as an additional cost element in the sensitivity analysis.

If the direct non-infrastructure public subsidies not already accounted for of €30bn, as identified above, are categorised as an additional cost element, therefore added to the denominator of the cost coverage ratios, the direct effect is as follows:

Values from STICITE

	Overall cost coverage	Variable infrastructure and external cost coverage
Passenger transport		
High-speed train	26%	208%
Electric pax train	16%	70%
Diesel pax train	22%	101%
Freight transport		
Elec. Freight train	12%	35%
Diesel freight train	26%	61%

Values after reassessment

	Overall cost coverage	Variable infrastructure and external cost coverage
Passenger transport		
High-speed train	24%	91%
Electric pax train	15%	46%
Diesel pax train	18%	54%
Freight transport		
Elec. Freight train	10%	30%
Diesel freight train	24%	53%

Table 11: Original and re-evaluated cost coverage ratios after application of direct government economic support

It should be noted that the total economic support calculated in this way is greater than the total revenues.

The above calculations only partially include figures for metro rail, tram and bus services. Metro rail and tram do not appear to be part of the rail system investigated by STICITE. However, they do appear to be relevant, since they are both types of rail transport and operate alongside road in urban areas. A full investigation would require investigation of a large number of urban areas in the EU, differentiating the data from national transport services and between modes and vehicle categories within the urban areas.

We have identified figures from three major cities (London, Rome, Paris) indicating the extent to which urban transport services are funded by local and national governments. No EU-wide conclusions can be drawn from these figures, but they indicate material additional government funding that is relevant to the transport system. This may be borne out by the EEA (2007) study, which reports €30bn in total subsidies that cannot be attributed to a single mode. The sources for this information are not clearly presented, but this appears likely to represent both infrastructure and operational funding for urban transport. The data are old (2004) so no specific conclusions can be drawn, but it could be consistent with the more recent figures below.

London: Transport for London (2019) reported a net operating deficit for the year to 31st March 2019 of £692m. This includes underground (metro), urban rail and bus services.

Rome: For 2017, the urban transport service ATAC was due to receive €77m from the regional government for service contracts (Regione Lazio 2017). A service contract with the municipal government created a provision for up to €493m. Figures for the actual amounts paid are not available and may be less than the sum of these figures. ATAC includes metro, urban rail and bus services.

Paris: For 2018, Ile de France Mobilités (2019) reported public participation to its costs of €754m from the region, €625m from the department and €161m from the state. It is not clear whether any of these overlap with government funding for the national rail service. The services covered are metro, urban rail and bus.

Due to the many sources of data on subsidies and other government support, and the need for detailed interpretation, further dedicated study on this topic would be beneficial. Its scope could be expanded to urban transport to ensure a consistent set of data. This is further addressed in Annex X.

5.4 Robustness of results and sources of uncertainty

As with external cost categories in the previous chapter, the main sources of uncertainty in infrastructure costs, revenues and subsidies are summarised in the table below.

Category	Methodology	Published input data	Access to data
Infrastructure	Consistent, well-designed, reliable sources. Off-road parking not included.	Allocation factors for commercial vehicles – some uncertainty.	No issues.
Revenues	Reliable sources.	Generally robust transport performance data.	No issues.
Subsidies (our review)	Reliable method used. Scaling up to EU level and allocation to rail categories introduces uncertainties.	Direct from national rail companies. Interpretation difficult but mostly consistent.	All data used is referenced.

Table 12: Sources of uncertainty for infrastructure costs, revenues and subsidies

Infrastructure costs and revenues appear to be mostly robustly calculated and apportioned.

The methodology and data used in our calculation of subsidies appear to be generally robust, but the many sources, lack of standardisation, different languages, non-unique descriptions and scaling up method generate some uncertainty in the total values. Some uncertainty also arises due to the assumptions we made for the apportionment of the subsidies to different rail types.

6 THE IMPACT OF FUTURE REGULATIONS AND TECHNOLOGY

Summary

In all transport modes, existing and expected regulation is expected to drive significant reduction in external costs of transport by 2030, with the possibility of heading towards zero by 2050.

Road transport is expected to be characterised by electrification and connected & automated vehicles, reducing the external costs of pollution, climate, noise and accidents in particular.

Further electrification of the network, quieter couplings / other devices and potentially the development of electric trains not requiring overhead lines are expected to reduce rail external costs.

The future net impact on external costs in aviation is uncertain, due to the expected growth of the sector counteracting low carbon fuels and efficiency improvements.

Pollution costs in waterborne transport can be expected to decrease significantly by 2030 due to low sulphur fuel and technology improvements driven by emissions regulation.

The STICITE study documents quite extensively address how regulation can contribute to reducing external costs and the circumstances under which these or internalisation methods may be the most effective.

The external costs associated with different transport sectors are directly affected by the technologies that are used. Changes in technology can increase or decrease external costs, and their impact may vary across external cost types. Technology developments are typically driven by policy changes (in turn related to a range of factors including safety, GHG reduction, air pollution reduction) and/or the desire for improved performance.

This section considers how the transport modes analysed in the STICITE study may change in the coming years. Initially we focus on the main regulatory developments for each sector, then address the most prevalent expected technology advancements, whether driven by regulation or otherwise. For each technology the potential effect on each external cost is discussed. This future perspective discussion is designed to provide an initial assessment of how representative the STICITE cost outputs may be in 2030 and beyond.

6.1 Road transport

6.1.1 Regulation

Emissions of both pollutants and greenhouse gases from internal combustion engine (ICE) vehicles are being reduced due to regulations at a country and EU level. The EU has set CO_2 targets that require new passenger cars to emit no more than 95 gCO_2/km in 2021 on the standard test cycle (average over all cars sold in the EU). This represents a 27% decrease in permissible CO_2 emissions compared to the 2015 target, and 20% compared to the 2018 fleet average. The 2021 light commercial vehicle (LCV) standard will be 147 gCO_2/km. Limits were set in 2019 requiring a further 15% decrease in 2025 and 37.5% (31% for LCVs) in 2030. The European Commission Impact Assessment (SWD(2017)650) calculated that these will reduce total CO_2 emissions from passenger cars by approximately 33% from 2005 to 2030. The reduction from 2005 to 2016 was 2% (EEA Greenhouse Gas Viewer). A 31.5% reduction between 2016 and 2030 is therefore projected. Standards are also in place to reduce CO_2 average emissions of heavy-duty vehicle classes representing about 80% of fuel consumption in that sector, for 2025 and 2030, by 15% and 30% respectively compared to a 2019 baseline.

Pollutant emissions are regulated by Euro standards, currently Euro 6 for light duty and Euro VI for heavy duty. Both of these can be expected to generate improvements over the next decade, as the fleet is continually updated with new vehicles. In particular the Euro 6d light duty standard, introduced initially as from 2017 and with lower limits as from 2020, is intended to reduce real on-road emissions significantly. CONCAWE (2017) projected that in cities, the improvement in air quality of introducing zero emission vehicles compared to Euro 6d would be minimal. This would imply that the external pollution costs of passenger vehicles will gradually reduce towards zero as Euro 6d enters the market and older vehicles are taken out of circulation. The majority of vehicles on the road by 2030 are expected to be Euro 6d due to fleet turnover. A similar trend could be expected for heavy duty vehicles, although fleet turnover is slower than for light duty. However, it is not yet possible to verify that the expected emissions improvements from these new standards will be realised, although a material downward trend can be firmly expected.

The European Commission is currently developing post-Euro 6/VI emissions standards, with the intention that they *“guarantee that the vehicle is as clean as possible under all driving conditions over its entire useful life”*. Implementation is expected to be in the second half of the 2020s, meaning that by 2040 the majority of vehicles on the road should be certified to such a standard.

Regulations were adopted in 2014 that regulate noise emissions from motor vehicles. These require a 4dB reduction for all new passenger cars from 2026 compared to 2016, and a 3dB reduction for larger passenger vehicles (buses and coaches) and commercial vehicles. 3dB represents a reduction of 50% in noise levels. This can be expected to reduce the noise costs of motor vehicles. The actual reduction in noise, its effect on health and the resulting reduction in external noise costs will depend on many additional factors. For motorcycles, maximum noise levels are reduced by 3dB with upcoming regulation. Again, the extent to which this translates into reductions in external noise costs depends on factors related to driving behaviour, road surface attributes and human exposure.

6.1.2 Engine improvements

The above regulations will drive improvements in CO_2 and pollutant emissions from ICEs, in parallel to the expected ramp-up in electrification. Technologies for improved aftertreatment for gasoline and diesel engines is being developed to enable pollutant emission compliance. Non-plug-in hybrid systems will contribute reduction of both CO_2 and pollutant emissions.

6.1.3 Electric vehicles (plug-in, hydrogen)

Plug-in electric vehicle (EV) deployment is increasing across the EU, comprising battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). This is driven by the need to reduce GHG emissions in response to climate change and is being supported by a range of government policies, in addition to the EU vehicle CO_2 standards. EU member states have started to announce targets for either the banning of ICE vehicle sales or 100% zero emission vehicle sales. Denmark, Ireland, Netherland and Slovenia have all set a target of 2030 and the UK, 2035. France, Portugal and Spain are aiming for 2040.

In 2018, 2% of all new car sales in Europe were plug-in electric vehicles, compared to less than 0.01% in 2010, according to figures from ACEA (2019). Furthermore, the most recent sales data shows that in Q4 2019, plug-in electric vehicles comprised 4.4% of total sales, up from 2.7% in the same period in 2018. In the EU, Germany and the United Kingdom had the most EV sales in 2019 with ca. 109,000 and 73,000 respectively. Despite the targets set by governments, there is uncertainty around the rate of future deployment of EVs. The Fuelling Europe's Future (2019) study projects that by 2030 plug-in EV sales will account for 23% of total sales, and this will grow to 74% in 2050 (the remainder of sales being hydrogen FC vehicles). This central scenario is in line with the Paris Climate Agreement and was validated by a panel of industry experts. It would result in a reduction in annual CO_2 emissions from cars of around 90% between 2018 and 2050 (Fuelling Europe's Future, 2019).

Hydrogen also offers a future technology option for passenger cars, but it is still a relatively immature market. There are currently three hydrogen fuel cell car models being sold and around 100 cars operating in Europe. Production volumes are still very small but announcements from the active vehicle manufacturers indicate that these will grow in the early 2020s.

As well as cars, deployment of electric motorbikes and mopeds is growing. There is an increasing number of these zero emission vehicles available, shown by the fact that over 30 models are now eligible for the UK's plug-in grant incentive. Combined EU registrations of electric mopeds, motorcycles and quadricycles in the EU reached 58,295 units during the first nine months of 2019 which represents an increase of 61.3% compared to the same period in 2018. The market is currently dominated by electric moped sales, which comprised almost 80% of the sales referenced. The EU countries with the most registrations are France, Belgium and the Netherlands.

Public transport also represents an important sector to decarbonise. There is a series of policies, targets and initiatives designed to increase the uptake of low and zero emission buses, from a local to global level. For example, the C40 Cities Fossil-Fuel-Free Streets declaration is a pledge made by cities around the world only to procure Zero Emission (ZE) buses from 2025. Several EU cities have signed up to the scheme including Paris, Amsterdam, Milan and Berlin. The EU has also now implemented low emission bus procurement targets to support the move away from diesel buses. These require local authorities to purchase a minimum share of clean vehicles (running on gas or electricity) by 2025 and 2030. The country-specific targets will reflect population and GDP.

Private bus companies are also now starting to signal their intent to decarbonise. In the UK for example, a series of bus operators, including the 5 biggest, have announced in September 2019 that they will only buy zero emission buses from 2025.

In 2019, Europe's electric bus fleet reached just over 2,000 vehicles. This represents the second biggest market in the world but is significant smaller than the market in China, which had almost 380,000 by then end of 2018. The Europe electric bus fleet is projected to reach 63,000 in 2030, and then 170,000 by 2040 (Bloomberg, 2019).

Hydrogen fuel cell (FC) bus uptake in Europe to date has been dominated by EU-funded deployment projects. Successive projects have resulted in a reduction in the upfront cost of FC buses and there are now just under 100 buses in operation. The number of FC buses on the road in Europe is projected to rise, with the H2Bus Consortium announcing that it aims to deploy 1,000 buses.

Heavy Goods vehicles (HGV) represent a transport sector that is more difficult to decarbonise. This is due to the demanding operational requirements, including heavy loads and long driving distances. These factors make trucks particularly hard to electrify, since, based on current energy densities, the battery sizes required would be prohibitively large for a significant portion of use cases. However, for smaller trucks with less demanding daily requirements, electric alternatives are starting to come to market. These models tend to be below 10 tonnes. Larger electric (including hydrogen electric) trucks, in excess of 30 tonnes, are being developed and are expected to be released in the coming years. The electric HGV market is still relatively immature with only a small and limited supply of vehicles available. The future of the market is uncertain, and it competes with natural gas trucks which are a more established and mature technology.

6.1.4 Connected and Autonomous Vehicles

Vehicles with automated driving functions are categorised according to their level of automation. This ranges from no automation (L0) to full automation (L5). Vehicles that fall into categories L3 to L5 are considered connected and autonomous vehicles (CAVs). L3 vehicles may require the driver to intervene during operation whereas L5 vehicles are fully automated in all driving modes.

Current deployment of CAVs is limited. However, the 2019 Market Forecast for UK Connected and Autonomous Vehicles projects that in Europe, L3 CAVs could make up 8% of all passenger car sales in 2030. This is forecast to increase to 14% in 2035. L4 and L5 CAVs combined are projected to account for around 3% of total car sales in 2030 and 26% in 2035.

Automation is also expected to be developed in other vehicle sectors but will lag uptake in passenger cars. By 2035, L3-5 vehicles are projected make up ca. 10% of van sales, 3% of truck sales and 10% of bus sales (Element Energy and Cambridge Econometrics, 2019).

6.1.5 Impact of future technologies on external costs

Battery electric vehicles have zero tailpipe emissions. This results in a complete reduction in climate costs from the vehicle in operation and significant reduction in air pollution costs. The only remaining air pollution costs would be caused by particles from tyre and brake degradation, which are estimated to be approximately one third of total particulate matter emissions in 2015 and the majority in 2030 (CONCAWE 2018).

The impact on WtT costs of electric vehicles depends on how the electricity or hydrogen is generated. Based on the average carbon intensity of the UK grid, the WtT CO_2e emissions for an EV are around 5 times higher per unit of energy than for diesel and petrol, and as such the WtT costs would be greater. However, it is important to note that even when charged with grid electricity, the well-to-wheel emissions (WtT plus tailpipe emissions) of a fully electric vehicle are significantly lower than for a conventional ICE vehicle. In addition, when charged with low carbon renewable electricity the WtT emissions for a battery electric vehicle are negligible as are the external WtT costs.

Electric vehicles also result in lower noise costs due to the nature of their propulsion technology. This is most pronounced for electric motorbikes as their conventional counterpart can generate noise during aggressive acceleration.

Accident and congestion costs are likely to be the most affected by the introduction of CAVs. The automation of vehicles removes the possibility of human error causing accidents. Fully automated vehicles may still experience collisions, but it is expected that it will be significantly less common. As a result, accident costs would be reduced.

The impact that CAVs will have on congestion is uncertain. This depends on how they are introduced, the regulations that are in place and consumer behaviour. If the introduction of CAVs leads to people moving away from public transport and results in a rise in private car use, then congestion would likely increase. However, if CAVs are regulated in such a way that brings about a shift to shared autonomous vehicles, inefficient car use could decrease which, combined with the connected operation of vehicles, could be expected to bring about a decrease in congestion.

Specifically, the idea of CAVs being shared will be crucial to ensuring the technology is able to reduce congestion. For example, in the case where CAVs are privately owned and operated, a parent may send their child to school in a CAV, which then returns home and takes the parent to work. The journey from school back to home is an additional journey on the road, with no passenger, which would otherwise not have existed. If the CAV was part of a shared operation, this extra journey would be avoided and the vehicle better utilised, thereby reducing overall trip numbers and in turn congestion. The connected nature of CAVs is also important for minimising congestion. If vehicles are connected with each other, as well as with traffic lights and signs, these components can share information to coordinate journeys and reduce overall travel time.

Estimated order of magnitude of the effect of introduction of new technologies on average external costs of the vehicles in question by 2030 is summarised in the table below, according to our evaluation. The following rough levels of influence of the technologies in achieving the respective projected cost impacts are indicated:

<u>Projected magnitude of change in external cost category by 2030</u>

Strong – up to 100% change

Significant – up to 50% change

Moderate – up to 25% change

Low – up to 10% change

<u>Expected contribution of individual technology on external cost changes</u>

✓ some impact

✓✓ strong impact

✓✓✓ very strong impact

	Air pollution	Climate	WtT	Noise	Accidents	Congestion
External cost change in 2030 related to whole EU fleet:						
Expected magnitude of change	Strongly down	Strongly down	Moderately down	Significantly down	Moderately/ significantly down	Uncertain
Contribution level:						
IC engine improvements	✓✓	✓	✓	✓		
Electric vehicles	✓✓✓	✓✓	✓ (*)	✓✓		
CAV					✓✓✓	Uncertain

* Degree of decrease depends on whether electricity or hydrogen is generated using fossil fuels or renewable energy

Table 13: Projected reduction in external costs due to technology implementation, 2030

In aggregate, by 2030, air pollution costs should exhibit the strongest reductions due to the introduction of vehicles complying with real driving emissions regulations (Euro 6d onwards) and of zero-emission vehicles. Net climate costs (including well-to-tank) should reduce strongly. Noise costs are expected to drop moderately.

The effect on accidents is the most uncertain in terms of magnitude, since the expected benefits of connected and automated vehicles is dependent on many currently unknown factors related to how the technology develops and is accepted and deployed by users. Connected and automated vehicles are likely to improve efficiency of traffic but without additional control measures in place, this may have the effect of increasing capacity rather than reducing congestion.

For 2050, continued reductions in air pollution towards zero should be expected. Climate emissions should also head towards zero, if the EU's ambition of net zero emissions in 2050 is to be realised, which will heavily depend on decarbonisation of the energy sector. If the current expectations for artificial intelligence and its application to road vehicles are realised in order to meet the EU's "Vision Zero" goal, the human factor in road accidents could be all but eliminated by then, reducing accident costs towards zero.

6.2 Rail

6.2.1 Regulation

Stage III A and III B emissions standards have been in force since 2006 and 2012 respectively for engines above 130 kW used for the propulsion of railroad locomotives and railcars. From 2021, Stage V standards will be introduced, with NO_x and particulate matter limits approximately halved and new particulate number limits for railcars. Progressive introduction of rail vehicles complying with these standards should reduce pollution costs attributed to trains, for those powered by diesel engines.

A 2015 Implementing Act of the Single European Railway Area Directive enforces differentiation of rail access charges according to noise levels as from 2016. An evaluation of the implementation and effects of Noise Differentiated Track Access Charges (NDTAC) schemes is currently ongoing. This is expected to lead to new standards that could incentivise significantly reduced rail noise levels, which is the largest single external cost element for this mode.

6.2.2 Overview of future technologies

Technology developments in the rail sector are being primarily driven by the need to reduce GHG emissions. The need to for new technology deployment varies between countries in the EU, as member states differ in terms of the proportion of their rail networks that are already electrified. This ranges from 3% for Ireland to 86% and 95% in Belgium and Luxembourg respectively (European Commission 2016). Electric railway lines typically have an overhead cable system and can be decarbonised through the shift towards a renewable energy-based electricity grid.

More recent technology developments include battery electric trains, hydrogen fuel cell trains, and fuel cell range extended electric trains. These options seek to address the cost barrier that exists with installing electric trains with overhead lines. Battery electric trains are generally thought to be a suitable option for relatively short-range lines, with the latest models being capable of 60 miles (97km) on a single charge. The technology is relatively immature though and so range improvements are expected as battery technologies improve.

Plans involving hydrogen trains exist in several countries, with at least three companies working to supply them. Germany already has two hydrogen trains operational, completing daily distances of around 800 km. Moreover, a number of states across the country have signed letters of intent to introduce over 50 hydrogen trains. The hydrogen fuel cell technology is most competitive for services that require large trains to move long distances with low-frequency network utilisation. This aligns with the operational demands of rail freight. The use of hydrogen fuel cell technology as a range extender on battery electric trains is also being explored as a future technology option. However, currently only one model has been developed.

6.2.3 Impact of future technologies on external costs

Replacement of diesel trains by electric, battery electric and hydrogen fuel cell trains eliminates the direct climate costs and nearly eliminates the air pollution costs associated with rail travel. Since battery electric and hydrogen fuel cell trains do not require overhead electric power, their penetration into the market could speed up this effect as they become available and economic.

The impact on WtT costs of (battery) electric trains depends on how the electricity is generated. If renewable energy is used, then the WtT emissions and therefore costs would be negligible. However, if the electricity is produced from fossil fuel sources this will result in WtT cost that may be higher than those associated with conventional diesel trains. As with battery electric trains, the WtT costs are determined by the method of hydrogen production. If natural gas reformation or electrolysis based on non-renewable electricity is used, this would result in relatively high WtT costs. Electrolysis that uses renewable electricity on the other hand would produce minimal WtT costs.

Battery electric and hydrogen fuel cell rail services would result in a reduction in external noise costs, as the nature of electric motor operation means that they are quieter than diesel engines.

Quieter couplings and additional technical measures to reduce noise can also be expected.

6.3 Aviation

6.3.1 Regulation

There is no specific regulation for pollutant emissions from aircraft. STICITE estimates pollution external costs to be very low and even with projected increases in traffic, this element appears unlikely to be of material impact.

The magnitude of climate costs (including well-to-tank) is material. CO_2 is regulated indirectly through the EU Emissions Trading System. ICAO CO_2 standards for aircraft will be implemented as of 2020. With the projected future increase in air traffic, the net impact on external costs is uncertain, and a reduction will depend on the ETS allowance price and deployment of technologies (see below).

6.3.2 Overview of future technologies

Aviation is one of the most difficult sectors to decarbonise, as evidenced by the fact that it is one of the few sectors for which annual emissions have increased in the EU since 1990 (due primarily to increase in demand for air travel). Future technologies that are intended to support this decarbonisation are much less developed than their equivalents in other sectors. The key options being explored are sustainable aviation fuels (SAFs) and electric planes.

SAFs currently only play a minor role in the industry, accounting for only 0.004% of total jet fuel used by commercial operators worldwide in 2017. Nonetheless, they are seen as one part of the strategy to decarbonising aviation, and benefit from the fact that they can reduce emissions from the existing aircraft fleet due to compatibility with existing engines and fuel infrastructure.

The International Civil Aviation Organisation's (ICAO) 2050 Vision for Sustainable Aviation Fuels highlights that aviation does not have a true alternative to liquid fuels as a source of energy. It therefore calls for a 'significant proportion of conventional aviation fuels to be substituted with sustainable aviation fuels by 2050'. It is likely that rate of the use of SAFs will increase in coming years, but the rate of this increase is uncertain and difficult to forecast. In addition, it should be noted that while biomass based SAFs may reduce CO_2 emissions, a significant portion of the global warming impact of aviation is related to non-GHG emissions such as SO_2, which causes the aerosol effect.

Battery electric planes are currently a very immature technology which only exist in small scale demonstrations with short ranges. It is difficult to predict how this technology may develop, but if they are to be used more in the coming decade it is most likely to be for domestic flights with few passengers.

6.3.3 Impact of future technologies on external costs

The use of SAFs would lead to a reduction in the climate costs associated with aviation. There is a wide range of SAFs that differ greatly in terms of the production methods. As such, the effect on WtT and air pollution is uncertain.

Battery electric planes would result in a complete removal of direct climate and air pollution costs. As with the other battery-based technologies, the impact on WtT costs of battery electric planes would depend on how the electricity is generated. If renewable energy is used, then the WtT emissions and therefore costs would be negligible. However, the electricity is produced from fossil fuel sources this will result in WtT cost that may be higher than those associated with conventional diesel planes.

6.4 Maritime and inland waterways

6.4.1 Regulation

Stage IIIA pollutant emission standards for inland waterway vessels have been in place since 2007/2009 and Stage V will be implemented in 2019/2020 with somewhat lower limits for hydrocarbons, NO_x and particulate matter. No explicit CO_2 standards are in place. Aggregate CO_2 emissions are very low compared to other sectors.

Pollutant and CO_2 emissions of maritime vessels generate average external costs of a similar order to diesel freight trains according to the STICITE figures. Aggregate emissions and external costs are significantly higher. Currently there is no regulation on CO_2 emissions and their development will depend on technology deployment (see below) and shipping traffic volumes. Regulations to control sulphur content of ships have been progressively tightened and should bring about lower sulphur dioxide emissions. NO_x emissions standards are in place and are being progressively tightened, with the most recent stage Tier III in force since 2016 in emission control areas. These should gradually reduce relevant pollutant emissions in the EU and thereby the external costs as the relevant fleet is renewed.

6.4.2 Overview of future technologies

As with aviation, the maritime sector is extremely challenging to decarbonise. Some vessels travel vast distances and carry huge loads. About 80% of fuel use in the maritime sector is in international shipping, of which 90% is used for maritime freight.

The options for technology developments include methods for improving energy efficiency, technologies that treat or capture exhaust emissions on ships that use bunker fuel, battery electric ships and hydrogen ships.

For large freight vessels the size of batteries required to enable a battery electric ship is prohibitively large. Smaller vessels with less demanding operational characteristics may be more suited to battery technologies. For example, it is thought that to decarbonise the ferry that runs between Dover (UK) and Calais (France), the battery would make up around 1 percent of the weight of the ship. This is more feasible and highlights the potential for battery electric boats in certain use cases.

Inland waterway freight transport is also a potential application for battery electric technologies. 100% electric barges designed to transport goods around the inland waterways of Belgium and the Netherlands are due to become operational in the near future. These carry 24 shipping containers each and are capable of automated travel.

The use of hydrogen in shipping is very limited. Hydrogen in the form of hydrogen-based fuel is the leading option for longer distance vessels. Hydrogen fuel cell technologies are thought to be more suitable for shorter routes within national jurisdictions. There are a small number of projects currently using hydrogen fuel cell technology but mainly for auxiliary power demands. There are however plans in California, Ireland and Norway to develop projects that use fuel cell technology as the main power source, sometimes supplemented with batteries.

A report commissioned for the UK Department for Transport presents two potential future maritime technology developments. One is methane catalysts for the removal of methane from exhaust emissions, and the other is to develop on board carbon capture for storage and sequestration (CCS). Neither of these concepts have been tested yet however they have the potential to decarbonise shipping vessels without needing to solve the challenge of changing the energy source.

6.4.3 Impact of future technologies on external costs

The introduction of battery electric and/or hydrogen vessels would remove the external climate and air pollution costs associated with maritime and inland waterway activities.

As with the other battery-based technologies, the impact on WtT costs of battery electric vessels would depend on how the electricity is generated. If renewable energy is used, then the WtT emissions and therefore costs would be negligible. However, the electricity is produced from fossil fuel sources this will result in WtT cost that may be higher than those associated with conventional vessels.

The WtT costs related to hydrogen vessels would depend on how the hydrogen is produced. If natural gas reformation or electrolysis based on non-renewable electricity is used, this would result in relatively high WtT costs. Electrolysis that uses renewable electricity on the other hand would produce minimal WtT costs.

The electric barge technology could result in reduced accident costs if the automation capabilities are utilised. These would help to remove the potential for human error in operating the vessels.

7 SENSITIVITY ANALYSIS AND MARGINAL SOCIAL COST PRICING

Summary

The external costs values presented by STICITE and those calculated according to our sensitivity analysis are subject to the identified uncertainties.

Using alternative assumptions, we found total external costs for road vehicles (except motorcycles) to be up to 20% lower than STICITE values. For motorcycles, we found total external costs to be 44% lower than STICITE values.

Accordingly, the sensitivity analysis leads to cost coverage ratios for road vehicle categories that are higher than reported by STICITE. For example the variable cost coverage ratio for passenger cars increases from 48% to 71%.

For aviation and IWT, the sensitivity analysis did not result in alternative values for the total external costs when considering the cost categories reported by STICITE. Cost coverage ratios were unchanged.

For rail services, the sensitivity analysis did not result in any changes in the total of the external cost categories considered by STICITE. However, accounting for subsidies and other government support as additional costs, variable cost coverage ratios for all rail types are reduced to levels below 100%. For example, for high-speed rail the ratio reduces from 208% to 91% and for electric passenger rail from 70% to 46%. The resulting cost coverage ratios are within a similar range to those for road vehicle types.

STICITE's marginal cost coverage ratios indicate that MSCP is applied to cost categories excluding congestion, in particular to passenger cars, motorcycles, LCVs and high-speed rail.

Analysing external cost categories individually, marginal social cost pricing fully applies to external well-to-wheel climate costs for all road vehicle types that use gasoline or diesel fuel, due to the fuel duties. It can be considered to apply approximately to external pollution costs for most passenger cars and for the newest vehicles of other road types. It also fully applies to external well-to-wheel climate costs of diesel rail in 13 out of the EU28 Member States and partially in the other 15. The external costs internalised by MSCP in this way represent approximately 80% of the total external costs of these two categories.

Compared to the STICITE figure of €987bn for total external costs of transport, the sensitivity analysis results in €652bn, due to the lower estimates for accident and congestion costs.

Of this, €448bn represents those external cost categories whose costs are borne mainly outside the transport system, for which pricing through taxes and charges can be considered most relevant. The remainder (accidents and congestion) are borne mainly inside the system, for which pricing would preferentially involve transactions between those parties inside the system.

For 2016, for each cost category and for revenues, we have performed a sensitivity analysis based on an alternative methodology, alternative assumptions or different data than those used in the STICITE study. In some cases, this results in a specific value alternative to that in the STICITE study. Where alternative values have been generated, these are subject to the same uncertainties as those in the STICITE study. The objective of this sensitivity analysis is to see where different data and methods could lead to different results.

Uncertainties and concerns about the robustness of the underlying data and assumptions are addressed in the STICITE State of Play report. For example, p17-18 highlights uncertainty around external cost estimates, while on p19 the uncertainties around infrastructure costs are highlighted. Other robustness issues are highlighted throughout the STICITE report.

7.1 External costs and cost coverage ratios for each mode and vehicle category

Our analysis has concluded that there is a wide range of possible outcomes for most of the figures for external costs. In some cases, the sensitivity analysis indicates that different values for external costs can be generated under alternative assumptions. Specifically, for accident costs, the identification of a portion of the costs as internal results in a lower overall figure for road modes. Our assessment of road congestion costs lead to a value equal to the lower bound reported by STICITE (deadweight loss).

Indications of congestion/scarcity costs for rail indicate these may be material, but are both difficult to quantify with available analysis. Average rail congestion costs appear to be lower than those for road vehicles.

For the other cost categories, namely pollution, well-to-wheel climate, noise and habitat, there was not sufficient evidence to generate specific alternative values of external cost, for any mode.

We have also identified one additional potentially material external cost category. This is embedded emissions for all vehicle types, which can be estimated from literature and the level of well-to-wheel climate costs.

In summary, we base the external cost sensitivity analysis on the following assumptions:

- The same VSL applied by STICITE is used, notwithstanding the uncertainties identified in that figure.
- Congestion costs for non-road modes are not included but discussed below.
- 50% of vehicle taxes are treated as variable

The following are the cost categories for which the sensitivity analysis results in a change in values compared to STICITE:

- External accident costs in road transport are calculated according to identification of costs of at-fault drivers and compensation payments as internal.
- Deadweight loss is applied as the external congestion cost for road.
- Embedded climate costs are added for road vehicles.
- Direct government funding for transport operations through incentives and subsidies are included as an additional cost element (partly variable, partly fixed).

The summary results for the sensitivity analysis of external costs are presented graphically below for each mode and vehicle type by cost category, comparing against the STICITE results.

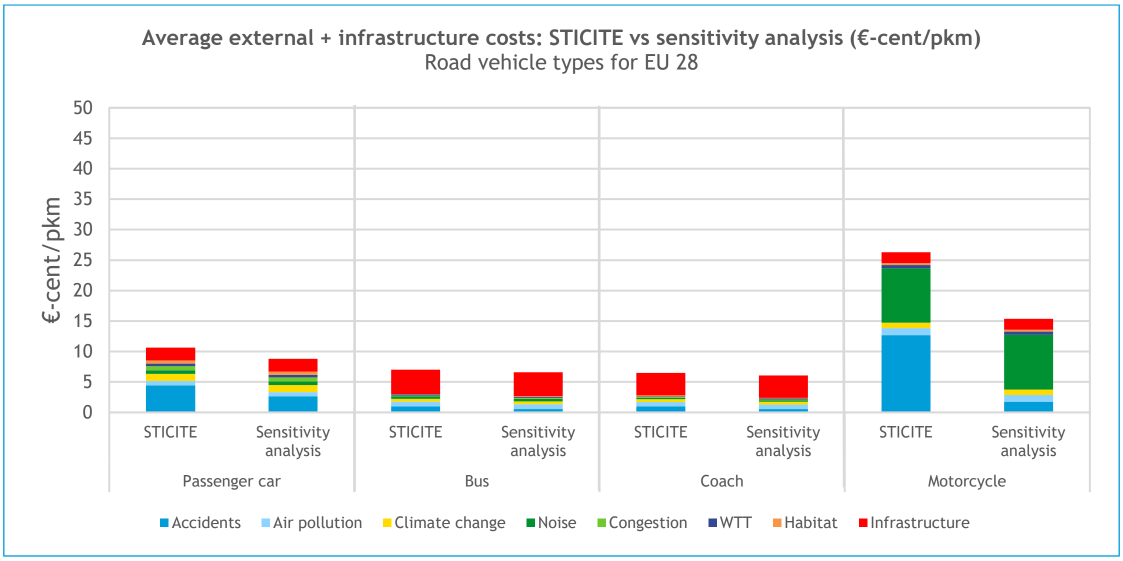


Figure 2: Summary of results of sensitivity analysis for average external costs of passenger transport - road

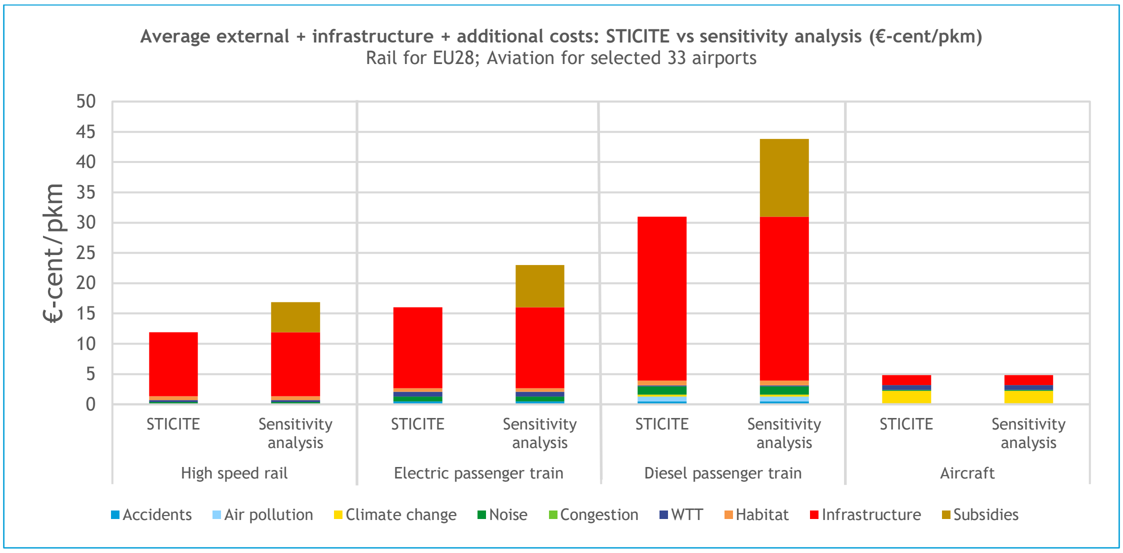


Figure 3: Summary of results of sensitivity analysis for average external costs of passenger transport – rail and aviation

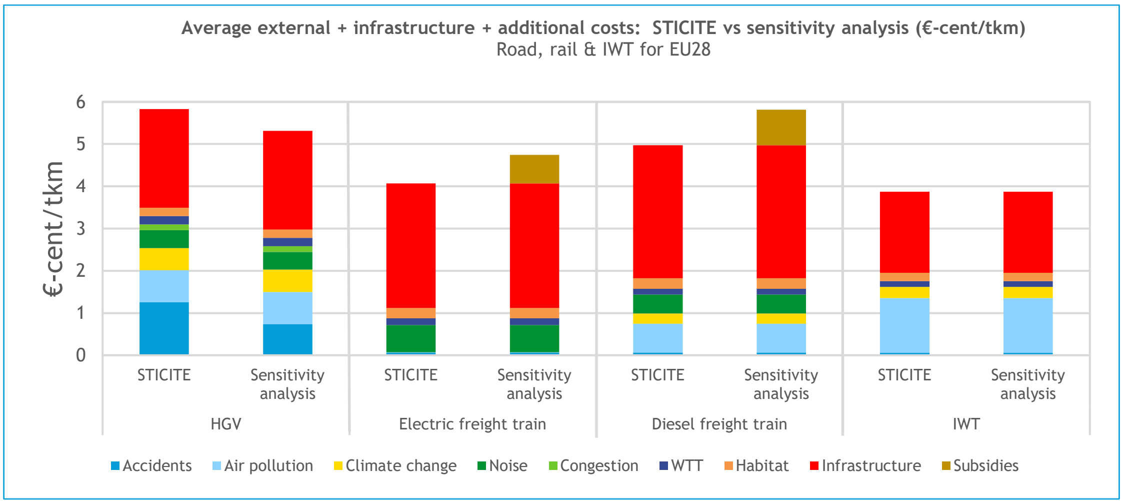


Figure 4: Summary of results of sensitivity analysis for average external costs of freight transport

The cost coverage ratios could be considered as the predominant numerical result of the STICITE study, since they encompass information about the relationships between all relevant cost and revenue figures. It is therefore appropriate to scrutinise the ratios in detail, assess the changes from the sensitivity analysis of the costs and revenues and determine sound interpretations of the original and amended ratios. They are discussed individually per mode below, mainly focusing on observations and recalculated values of the first three ratios.

The table below shows the original values for all ratios and the alternative values for ratios 1, 2 and 3, according to the above assumptions. It is to be reiterated the ratios are subject to the uncertainties identified in this review in the cost and revenue values, including those on which we have performed sensitivity analysis.

	Overall cost coverage		Overall cost coverage excluding fixed infra costs		Variable infrastructure and external cost coverage		Total infrastructure costs coverage	Variable infrastructure cost coverage
Passenger transport	Old	New	Old	New	Old	New		
Passenger car	51%	60%	63%	76%	48%	71%	27%	417%
Bus	17%	18%	24%	25%	21%	24%	3%	6%
Coach	18%	19%	26%	28%	23%	27%	3%	6%
Motorcycle	19%	34%	20%	38%	15%	33%	35%	576%
High speed train	26%	24%	145%	79%	208%	91%	28%	394%
Electric pax train	16%	15%	61%	39%	70%	46%	19%	160%
Diesel pax train	22%	18%	91%	52%	101%	54%	16%	122%
Aircraft	34%	34%	45%	45%	46%	46%	82%	247%
Freight transport	Old	New	Old	New	Old	New		
LCV	43%		53%		48%		11%	153%
LCV adjusted*	36%	38%	44%	48%	39%	46%	11%	153%
HGV	26%	28%	37%	43%	33%	40%	14%	44%
Elec. freight train	12%	10%	30%	24%	35%	30%	16%	86%
Diesel freight train	26%	24%	55%	60%	61%	53%	25%	138%
IWT vessel	6%	6%	12%	12%	13%	13%	12%	176%
Maritime vessel	4%	4%	4%	4%	4%	4%	127%	4571%

Key: xx% - no/little change; yy% - increased; zz% - decreased

* to allow comparison, original values could not be reconciled

Table 14: Alternative values for cost coverage ratios from sensitivity analysis

The sections below describe the potential impacts on external costs for each vehicle category, from the alternative assumptions adopted in this sensitivity analysis. They further indicate the order of magnitude of expected future changes due to regulation and application of technology. They additionally assess the impact for each on the cost coverage ratios from this sensitivity analysis.

All data and calculations used to generate these figures are available on request.

7.1.1 Car, bus and coach, motorcycle

The methodological issues identified in our analysis lead to the conclusion that for pollution, well-to-wheel climate and habitat costs the figures reported by STICITE are possible external cost values, but subject to significant uncertainty (with upper and lower errors possible).

External costs of passenger cars, excluding congestion costs (reflecting the treatment in the STICITE study), are 17% lower than reported by STICITE, due to the following factors:

- External accident costs were found to be approximately 40% lower than those reported by STICITE for cars (according to the assumptions quoted above). This result is due to the accounting for the accident costs of at-fault drivers and personal liability payments as internalised.
- An additional external cost for embedded emissions, approximating to 15% of the well-to-wheel climate costs, is added.

Including congestion and comparing to the STICITE figure used in the evaluation of total external costs (e.g. Study Summary p47), total external costs of passenger cars are 40% lower than reported by STICITE. This larger reduction is due to STICITE's use of congestion delay cost when calculating total external costs, in contrast to its use of deadweight loss congestion cost when calculating for individual modes and vehicle types.

For motorcycles, our findings indicate that external accident costs drop by a larger proportion than for cars, reducing their external costs significantly. Since PTWs have a higher vulnerability than other vehicle categories and are less likely to cause costs to persons in the opposing vehicle (Handbook p40), the internalisation of the costs of at-fault riders internalises most of their costs. Due to additional questions identified in determination of noise costs for motorcycles (Section 4.7 above), this other dominant cost block has a higher uncertainty than for other road vehicles. Embedded emissions are added in the revaluation. The net result is that the total external costs of motorcycles are lower by 44%. Including mopeds in the analysis would increase the net external costs slightly, but the data is not available to determine the magnitude of the change accurately.

For buses and coaches, the uncertainty in the values is also present. The effect of our lower value for accident costs has relatively smaller impact than for cars and motorcycles, due to the higher relative levels of the other costs categories. The net result of the sensitivity analysis is either a 14% reduction in total external costs excluding congestion or 30% including congestion, compared to STICITE figures.

Due to the development and implementation of new technology, driven by both regulation and consumer demand, the total external costs for these categories can be expected to drop materially by 2030 and potentially towards zero by 2050. This is likely to occur faster for cars and motorcycles, due to their shorter lifetimes and therefore faster vehicle turnover in the fleet.

The figures for infrastructure costs and revenues appear to be mostly robust, with some sensitivity to the assumptions and factors used for their apportionment to different vehicle types. This apportionment can have a material impact on the average costs of buses and coaches, again introducing a level of uncertainty in the results.

Cost coverage ratios

The ratio for overall cost coverage for cars is higher than for all other modes according to the STICITE results. This reflects mainly the high revenues through fuel duties and the relatively low apportionment of infrastructure costs. Applying the sensitivity analysis, total cost coverage ratio (ratio 1) is 17% higher than reported by STICITE. Variable cost coverage ratio (ratio 3) is 47% higher.

All cost coverage ratios for buses and coaches are significantly lower than those for passenger cars, in particular those relating to infrastructure cost coverage. This reflects the significantly lower fuel duty revenues per pkm and the much higher infrastructure cost apportionment by STICITE. According to STICITE, the total cost coverage ratio for buses and coaches are of a similar magnitude to those for passenger rail, whereas the variable cost coverage ratio is significantly lower. This reflects both the higher variable costs and lower variable revenues of these vehicle types compared to rail (before consideration of subsidies as variable costs, see below sections). The ratios for buses and coaches are slightly higher (by 1 to 4 percentage points) after the sensitivity analysis.

According to STICITE, motorcycle cost coverage ratios 1, 2 and 3 are low (≤20%), mostly reflecting STICITE's high valuation for their average external costs. When the lower value for accident costs discussed above is applied, total cost overage ratio is higher by approximately 75% and variable cost coverage ratio more than double.

7.1.2 Passenger rail

The external cost figures appear to be representative, but are subject to the same uncertainties as those referred to above. None have been explicitly revalued by our sensitivity analysis. If estimated congestion costs equivalent to 20% delay costs of passenger cars are assumed as a first approximation, this would have an impact of <10% on the external costs of rail.

Future technology is likely to reduce the external costs, with the extent of electrification, low carbon electricity and improvements in diesel emission levels being the predominant factors.

The values generated by STICITE for infrastructure costs and revenues appear to be consistent.

<u>Cost coverage ratios</u>

The main characteristic of the cost coverage ratios reported by STICITE for rail is the high values (>100% in some cases) for ratios 2 and 3. STICITE identifies this as efficient use of variable infrastructure investments (since "sunk" investment costs are excluded).

The findings of Section 5.3.2 regarding the inclusion of direct government support in the variable investment costs can be applied to these ratios. This treatment results in significantly lower values for the variable cost coverage ratios 2 and 3.

7.1.3 Aviation

No explicit changes to the external costs for aviation have been identified from the sensitivity analysis. The dominant external costs are those representing well-to-wheel climate emissions. These depend on the cost assigned per tonne of carbon dioxide equivalent, and are therefore subject to choices made on which value to use.

Future changes appear likely to depend mostly on the projected growth of the sector, which should be partially offset by efficiency improvements.

<u>Cost coverage ratios</u>

Ratios 1, 2 and 3 are somewhat lower than those for passenger cars, due to the absence of revenue from fuel duties. Total and variable infrastructure cost coverage is however, relatively high, due to airport charges and taxes.

7.1.4 Heavy goods (HGVs) and Light commercial vehicles (LCVs)

As for cars, the results of our analysis are that HGV and LCV accident costs are reduced by approximately 40% compared to the STICITE estimate. Embedded emissions are added for each category. The net effect of the sensitivity analysis is a reduction in total external costs of both LCVs and HGVs by 12% to 13%. The other external cost categories are subject to the uncertainties identified above.

Future external costs can be expected to drop steadily by 2030 and significantly by 2050. The extent of the changes will depend on the adoption rate and impact of connected and automated vehicles on accidents as well as the electrification rate, which is expected to be slower than for passenger vehicles.

Different assumptions on the method for allocation of infrastructure costs to different vehicle types could result in redistribution of the costs between road vehicle types, with a small impact on the resulting values for HGVs.

Cost coverage ratios

We could not recreate the original STICITE values for cost coverage ratio of LCVs using the data available. Using available data and calculating in the same way as for other vehicle types, the LCV ratios are approximately 20% lower than STICITE values. These adjusted values are the basis for the comparison to the sensitivity analysis.

The ratios reported by STICITE for LCVs are higher than those for HGVs, reflecting the lower apportionment of infrastructure costs to the smaller vehicles. The exception is total infrastructure cost coverage, which reflects the higher apportionment of variable revenues to HGVs.

According to the results of the sensitivity analysis, total cost coverage ratio is higher than reported by STICITE for both LCVs and HGVs by up to 10%. Variable cost coverage ratio is higher by 20% for both vehicle types.

7.1.5 Rail freight

The general analysis for external costs, infrastructure and revenues for rail freight is equivalent to that for passenger rail: the figures are consistent but subject to the identified uncertainties in the external cost calculations.

Cost coverage ratios

Ratios for diesel freight trains are higher by a factor of nearly 2 than electric, reflecting the significantly higher taxes on diesel fuel than electric power, despite diesel's higher infrastructure and external costs.

By accounting for the cost of direct government support for the rail sector to rail freight types as an external cost, the cost coverage ratios are reduced by 10% to 20%.

7.1.6 Inland waterways and maritime

The dominant external cost for the waterborne modes is air pollution, comprising about 70% of average external costs, followed by about 15-30% for well-to-wheel climate costs. These are subject to the uncertainties mentioned above.

In both cases regulation and technology are likely to reduce the costs over time, but the relatively low reduction in regulated pollutant levels, barriers to electrification and relatively long lifetime of ships limit the pace of improvements that can be expected.

Calculation of infrastructure costs and revenues appears to be robust.

Cost coverage ratios

The cost coverage ratios 1, 2 and 3 for IWT and maritime are the lowest of all the modes and vehicles assessed by STICITE. This reflects the external costs as mentioned above compared to relatively low revenues.

7.1.7 Extent of marginal social cost pricing

STICITE presents two methods of measuring marginal social cost pricing (MSCP):

- Simplified: using the variable external and infrastructure cost ratio. Our evaluation of these ratios is slightly different from STICITE, due to our alternative assumption on the partial variable nature of vehicle taxes.
- Accurate: using the marginal cost coverage ratio. STICITE presents values for each mode and vehicle type for individual EU and EEA Member States for three or four scenarios (high, average/representative, low external costs, and very low for some road vehicles). These are available in the STICITE background spreadsheets (Annex I Final_marginal.xls). The following observations can be made from the STICITE figures:
    - For the high and average/representative scenarios for passenger cars and LCVs, the STICITE figures indicate that marginal congestion costs comprise between 85% and 90% of the total marginal costs. For the low cost scenario STICITE assumes them to be zero. To enable a direct comparison between all vehicles and modes, the marginal cost coverage ratio excluding congestion can be used.
    - The EU marginal cost coverage ratio excluding congestion of STICITE's average cost scenario passenger cars is greater than 100%. This is also the case for motorcycles.
    - For other road vehicles and for waterborne and aviation, the marginal cost coverage ratio is below 100%, with a wide range of values and significant differences between Member States.
    - For high-speed and passenger diesel rail, the ratio for the average cost scenario is greater than 100%. For passenger electric and freight rail types, it is below 100%. This excludes the impact of subsidies, which are difficult to apportion on a marginal basis.

The full table of EU marginal cost coverage ratios reported by STICITE is included in Annex VIII of this review for reference. Annex VIII also includes the descriptions of the scenarios for each mode and vehicle type. According to the analysis of Chapter 6 above, it can be expected that over time, the average/representative scenario will tend towards the low and, in the longer term, very low external cost scenarios.

Due to the above observations, it is informative to look more closely at individual marginal cost categories to determine the extent to which they are internalised by existing taxes and charges. These can be derived according to the results of the sections of Chapter 4 above:

- Climate: external well-to-wheel climate costs are fully internalised by MSCP through fuel duties, for all road vehicles running on gasoline/diesel fuel in almost all EU Member States. It also applies to diesel rail in about half the EU28 Member States. This is confirmed by figures in the STICITE Annex E and F spreadsheets. For gasoline the ratio of road fuel duties to well-to-wheel climate costs is 213% on average within the range 111% to 312%. For diesel the average is 149% within the range 71% to 260%. Denmark and Lithuania are the countries below 100%.

- Pollution: for individual vehicles, average and marginal pollution costs are similar (according to STICITE they are "equal"). Emissions are approximately distance based and approximately correlated to fuel consumption. If fuel duties are sufficient to cover individual vehicles' marginal pollution costs, this can be considered as approximate MSCP. This requires a separate calculation for each mode and vehicle type.
- Noise, congestion: in each case, due to the partial correlation between external costs and fuel duties / other variable revenues, there is a partial application of MSCP to the categories. However, the extent to which this is the case is very difficult to determine, depending on a number of parameters.
- Accidents, habitat, embedded climate emissions: in these cases there is either complex relationship between marginal and accident costs, or marginal costs are zero. No systematic correlation between accidents and transport activity / fuel duties / infrastructure costs can be inferred and MSCP is not applied.

An example is provided by the following chart for passenger cars, which demonstrates the extent to which fuel duties cover those external cost categories for which MSCP fully or approximately applies in practice. The marginal external pollution costs are from the STICITE Handbook Chapter 4, selecting the value for metropolitan area motorway driving (the highest of the cost values presented) in a medium vehicle certified to Euro 4 emissions (gasoline and diesel). The Euro 4 standard came into force for all passenger cars in January 2006. According to ACEA (2019), the average age of vehicles in the EU in 2016 was 11 years, implying approximately 50% of vehicles on the road in that year were Euro 4 or better.

This chart presents only those cost categories for which internalisation by MSCP fully or approximately applies in practice (climate and pollution) and can most effectively contribute in practice to meeting the objectives of internalisation.

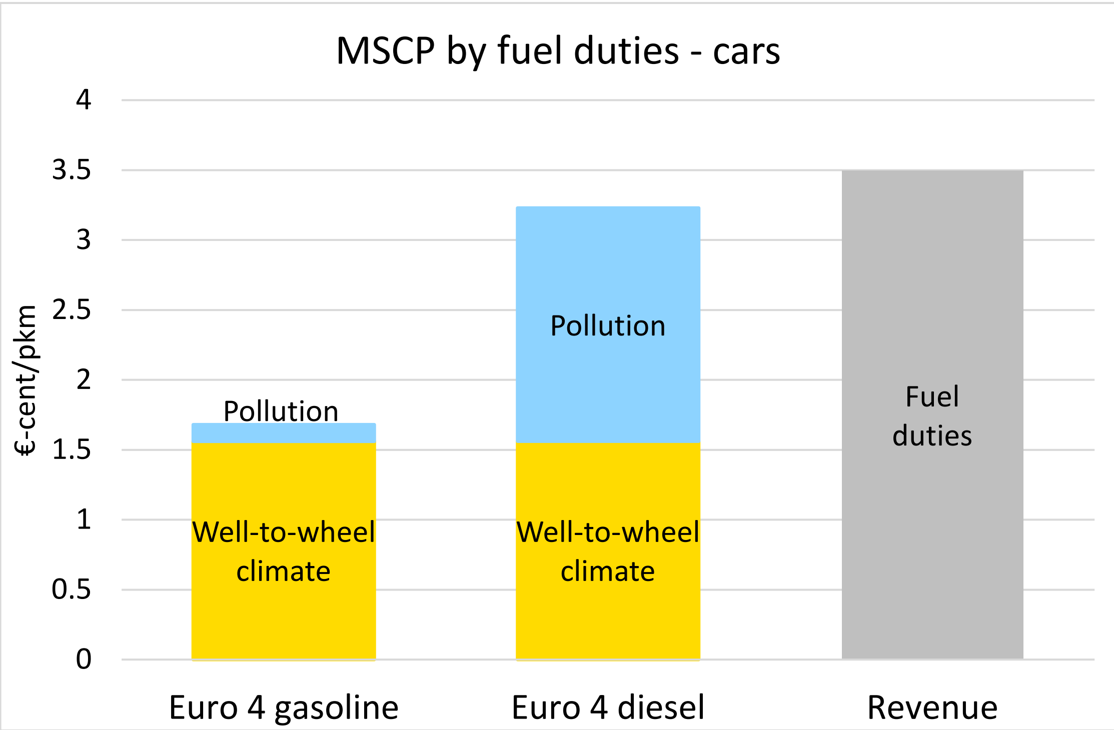


Figure 5: Test for MSCP of external WtW climate and pollution costs

The fuel duty revenue is sufficient to cover marginal WtW climate and pollution costs for Euro 4 passenger cars. This also applies to gasoline vehicles certified to Euro 1, 2 and 3 limits. For diesel, the fuel duty fully covers marginal WtW climate costs plus approximately 75% of marginal pollution costs for Euro 2 and 3 vehicles. This indicates that MSCP can be considered to apply fully or approximately to a large majority of the emissions from these vehicle types (in 2016). This conclusion applies to different extents in different Member States due to the variation in average age of vehicles on the road (ACEA 2019).

For buses and coaches, motorcycles, LCVs and HGVs, fuel duties are sufficient to cover marginal costs of both WtW climate and pollution for those vehicles certified to the most recent standards (Euro 3 for motorcycles, Euro 6 for LCVs and Euro VI for buses, coaches and HGVs).

For diesel rail, similar calculations indicate that fuel duties cover WtW climate costs in 13 out of the EU28 member States (diesel fuel duties are highly differentiated between Member States - STICITE Annex F spreadsheet).

In summary, the evidence indicates that MSCP is applied to those cost categories where it can effectively contribute in practice to meeting the objectives of internalisation: climate and pollution. MSCP fully applies to external well-to-wheel climate costs for all road vehicle types that use gasoline or diesel fuel, due to the fuel duties. It applies approximately to external pollution costs for most passenger cars on the road and for road vehicles of other types certified to the most recent emissions standards. It also fully applies to external well-to-wheel climate costs of diesel rail in 13 out of the EU28 Member States and partially in the other 15. An approximate calculation indicates that the external costs internalised by MSCP in this way represent approximately 80% of the total external costs of these categories across all modes.

7.2 Discussion on conclusions

On the basis of the ratios calculated by STICITE, the Study Summary reaches three main conclusions on internalisation of external costs. Based on our sensitivity analysis, we assess each of these conclusions in turn and make the following inferences:

- *"External and infrastructure costs are only partly internalised by current taxes and charges"*. This is consistent with our findings, also after our revaluation of the external cost values, as evidenced by the values for the total cost coverage ratio. This finding is valid, to different extents, for all modes and vehicle categories.
- *"Little evidence for application of marginal social cost pricing".* Partly in contrast to the STICITE conclusion, the evidence indicates that MSCP is applied in a number of cases. STICITE's marginal cost coverage ratios indicate that MSCP is fully applied under certain assumptions, in particular to passenger cars, motorcycles, LCVs and high-speed rail. According to our complementary analysis in the section above, MSCP is applied to those cost categories where it can effectively contribute in practice to meeting the objectives of internalisation: climate and pollution. In total, MSCP applies in this way fully or approximately to about 80% of the total well-to-wheel climate and pollution costs across all modes.
- *"Limited use of the 'users-pays' principle in the EU28".* Evidenced by the low values of cost coverage ratio 4, which compares infrastructure income to infrastructure costs, this conclusion appears to be valid for all vehicle categories except aviation and maritime. As mentioned in the STICITE conclusion, variable infrastructure cost coverage is above 100% for most categories.

7.3 Total external costs

The STICITE study summary quotes the results of its calculation of the total external costs of the transport system, €987bn in 2016, and tabulates the breakdown by mode and vehicle category. The modal comparisons are fully discussed above.

Our sensitivity analysis indicates a lower figure for total external costs than reported by STICITE. This is due to the lower values for accident costs after internalisation of certain portions of the costs. Additionally, it is due to application of deadweight loss as the figure for external congestion costs instead of using total delay costs, which is acknowledged by STICITE itself as not representative of the external costs. An additional cost category for embedded emissions is included, as discussed in Section 4.10. The sensitivity analysis did not result in specific revaluation of the other cost categories.

The resulting figure for total external costs of transport is €652bn, subject to the uncertainties identified in the constituent figures. Of this, €448bn relate to the cost categories that are mainly borne outside the transport system, for which pricing through taxes and charges can be considered most relevant. The remainder relates to the cost categories (accidents and congestion) mainly borne by users inside the transport system, for which for comprehensive achievement of the objectives, pricing would preferentially involve transactions between those parties inside the system.

8 OPPORTUNITIES AND RISKS OF INTERNALISATION

To consolidate the ideas and results discussed in the preceding chapters, we discuss the risks of internalisation, as requested in the Call for Tender of this review. We also assess its opportunities.

The opportunities and risks of internalisation can be characterised by the extent to which its objectives are met in practice. Opportunities are secured when the objectives are met, with the internalised sums therefore being applied efficiently. Risks are present if the objectives would not be met by internalisation, which would therefore imply that the internalised sums paid by users are not being efficiently or effectively used.

Internalisation is already an integral element in the transport system, realised to great extent through fuel duties and vehicle taxes in road transport, and fuel duties and access charges in rail. It applies fully to well-to-wheel climate costs for some modes and vehicle types in EU Member States and partially for some modes and vehicle types in other EU Member States. Similarly it approximately applies fully for pollution costs for some modes and vehicle types across the EU and partially for others. It is a form of marginal social cost pricing (MSCP), where average and marginal costs are identical or approximately equal.

It achieves the objective to reduce external costs, generates revenue and can be considered to be fair by compensating society (via that government revenue) for the costs. It can thus be said that effective opportunities for internalisation have been secured. This assessment is subject to the identified uncertainties in the external cost values. Further opportunities could be secured if the fuel duty revenue were sufficient to achieve internalisation of external climate and pollution costs for all modes and in all EU Member States.

For other external cost categories for which marginal and average costs diverge (notably accidents, congestion and noise), it is acknowledged that marginal pricing is difficult to apply in practice, potentially resulting in “sub-optimal decisions” when attempted. Achieving through pricing an effective reduction of external costs and the fairness objective appears less likely in those cases.

Opportunities and risks can be illustrated by addressing the case of congestion, as this is a prominent subject of discussion. The STICITE study acknowledges difficulties in applying marginal cost pricing in practice, in particular for congestion costs (Study Summary p77, State of Play p193). As also explained in Annex III, there are significant practical problems of introducing effective MSCP, mainly due to predictability concerns. In the theoretical case MSCP would be an opportunity for traffic efficiency, infrastructure improvements (funded by earmarked revenues) and incidental reduction in other external costs. Such opportunity could be extended by applying negative charges during uncongested times (see Section 4.3.1). If negative charges were applied, they would represent only quasi-MSCP and including elements of average pricing, in the same way as positive charges would (as explained in Section 4.3.4). Negative charges would therefore be sub-optimal to the same degree as any pricing applied.

In parallel, a number of risks can be identified if internalisation is applied:

- A steep demand curve at busy times (as may often be the case for transport) would result in the optimum traffic flow still being close to the level that occurs without the internalisation of external costs, therefore with little improvement in congestion itself. This is a risk even for a perfectly designed and functioning MSCP scheme.

- Congestion pricing in practice "inevitably" has elements of average costs pricing. It would have a sub-optimal impact on congestion during congested times, whilst also potentially applying charges at the non-congested times and zones.
- Variability from the predicted demand levels would lead to suboptimal flow, for example if demand is higher due to weather conditions or unexpected events.
- Dynamic perturbations caused by, for example, accidents or road obstacles could not be taken into account in predicted flows but would have significant impact on the costs.
- Some evidence suggests that in certain cases, those drivers most disadvantaged by MSCP in net terms (charges less benefit of saved time) may be those on low incomes. The distributional effects of MSCP need careful consideration.
- Such revenues are often sent by policy makers to general budgets, and not kept within the transport system to be used to reduce its external costs. This point is appropriately discussed in the STICITE Study Summary, in particular stating that earmarking could lead to a loss of overall economic efficiency according to economic theory. Within the context of the transport sector, however, it is relevant to consider the revenues as a potential source for reducing the external costs. This could be for example improved infrastructure to reduce congestion or charging stations to ameliorate the take-up of electric vehicles (with lower climate costs).
- External cost valuation is subject to high uncertainty. Valuations of external costs that are too low, when internalised, risk being ineffective in meeting the objectives. If they are too high, they may reduce transport use by more than is necessary to optimise economic efficiency.

9 FINAL CONCLUSIONS

The individual user perspective is the consistent approach for calculating external costs in transport, as it measures the impact of decisions and resulting actions on other persons or groups, consistent with the definition of external costs. This approach was applied in the STICITE analysis, without being explicitly named. However, our application of it is different in some cases from STICITE.

A consistent characteristic of the evaluation of external costs is the high level of uncertainty inherent to the underlying data and assumptions. The STICITE study has made a dedicated effort to evaluate external costs in a consistent manner, within a given context, while at the same time being transparent about robustness concerns the authors themselves identified. The results can be considered as the most comprehensive available according to the input parameters. The unavailability to third parties of the most detailed background data and the specific calculations prevents a full review of the evidence for this prominent area of EU public policy.

The inherent uncertainties mean that the use of specific concrete figures for external costs and their subsequent application to internalisation requires careful consideration. In addition to considering the uncertainties, we have undertaken sensitivity analysis of some of the external cost results, where the evidence suggests that different assumptions could lead to material differences in results. The sensitivity analysis generated alternative values specifically for accident costs, congestion costs and embedded emissions:

- By applying the responsibility approach to accident costs, we found total external accident costs for road transport to be approximately 45% lower than reported by STICITE (40% lower for cars). This result is due to the accounting for the costs of causer of the accident as internal. It assumes the same value for VSL as applied by STICITE and is therefore subject to the same uncertainties.
- STICITE applies two values to external congestion costs, using total delay costs for calculating the contribution to total external costs of transport, whilst using deadweight loss when calculating cost coverage ratios. Deadweight loss is approximately 1/6 of delay cost. Our analysis has determined that deadweight loss is the correct interpretation of external cost of congestion when applying the individual user perspective. Deadweight loss should therefore be used consistently in all cases.
- Costs of embedded climate emissions are those generated in manufacture and end-of-life of transport vehicles. These can be directly attributed to the use of the vehicles. These are material for road vehicles, adding approximately 15% on top of total climate and well-to-tank costs for passenger cars.

It should be noted that, based on current projections, external costs of well-to-tank and embedded emissions may be partially internalised in 2030 by carbon pricing in the EU Emissions Trading System, and potentially fully internalised in 2050.

According to this sensitivity analysis, total external costs of transport are €652bn. This contrasts with the figure reported by STICITE of €987bn. Of this, €448bn represents those categories whose costs are borne by parties outside the transport system, for which pricing through taxes and charges can be considered relevant. The remainder are borne by parties inside the system, for which pricing would preferentially involve transactions between those parties inside the system. A similar level of uncertainty exists in the figures resulting from the sensitivity analysis as in the STICITE figure.

STICITE's evaluation of infrastructure costs and revenues appears to be generally robust. There is some sensitivity to the method of allocation of the costs to vehicle types. This can have a material but not significant impact on costs for individual vehicle categories. Acknowledging the (partly) variable nature of vehicle registration and circulation taxes has a material impact on the variable cost coverage ratio.

Direct government economic support through payments to operators can be accounted for in the cost coverage ratios, as it represents a cost of maintaining the service. Such payments are made to cover operating losses and to pay for public service obligations, for example those offering concessionary fares. The total is estimated at €30bn per year for the rail sector, although the data are difficult to interpret and apportion with full accuracy. If these amounts are treated as variable external costs, the net effect is to reduce the cost coverage ratios significantly for all rail types. Additional government support is provided for urban transport services, which include the road and rail transport categories within the scope of the STICITE study. We have not estimated the total relevant amount, due to the many cities for which it is relevant, but the magnitude appears to be significant. Further investigation on cost of government support for urban transport is recommended, as highlighted in Annex X.

For transport categories that use gasoline and diesel fuels, the fuel duties are mostly sufficient to internalise the external well-to-wheel climate and pollution costs. This is a type of marginal social cost pricing (MSCP), for these categories, whose marginal costs are equal to, or approximately equal to, average costs since those costs vary linearly.

For those variable external cost categories for which marginal and average costs are different (accidents, congestion, partly noise), there are significant challenges to applying MSCP effectively in practice. It is likely that internalisation would have a significant element of average pricing in practice, even if differentiated according to vehicle characteristics. As indicated in the above section, average pricing could lead to sub-optimal decisions from a theoretical point of view in such cases. The earmarking of revenues from such schemes to invest in reducing the externalities is not guaranteed, since such income is often directed towards general budget revenue.

The STICITE study is not a cost-benefit analysis. However, the available literature around the benefits of transport suggests there are a number of direct, indirect and wider economic benefits of transport. These derive from employment and value added within the transport sector, the contribution of transport to the economic performance of other sectors, increased labour supply, induced property development, dynamic clustering and increased competition. However, the available literature indicates that the wider benefits cannot be considered as external.

STICITE reaches three general conclusions (Study Summary p14). From our review, we infer the following:

- The conclusion that *"External and infrastructure costs are only partly internalised by current taxes and charges"* is consistent with our findings, also after our revaluation of the external cost values. This finding is valid, to different extents, for all modes and vehicle categories, evidenced by the total cost coverage ratio.
- *"Little evidence for application of marginal social cost pricing".* Partly in contrast to the STICITE conclusion, the evidence indicates that MSCP is applied in a number of cases. STICITE's marginal cost coverage ratios indicate that MSCP is fully applied under certain assumptions. Our complementary analysis of the characteristics of each cost category indicates that MSCP is applied to those cost categories where it can

effectively contribute in practice to meeting the objectives of internalisation: climate and pollution.

- Evidenced by the low values of cost coverage ratio 4, which compares infrastructure income to infrastructure costs, *"Limited use of the 'user-pays' principle in the EU28"* appears to be valid for all vehicle categories. However, variable infrastructure cost coverage is above 100% for most categories.

STICITE also presents options for further internalisation for all modes, proposing distance-based charges differentiated by vehicle characteristics covering marginal climate, pollution, noise and congestion costs. These are discussed in turn:

- MSCP is already applied to climate and pollution costs through internalisation by fuel duties. This limits the benefits of further internalisation of these cost categories by differentiated charges
- The difficulties in achieving a fully differentiated pricing scheme in practice for congestion, that ensures that the marginal costs are compensated by those generating them, are acknowledged by STICITE. The proposal would in practice introduce quasi-average charging, which could contribute to the behavioural objectives of internalisation to a limited extent.
- The pricing of congestion would observe "polluter pays" and thus make a contribution to the fairness objective. Consistency with a strict interpretation of polluter-pays principles would require the pricing to generate transactions between users inside the transport system. This does not appear to be included in the proposal.
- Similarly, due to spatial, exposure and behavioural parameters, there are significant difficulties in designing a differentiated pricing scheme for noise that could accurately internalise the marginal costs. This would also represent a form of quasi-average pricing in practice, limiting the contribution to achieving the objectives of internalisation.
- For noise, fully achieving the fairness objective would require a mechanism for those affected by the costs to be compensated by the pricing revenues.

The extent to which the proposed differentiated charges could be expected to achieve the objectives of internalisation, above and beyond the impact of existing pricing mechanisms, is limited by the factors identified above.

BIBLIOGRAPHY OF STICITE DOCUMENTS

All STICITE documents are made available on the European Commission website: https://ec.europa.eu/transport/themes/sustainable-transport/internalisation-transport-external-costs_en

Text documents

Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities: Executive summary

Handbook on the external costs of transport – Version 2019

Overview of transport infrastructure expenditures and costs

Transport taxes and charges in Europe. An overview study of economic internalisation measures applied in Europe

State of play of Internalisation in the European Transport Sector

Sustainable Transport Infrastructure Charging and Internalisation of Transport Externalities: Main Findings

State of Play of Internalisation in the European Transport Sector Annexes A-C

Spreadsheets:

Complete overview of country data

Marginal costs air pollution, climate, WTT, noise

Overview transport infrastructure expenditures costs

Overview of transport taxes and charges - PPS adjusted figures

Average tax and charge rates per vehicle type

Overview of transport taxes and charges - PPS unadjusted figures

Internalisation-state-of-play-annexes Annex D Final_total_avg_Cross Modal Comparisons

Annex E Final_total_avg_Road

Annex F Final_total_avg_Rail

Annex G Final_total_avg_IWT

Annex H Final_total_avg_Aviation

Annex I Final_marginal

Previous Handbooks:

Ricardo-AEA (2014). *Update of the handbook on external costs of transport*

CE Delft, Infras, & Fraunhofer ISI (2011), *External costs of transport in Europe – Update study for 2008* (not on Commission website)

CE Delft (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)*

BIBLIOGRAPHY

ABI (Association of British Insurers), 9th March 2018 article
https://www.abi.org.uk/news/news-articles/2018/03/average-motor-insurance-claim-at-a-record-level-says-the-abi/

ACEA (European Automobile Manufacturers' Association), 7th February 2019 press release
https://www.acea.be/press-releases/article/fuel-types-of-new-cars-diesel-23.6-electric-33.1-in-fourth-quarter-of-2018

ACEA (2019). *Vehicles in use Europe 2019*
https://www.acea.be/uploads/publications/ACEA_Report_Vehicles_in_use-Europe_2019.pdf

Anderson, A. & Mohring, H. (1996). *Congestion costs and congestion pricing for the Twin Cities*

Anderstig, C., Berglund, S., Eliasson, J., & Andersson, M. (2012). *Congestion charges and labour market imperfections: "wider economic benefits" or "losses"?*

Belgian legislative database (1989), *Loi relative à l'assurance obligatoire de la responsabilité en matière de véhicules automoteurs, Article 29 bis.*
http://www.ejustice.just.fgov.be/cgi_loi/change_lg.pl?language=fr&la=F&cn=1989112130&table_name=loi

Blauwens, G., De Baere, P., & Van De Voorde, E. (2006). Transport economics. 2n ed. Antwerpen: De Boeck.

Bloomberg NEF, *Electric Vehicle Outlook 2019*
https://about.bnef.com/electric-vehicle-outlook/

Bristow, S. et al. (2015). International meta-analysis of stated preference studies of transportation noise nuisance. In *Transportation*, 42(1), pp. 71-100

Bundesministerium Der Finanzen, *Strukturieren Einnahmen und Ausgaben grundsätzlich nach Bundesministerien*
https://www.bundeshaushalt.de/#/2016/soll/ausgaben/einzelplan/1216.html

Cambridge Econometrics (2018). *Fuelling Europe's Future. How the transition from oil strengthens the economy*
https://www.camecon.com/wp-content/uploads/2018/02/ECF-Fuelling-Europe_EN_web.pdf

CARE, *Community Road Accident Database*
https://ec.europa.eu/transport/road_safety/specialist/statistics_en#/

CCC RE (Claims Commutations Run-Off) (2016). *Compensation of severe third party motor liability bodily injury claims in France. Analysis using CCR RE database 2016*
https://www.ccr.fr/documents/23509/29230/Plaquette+RC+auto+en+France+2016+VA.pdf/9af49b03-d79c-44b7-a1ef-acb2000ad9d2

CE Delft (2019). *Environmental Prices Handbook EU28 version*
https://www.cedelft.eu/en/publications/download/2622

CE Delft (2016). *Road taxation and spending in the EU*
https://www.cedelft.eu/en/publications/download/2250

CE Delft (2015). *External and infrastructure costs of HGVs in the EU28 in 2013*
https://www.cedelft.eu/en/publications/download/2078

CE Delft (2008). *Infrastructuurkosten van het vrachtverkeer over de weg*

Central Intelligence Agency (2017) World Factbook
https://www.cia.gov/library/publications/the-world-factbook/geos/ee.html

Christidis, P., Navajas, E., Brons, M., Schade, B., Mongeli, I., & Soria, A. (2014). *Future employment in transport - Analysis of labour supply and demand*

Christidis, P. & Brons, M. (2016). *External costs of freight transport in European Union Member States*

Christidis, P. & Brons, M. (2011). *External cost calculator for Marco Polo freight transport project proposals*

Coase, R.H. (1960). The problem of social cost. In *Classic papers in natural resource economics* (pp. 87-137)

CONCAWE (2018). *Air Pollution and Lung Cancer: A Review of Issues Affecting the Interpretation of the Epidemiological Literature*

CONCAWE (2018). *A comparison of real driving emissions from Euro 6 diesel passenger cars with zero emission vehicles and their impact on urban air quality compliance. Urban air quality study: extension I*
https://www.concawe.eu/wp-content/uploads/2018/04/Rpt_18_8.pdf

DfT (Department for Transport) (2004). *In Depth Study of Motorcycle Accidents*
http://www.righttoride.co.uk/virtuallibrary/ridersafety/indepthstudyofmotorcycleacc2004.pdf

Doll, C. (2015). *Allokation gemeinsamer Kosten der Straßeninfrastruktur. Anwendbarkeit der Konzepte kooperativer Spiele in der Wegekostenrechnung (Diss.)*

Econcept & Nateco (2004). *Externe Kosten des Verkehrs im Bereich Natur und Landschaft. Monetarisierung der Verluste und Fragmentierung von Habitaten. Studie im Auftrag des Bundesamtes für Raumplanung, des Bundesamtes für Strassen und des Bundesamtes für Umwelt, Wald und Landschaft*

Ecoplan & Infras (2014). *Externe Effekte des Verkehrs 2010. Monetarisierung von Umwelt-, Unfall- und Gesundheitseffekten*

Ecorys (2014). *The economic footprint of railway transport in Europe*

Ecorys & CE Delft (2005). *Infrastructure expenditures and costs. Practical guidelines to calculate total infrastructure costs for five modes of transport*
https://ec.europa.eu/transport/sites/transport/files/themes/infrastructure/studies/doc/2005_11_30_guidelines_infrastructure_report_en.pdf

EcoTransIT World
https://www.ecotransit.org/

EEA (European Environmental Agency) (2018). *Electric vehicles from life cycle and circular economy perspectives* – Transport and Environment Reporting Mechanism (TERM) 2018 report

EEA, *Greenhouse gas – data viewer*
https://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer

EEA, *Noise Map*
http://noise.eea.europa.eu/

EEA (2007). *Size, structure and distribution of transport subsidies in Europe. Technical report n. 3/2007*
https://www.eea.europa.eu/publications/technical_report_2007_3

Element Energy & Cambridge Econometrics (upcoming study), *Market Forecast for UK Connected and Autonomous Vehicles – 2019 update*

El-Geneidy A. M. & Levinson D. M. (2006). *Access to Destinations study: Development of Accessibility Measures*
https://conservancy.umn.edu/bitstream/handle/11299/638/200616.pdf?sequence=1&isAllowed=y

ECMT (European Conference of Ministers of Transport) (1998). *Efficient transport for Europe: policies for internalisation of external costs*

EPA (European Parking Association) (2013). *Scope of parking in Europe*
https://www.europeanparking.eu/media/1180/epa_data_collection_rev.pdf

ERA (European Union Agency for Railways) (2018). *Railway Safety and Interoperability in the EU – 2018 Report*
https://www.era.europa.eu/sites/default/files/library/docs/safety_interoperability_progress_reports/railway_safety_and_interoperability_in_eu_2018_en.pdf

Eurocontrol, *Our data*
https://www.eurocontrol.int/our-data#airline-delays

European Commission (2019). *Communication – The European Green Deal*. COM(2019) 640 final

European Commission (2018). *Transport in the European Union – Current Trends and Issues*

European Commission (2017). *Impact Assessment Accompanying the Proposal for a Regulation setting CO2 emission standards for passenger cars and light commercial vehicles.* SWD(2017) 650 final

European Commission (2016). *Impact Assessment Accompanying the document Proposal for a Directive of the European Parliament and of the Council on the promotion of the use of energy from renewable sources (recast)*. SWD(2016)405 final (p231, 275)

European Commission (2016). *Commission Staff Working Document accompanying the Fifth Report on Monitoring Developments of the Rail Market.* SWD(2016) 427 final

European Commission (2015). *Implementing Regulation setting out the modalities to be followed for the application of the charging for the cost of noise effects*. (EU) 2015/429 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32015R0429

European Commission (2015). *Impact Assessment* Accompanying the document Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions A policy framework for climate and energy in the period from 2020 up to 2030. SWD(2014) 15 final (p81)

European Commission (2011). *White Paper on Transport – Roadmap to a single European transport area – Towards a competitive and resource-efficient transport system*. COM(2011) 144 final

European Commission (2008). *Communication – Strategy for the internalisation of external costs.* COM(2008) 435 Final

Eurostat, *Structural Business Statistics* https://ec.europa.eu/eurostat/web/structural-business-statistics

Faber, J., & van Wijngaarden, L. (2019). *Economische- en Duurzaamheidseffecten Vliegbelasting: doorrekening nieuwe varianten*

Ferrovie Dello Stato Italiane (2017). *Relazione Finanziaria Annuale – 2016* https://www.fsitaliane.it/content/dam/fsitaliane/Documents/investor-relations/bilanci/Relazione_Finanziaria_2016_Gruppo_FS.pdf

Fraunhofer-ISI & CE Delft (2008). *Internalisation Measures and Policies for All external Costs of Transport (IMPACT) - Deliverable 2: Road infrastructure cost and revenue in Europe*

Goodbody Economics Consultants (2003). *Transport and Regional Development*

Goodwin, P.B. (1992), *A Review of New Demand Elasticities with Special Reference to Short and Long Run Effects of Price Changes*. Journal of Transport Economics and Policy 26(2):155-169.

GRACE (2006). *Generalisation of Research on Accounts and Cost Estimation* (GRACE) - *Deliverable 2: Marginal cost case studies for road and rail transport*

HEI (Health Effects Institute) (2018). *Seeking the Holy Grail: The Search for Causality in Air Pollution and Health Data*. Presentation at the "PM Causality Symposium" http://pmcausalitysymposium.org/wp-content/uploads/2018/12/Seeking-the-Holy-Grail-Searching-for-Causality-in-Health-and-Air-Pollution-Data.pdf

ICCT (International Council on Clean Transportation) (2012). *Estimated Cost of Emission Reduction Technologies for Light-Duty Vehicles*

Île de France Mobilités (2019). *Compte Financier 2018. Volets Budgetaire et Comptable* https://www.iledefrance-mobilites.fr/wp-content/uploads/2019/04/2018_CF_Rapport.pdf

HEATCO (2006). *Developing Harmonised European Approaches for Transport Costing and Project Assessment. Deliverable D5: Proposal for harmonised guidelines*

IEA (International Energy Agency) (2019). *The Future of Hydrogen. Seizing today's opportunities* https://www.iea.org/hydrogen2019/

Infras & IWW (2004). *External costs of transport: Update study*

Insurance Europe, *motor database* (spreadsheet) https://www.insuranceeurope.eu/sites/default/files/assets/Motor%20database%20publish.xlsx

Jaber, A. A. (2017). *Income inequality, social inclusion and mobility*. In International Transport Forum, *Income Inequality, Social Inclusion and Mobility* (pp. 13-44)

JRC (European Joint Research Centre) (2013). *Tank-to-wheels report version 4.a: Well-To-Wheels Analysis of Future Automotive Fuels and Powertrains in the European Context* http://publications.jrc.ec.europa.eu/repository/handle/JRC85327

Judicial College (2017). *Judicial College Guidelines for the Assessment of General Damages in Personal Injury Cases (14th edition)*

Kramlich, T. (2002) *Noch immer gefährliche Begegnungen: die häufigsten Gefahrensituationen für Motorradfahrer und die resultierenden Verletzungen*. In: *IfZ Forschungshefte Zweiradsicherheit No. 10*, p. 55-84

Lakshmanan et. al. (2001) Benefits and costs of transport. Classification, methodologies and policies. Papers Reg. Sci. 80, 139-164

Lakshmanan, T. (2011). *The broader economic consequences of transport infrastructure investments*. In *Journal of Transport Geography*, pp. 1-12

Lakshmanan, T., & Chatterjee, L. (2005). *Economic consequences of transport improvements. In Access* (n. 26-2005; pp. 28-33) https://www.accessmagazine.org/wp-content/uploads/sites/7/2016/07/Access-26-06-Economic-Consequences-of-Transport-Improvements.pdf

MAIDS (2004). *In-depth investigations of accidents involving powered two wheelers* https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/projects_sources/maids_report_1_2_september_2004.pdf

Ministère Des Transports - Mission conduite par Jean-Cyril Spinetta (2018). *L'avenir du Transport Ferroviaire* https://www.ecologique-solidaire.gouv.fr/sites/default/files/2018.02.15_Rapport-Avenir-du-transport-ferroviaire.pdf

Nederlandse Spoorwegen, NS. (2017). *NS Annual Report 2016*. http://2016.nsjaarverslag.nl/FbContent.ashx/pub_1000/Downloads/NS_annualreport_2016.pdf

NEEDS (2007). *New Energy Externalities Developments for Sustainability: Deliverable 3.7 - RS1b/WP3 "A set of concentration-response functions"* http://www.needs-project.org/2009/Deliverables/Rs1b%20D3.7.pdf

ÖBB (Österreichischen Bundesbahnen) (2017). *Always on the Move - Annual Report 2016* https://presse.oebb.at/file_source/corporate/presse-site/Downloads/Publikationen/Geschäftsberichte/EN_OEBB_GB2016_web.pdf

OECD (2017). *Quantifying the Socio-economic Benefits of Transport*

OECD (2012). *Mortality Risk Valuation in Environment, Health and Transport Policies* https://www.oecd.org/environment/mortalityriskvaluationinenvironmenthealthandtransportpolicies.htm

OECD (2005). *Environmentally Harmful Subsidies* https://www.oecd-ilibrary.org/agriculture-and-food/environmentally-harmful-subsidies_9789264012059-en

OECD (1993). *Glossary of Industrial Organisation Economics and Competition Law* http://www.oecd.org/regreform/sectors/2376087.pdf

Office of Rail and Road (2017). *UK Rail Industry Financial Information 2015-16* https://orr.gov.uk/__data/assets/pdf_file/0020/24149/uk-rail-industry-financial-information-2015-16.pdf

Piecyk, M., & McKinnon, A. (2007). *Internalising the External Cost of Road Frieght Transport in the UK*

Pigou, A.C. (1920). *The Economics of Welfare*

Regione Lazio (2017). *Contratto di Servizio per l'affidamento dell'esercizio di servizi di trasporto pubblico ferroviario di interesse regionale e locale* http://www.regione.lazio.it/binary/rl_main/tbl_documenti/MOB_DGR_221_28_04_2017_Allegato_1.pdf

Renfe-Operadora (2017). *Informe de auditoría de las cuentas anuales consolidadas – Ejercicio 2016*
http://www.renfe.com/docs/INFORME%20AUDITORIA_%20CUENTAS%20CONSOLIDADAS_%20INFORME%20GESTION%20EPE%202016.pdf

Ricardo-AEA (2014). *Update of the handbook on external costs of transport*

Rodrigue J-P., Notteboom T. (2017). *The Geography of Transport Systems*
https://transportgeography.org/?page_id=5260

Rothengatter (1994) Do external benefits compensate for external costs of transport? Tanspn, Res.-A. Vol. 28A, No. 4, pp. 321-328

Sanchez, F.P., Bandivadekar, A., German, J. (2012). *Estimated cost of emission reduction technologies for Light-Duty Vehicles*
https://theicct.org/sites/default/files/publications/ICCT_LDVcostsreport_2012.pdf

Transport for London (2019). *Annual Report and Statement of Accounts 2018/19*
http://content.tfl.gov.uk/tfl-annual-report-and-statement-of-accounts-2018-19.pdf

SNCB (Société Nationale des Chemins de Fer Belges) (2017). Rapport Annuel Consolidé 2016
https://cdn.belgiantrain.be/-/media/corporate/entreprise/publications/rapporten/2016/fr/rapport-annuel-consolide-2016.ashx?_ga=2.109736197.1037972309.1572799749-608507605.1538403919

SNCF (Société Nationale des Chemins de Fer) (2018). *Rapport Financier Annuel 2018*
https://medias.sncf.com/sncfcom/finances/Publications_Groupe/Rapport_financier_annuel_2018_Groupe_SNCF_28.02.2019.pdf

SNCF (2016). *Rapport Financier 2016*
https://medias.sncf.com/sncfcom/finances/Publications_Groupe/rapport_financier_annuel_2016_groupe_sncf.pdf?_ga=2.29307583.267200653.1573140285-1239799319.1573140285

The Conference Board of Canada (2013). *Where the Rubber Meets the Road: How Much Motorists Pay for Road Infrastructure*

TREMOD, *Transport Emission Model*
https://www.ifeu.de/wp-content/uploads/Endbericht_TREMOD_2016_160701.pdf

UCS (Union of Concerned Scientists) (2015). *Cleaner Cars from Cradle to Grave. How Electric Cars Beat Gasoline Cars on Lifetime Global Warming Emissions*
https://www.ucsusa.org/resources/cleaner-cars-cradle-grave

UNITE (2002). *UnIfication of accounts and marginal costs for Transport Efficiency. Deliverable 5: Pilot Account Results for Germany and Switzerland*
http://www.its.leeds.ac.uk/projects/unite/

United Kingdom (1976). *Fatal Accidents Act 1976*
http://www.legislation.gov.uk/ukpga/1976/30/section/1A

Veryard, D. (2017). Improving transport cost-benefit analysis: Overview and findings. In International Transport Forum, *Quantifying the Socio-economic Benefits of Transport* (pp. 11-36)

Which? (2017). *Millions of rail passenger journeys delayed in the past* year https://www.which.co.uk/news/2017/12/millions-of-rail-passenger-journeys-delayed-in-the-past-year/

WHO (World Health Organisation) (2013). *Health risks of air pollution in Europe – HRAPIE project. Recommendations for concentration–response functions for cost–benefit analysis of particulate matter, ozone and nitrogen dioxide*

ANNEX I: TEXT OF CALL FOR TENDER

FIA Region I now wishes to conduct an expert review of the STICITE 2019 study, its analysis and the underlying methodological approach. The study may be addressed by one or more consulting service providers.

FIA Region I wishes the contractor to focus on the following main aspects:

1) assess the overall analysis made in the study as well as the underlying methodological approach, also in view of the previous most relevant studies;
2) review the assumptions made and parameter values defined in the study, and analyse the sensitivity, variability of assumptions and parameter values and their impact on the level of the calculated income and external costs of transport, in particular:
    - identify assumptions, which, if modified, may have a significant impact on the level of external costs,
    - identify significant income and external costs of transport that have either been under- or overestimated or that have not been accounted for in the study, in particular with regard to direct and indirect public subsidies, debt clearance, protective and discriminatory market regulation, including service obligations, and uncompensated use of public resources,
    - discuss in how far direct and indirect public subsidies, debt clearance, protective and discriminatory market regulation, including service obligations, and uncompensated use of public resources, can be considered as externalities,
    - evaluate in how far the methodological approach, the assumptions and parameter values, as well as the available data allow a fair and accurate comparison of income and external costs of the different modes of transport;
3) identify and evaluate the benefits of transport to society:
    - identify significant benefits of transport to society, in particular with regard to employment and wealth,
    - provide an overview of existing analysis having assessed direct (e.g. increase in economic wealth from investment and operation) and indirect (e.g. increase in productivity from network and agglomeration effects) benefits of transport to society,
    - discuss the risk of undermining the social benefits of transport through hampering mobility in an attempt to internalise external costs;
4) Analyse the conclusions drawn in the study with regard of its objectives, in particular:
    - discuss the conclusions with regard to the funding purposes ("user-pays" principle") and the incentive effects of an internalisation of external costs ("polluter-pays" principle"),
    - discuss the economic efficiency of an internalisation of external costs through (variable) charging compared to a reduction of external costs, in particular through safe and clean vehicles standards and market surveillance, traffic management measures and implementation of Intelligent Transport Systems, transport infrastructure management, flexible working hours schemes, promotion of shared mobility,

- evaluate the risks deriving from an internalisation of external costs based on inaccurate assumptions, parameter values and missing data, leading to faulty incentives and welfare loss.

The analysis and the underlying methodological approach of this expert review study need to be thoroughly explained and justified by amongst others making use and referring to economic theory.

A specific aspect to be discussed in this review study is the assessment of public subsidies, debt clearance, protective and discriminatory market regulation, including service obligations, and uncompensated use of public resources. The STICITE 2019 study should be evaluated with view of the recommendations drawn from this assessment.

The critical review is further aimed at substantiating or refuting the arguments presented in the position paper of FIA Region I and to possibly further fine-tuning this position.

The outcome of the work should eventually help FIA Region I to generate a political message in response to the publication of the study of the European Commission.

ANNEX II: GRAPHICAL RESULTS FROM STICITE STUDY

The charts in this annex are extracted from the STICITE Study Summary pages 48-69.

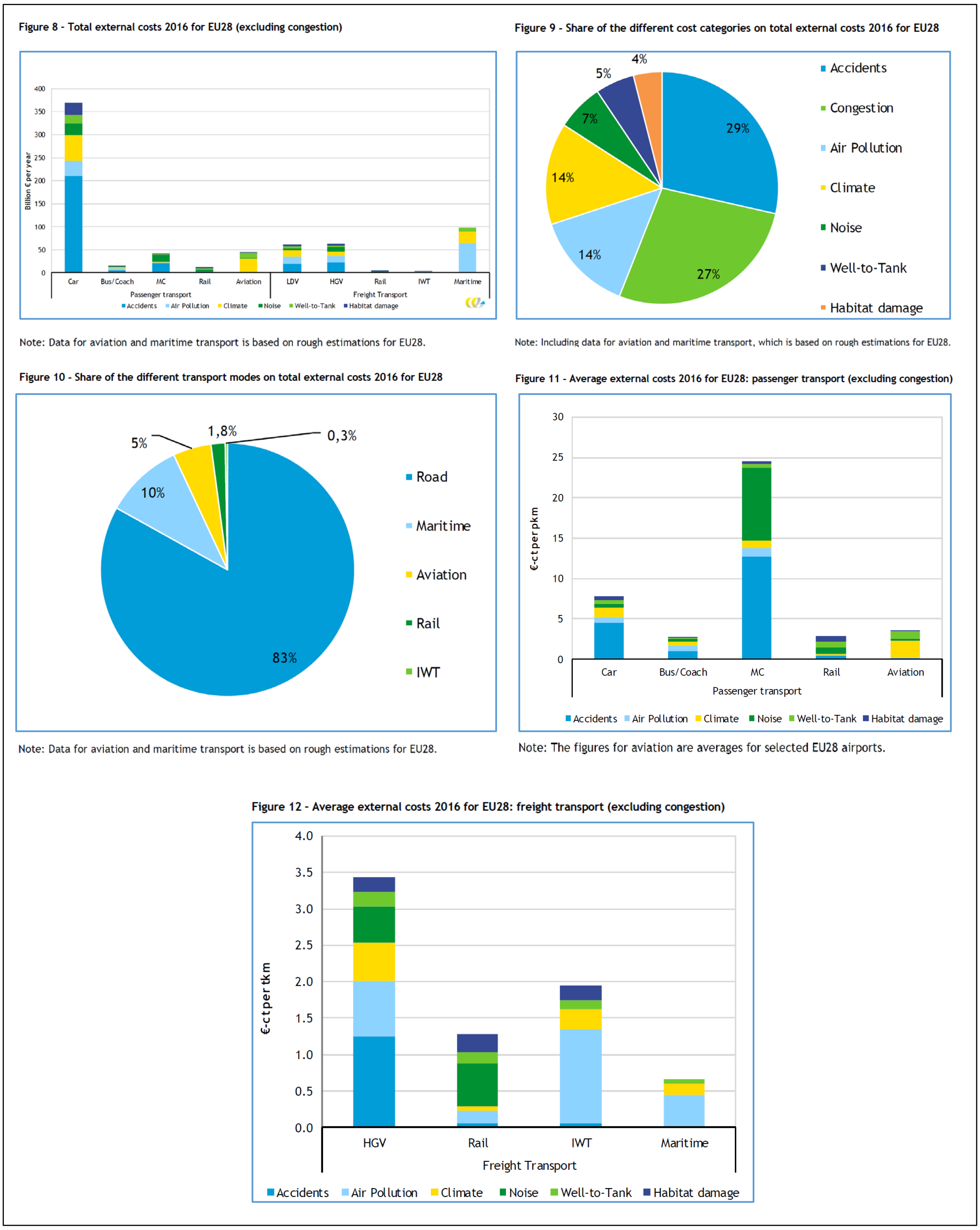


Figure 6: STICITE charts on external costs

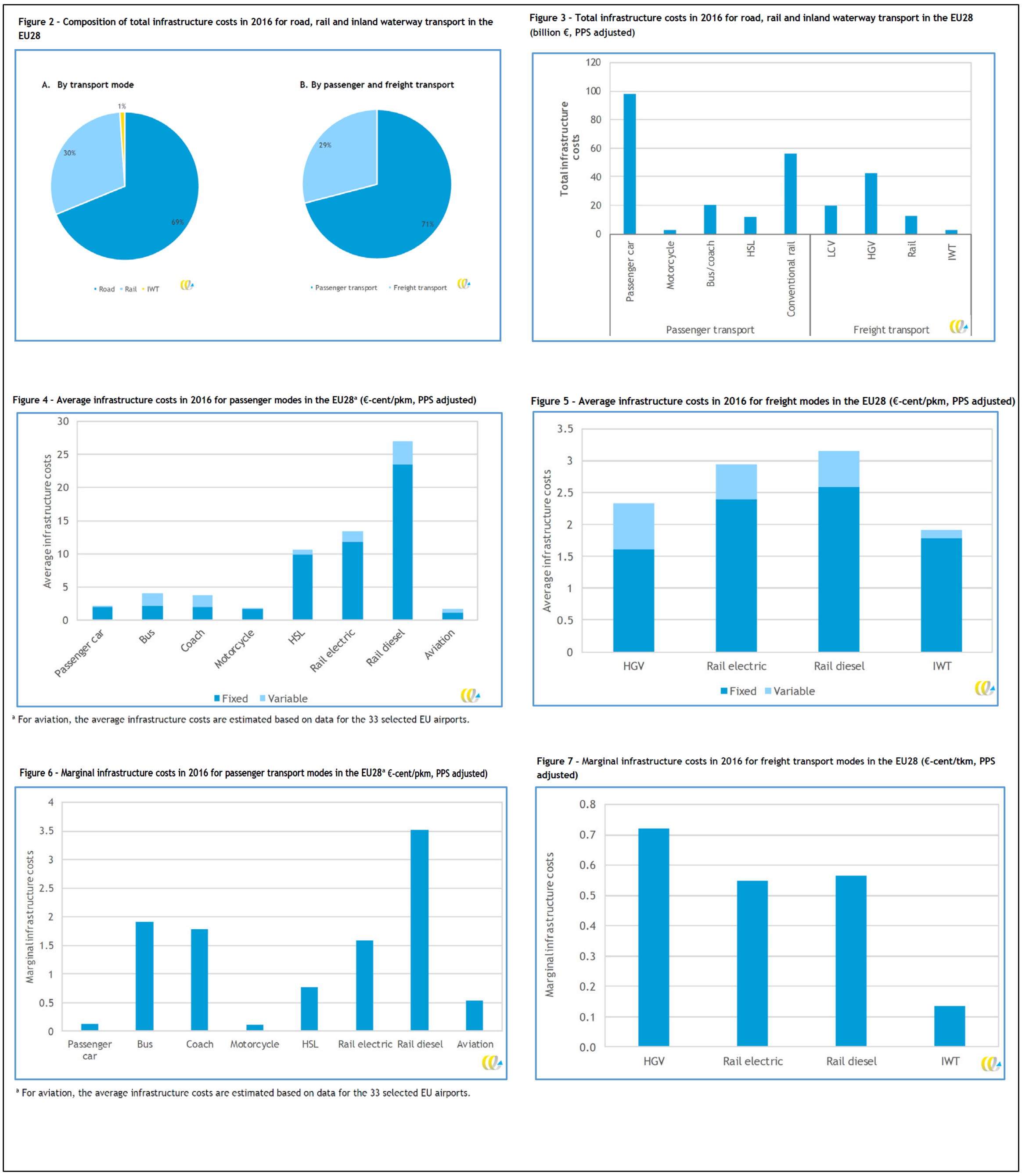
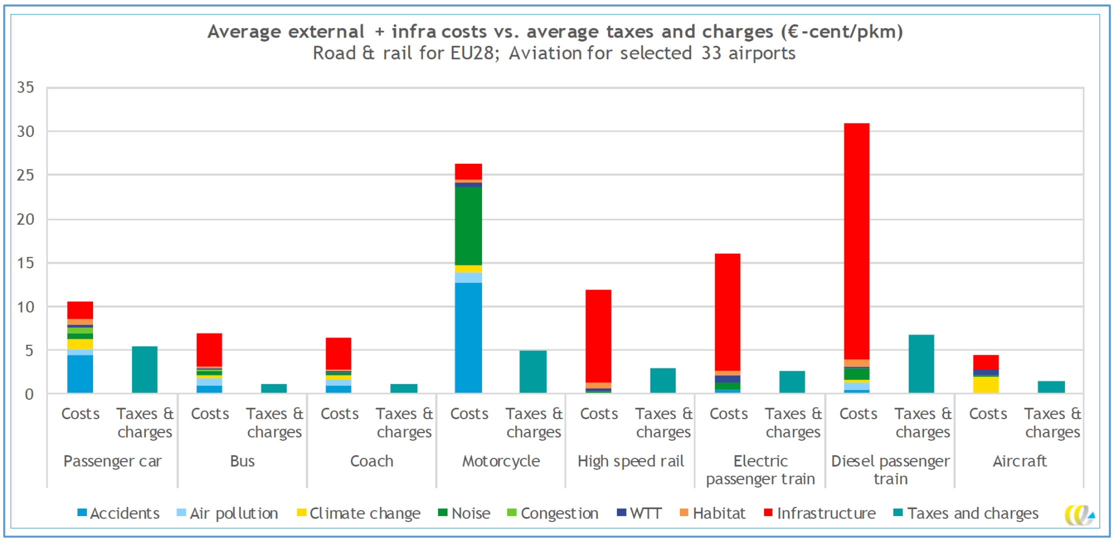


Figure 7: STICITE charts on infrastructure costs

Figure 8: STICITE charts on revenues



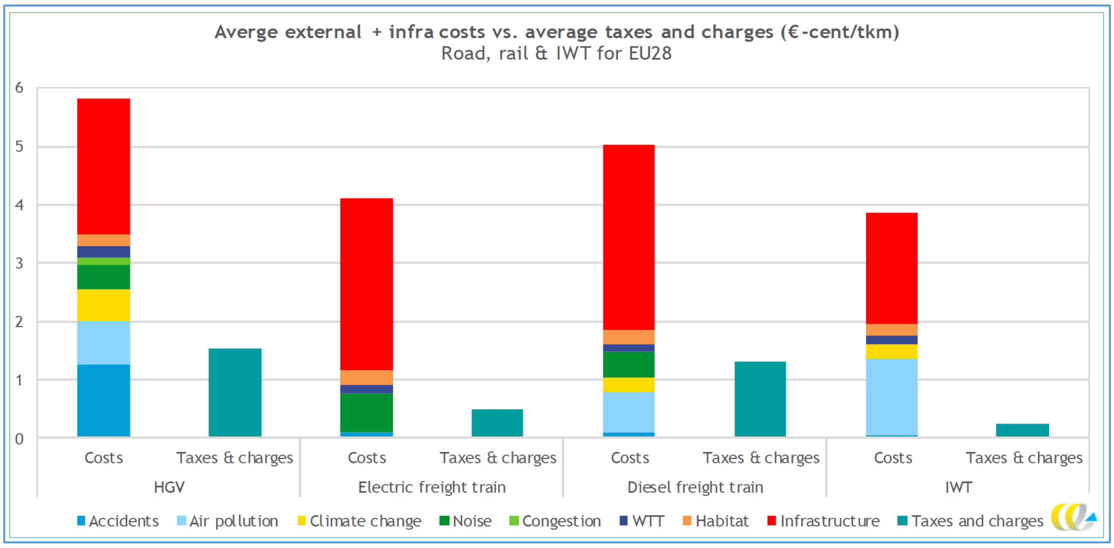


Figure 9: STICITE charts on cost coverage

ANNEX III: DETAILED ANALYSIS OF ACCIDENT COSTS

A. VULNERABLE ROAD USERS (VRU)

The consideration of accident costs of vulnerable road users, being motorcycles and mopeds (collectively powered two-wheelers or PTWs), cyclists and pedestrians, has an effect on the costs attributed to those vehicle types and also to other vehicle types.

In particular, the designation of fault for accidents has a significant impact on the net external costs (calculation results below).

Non-motorised VRUs

Many EU Member State countries apportion by law to the motor vehicle driver the responsibility for an accident with bicycles and pedestrians. In some Member States this is qualified by the possibility for the driver to claim negligence of the VRU (e.g. Belgium law on the responsibility of motor vehicles, 1989). It is argued that as the most vulnerable (in terms of level of protection by their own "vehicle"), this concept should generally apply, with the duty of care on the side of the driver. Conversely, law in other countries does not make this distinction and there are many cases in which the fault for fatality or injury is apportioned to the pedestrian or cyclist. As a base case we assume that fault for pedestrian and bicycle accidents rests with the vehicle driver. As a sensitivity analysis, we take a figure of 25% for fault apportioned to the bicycle or pedestrian in accidents with vehicles (no specific reference).

Motorcycles

STICITE reports external cost data for motorcycles, excluding mopeds. Our analysis concentrates on motorcycles to enable comparison, but we also take into account mopeds to be comprehensive. Collectively, motorcycles and mopeds are powered two wheelers (PTWs). Some of the following data sources refer to motorcycles, some to PTWs.

For PTWs, according to MAIDS (2004), the rider was the primary cause factor in 1% of accidents, with the car the primary cause factor in over 50% of all cases, with human factors responsible in 87.5% of cases in total. DfT (2004) states that of the 38% of cases involving right-of-way violations, the motorcyclist was to blame in less than 20% (i.e. less than 7.6% in total). This is supported by Kramlich (2002), which finds that in nine out of ten collisions the car driver should have given right of way to the motorcyclist. These are somewhat in contrast to Broughton (2005), which states that 72% of motorcyclists were found to be principally responsible. Due to the age of these studies and the wide variation in results, our base case assumption is that fault apportionment for PTWs is the same as for other motor vehicles. A sensitivity analysis can be performed to test the impact of alternative assumptions. Results are reported in the section below, based on our own calculations.

A further consideration is the potential for fault to be attributed to other factors relevant to the system. MAIDS reports that road maintenance defects were the cause or contributing factor in 3.6% of PTW accidents, with a further 3.8% attributable to "traffic hazards" (undefined). Defects and hazards can be considered as part of the transport system and therefore if fault can be attributed solely to them in such cases, the accidents costs could be considered as external. This issue is relevant to PTWs due to their relative vulnerability and for that reason are less likely to be of material impact for cars and other vehicles.

Data from the RAC Foundation (2016) indicate that accidents involving PTWs are less likely to result in fatalities or serious injuries for the occupants of the opposing vehicle (car, bus, HGV etc). Such casualties represent less than 1% of the total. Similarly, casualties of pedestrians due to PTWs are less than 5% of the total.

Vulnerability of powered vehicle road users appears to have been taken into account in the CE Delft calculations, but this cannot be explicitly verified due to the unavailability of the background data. For example, motorcycles suffer 21% of fatalities of motor vehicles but only 7.5% of the external costs are apportioned to them (CARE database and STICITE "Complete overview of country data" spreadsheet). The degree of risk internalisation, quoted as an indication of vulnerability (Handbook p40), appears to have been applied.

In our analysis below, as a preliminary assumption fault is assumed to be equally likely to be attributed to a motorcycle or a larger vehicle. Sensitivity analysis has been applied to this assumption.

B. NON-ROAD MODES

For aviation, shipping and water modes, almost all accidents involve vehicles with one active driver and many passengers. Consistently applying the individual user perspective as above, the accident costs of the at-fault party would be internal. Fault is either human (driver or pilot) or system error. System errors would imply that all costs are external. In the case of driver/pilot error, the costs for that person would be internal, whereas those of the passengers remain external. Since passengers overwhelmingly outnumber drivers/pilots, application of the individual user perspective would not have a material impact on the external costs.

STICITE has calculated accident costs for other modes, notably for rail. The figure reported in the Complete overview of Country Data spreadsheet is €2.33bn. STICITE states that this will be an underestimate due to the absence of data on slight injuries.

A simple verification can be performed using data from the European Railway Agency by multiplying the number of fatalities and serious injuries in 2016 (964 and 778) by the cost per casualty (€327m and €0.48m). The result is €3.54bn. The source of the difference to the €2.33bn is not clear. No details are given regarding whether there is any internalisation of the costs.

C. SENSITIVITY ANALYSIS OF EXTERNAL ACCIDENT COSTS

To calculate the effect of these parameters on external accident costs, assumptions are required. The following is one set of assumptions to be investigated, with an indication of the potential uncertainties involved:

Assumption	Direction and extent of potential error
Multi-vehicle accidents involve two vehicles In multi-vehicle accidents one party is always at fault, as a simplification 50% of drivers are at-fault, 50% not at-fault.	Some multi-vehicle accidents involve more than two vehicles, increasing the external cost part. Some multi-vehicle accidents may have more than one at fault party, decreasing the external cost part.
The share of single vehicle accidents in total accidents is the same for all motorised vehicle types except cars/taxis and motorcycles, for which specific data are available.	This affects the distribution of the individual accidents across all vehicle categories heavier than cars. The possible scope of actual distribution appears unlikely to generate a material difference in the

	results. This is confirmed from the RAC Foundation data.
Fault for pedestrian and bicycle accidents are apportioned to the vehicle.	This is a baseline case. Apportioning fault for 25% of such accidents to the pedestrian or cyclist (internalising their costs) would materially change the figures. Further analysis is shown below.
The sharing of accidents between vehicles types and drivers/passengers is identical for fatalities, serious injuries and slight injuries (simplification due to lack of detailed data).	The possible scope of actual distribution for different human accident outcomes would not appear to generate a material difference in the results. This validity of this assumption is borne out by the RAC Foundation data.
The figures for external accident costs in the STICITE study and annexes are the aggregate human and damage costs for all fatalities and injuries, with no internalisation for compensation payments accounted for (to be reviewed).	If this assumption is not correct, the STICITE figures indicate that the compensative payments accounted for are a very small proportion of external costs and this assumption if incorrect would not therefore make a material difference.

Table 15: Assumptions for calculation of external cost part and their potential error bars

The calculations to demonstrate the impact of the above assumptions on the external / internal portions of the accident costs according to the designations in the table above can be made available in our background spreadsheets. They represent the most that can be achieved with available data, since data for many parameters (including those mentioned in the table above) are not published.

We apply the responsibility approach within the individual user perspective. The accident costs of the at-fault or individual accident parties internalised as indicated above. The result is that 35% of the human accident costs are internalised (base assumption for PTW and VRU fault). This proportion of internalisation rises depending on the treatment of accidents involving fatalities or injuries of bicycles or pedestrians. For example, if fault for accidents of both bicycles and pedestrians are each 25% (instead of zero, as discussed in the section above), this internalisation figure rises to 43%. Conversely, if fault is apportioned to PTW in 25% of relevant accidents (base assumption 50%), the internalisation rate is 33%.

Consistent with the statements in the Handbook, compensation payments should be taken into account as internalisation of part of the costs. For human costs, this is accident liability insurance payments and gratification payments (as stated in UNITE), since these can be directly associated to the accident and are apportioned to the at-fault party. An estimate can be generated from individual country data. Annex VII contains data from which an estimate of total compensation payments has been generated, €25bn. For the purposes of the calculation below, this internalised part is allocated to the vehicle types proportionally to the total external human costs attributed to them.

Taking into account all the considerations above, the following table presents the overall results for road and a breakdown of the results for individual vehicle types, assuming the proportion of internalisation (base case) is identical for each:

Scope of costs	Scenario	STICITE	Review	Change
Road total	1. Base assumptions	€279.3bn	€155.2bn	44%
Passenger car	1. Base assumptions	€ 210.2bn	€ 123.9bn	41%
Bus/coach	1. Base assumptions	€ 5.3bn	€ 3.1bn	42%
Motorcycle	1. Base assumptions	€ 20.9bn	€ 2.9bn	86%
LCV	1. Base assumptions	€ 19.7bn	€ 11.6bn	41%
HGV - total	1. Base assumptions	€ 22.9bn	€ 13.5bn	41%
Road total	2. Sensitivity case 25% fault cycles and pedestrian (instead of 0)	€279.3bn	€ 135.2bn	52%
Road total	3. Sensitivity case 25% fault PTWs (instead of 50%)	€279.3bn	€ 161.1bn	42%

Table 16: Resulting figures for external costs of accidents under different scenarios

The main driver for the variance in figures is the difference in treatment of the costs of at-fault drivers and of drivers in single-vehicle accidents, which are considered external by STICITE but internal according to our approach and assumptions.

The significantly lower value for external costs of PTWs reflects the internal nature of the PTW rider's costs when at fault and the apportionment to the other vehicle's driver when he/she is at fault. The remaining external costs are those of PTW passengers and any victims in other vehicles or pedestrians.

Further points may have a bearing on the determination of the external cost part:

- If an infrastructure defect or other system factor is at fault, costs could be considered external. The little data available on this point applies to PTWs, for which it is quoted in a small percentage of accidents. Defects etc. are likely to be even less of a factor for other motor vehicles and therefore not including them in the calculation appears unlikely to have a material impact.
- External costs in buses could be considered in a similar manner to aviation and rail, in that all accident costs except at-fault drivers are external. Since bus/coach fatalities are 0.6% of the total but accident costs reported by STICITE are 1.9% of the total (STICITE and CARE), this may have been taken into account in the figures.
- The suffering of family and friends is external to the transport system even if at-fault drivers have internalised their costs. The UNITE study states, quoting Doll et al (2000), that it is not possible to separate these costs from those of the victim him/herself. An estimate could be attempted, but would be subject to high uncertainty.

D. VALUE OF STATISTICAL LIFE AND OF LIFE YEAR LOST

The concept of human costs defined in monetary terms, by its nature, requires subjective decisions to be made, about loss and suffering, alongside qualitative determinations about utility, production and consumption.

VSL

A summary of the methodology used to determine the VSL is presented in the main text of the Handbook. A more detailed discussion of Value of Statistical Life is provided in Annex A of the Handbook. The study acknowledges that there is a high degree of uncertainty around VSL estimates and that human costs are highly dependent on the VSL that is used. A word of caution about the use of VSLs would have been appropriate, but the choice of VSL seems well-founded and the best-available method.

VSL is an average value society attaches to a fatality. In economics, there are two main ways in which the VSL can be calculated: labour market studies or willingness-to-pay (WTP) studies (for preventing a fatality). For the STICITE study, the choice was rather made to use a WTP meta-analysis by the (OECD, 2012) as a basis for the VSL values. Adjustments were made from 2005 dollar to 2016 Euro, setting the EU28 VSL at €3.6m, with a recommended range of €1.8m to €5.4m. Adjustments were made for each MS in line with suggested approach in the OECD study. However, few details on the adjustment calculations are provided.

Consumption losses are deducted from the VSL to avoid double counting with gross production costs. Consumption loss is calculated by combining data on the consumption expenditure per capita per annum with the amount of life years lost due to an accident (on average 42 years). This results in an EU28 average consumption loss for a fatality of € 668,000. Therefore, the average human cost of a casualty in the EU28 is reduced to €2.9m. This is consistent with the approach taken in the previous handbook.

The Handbook (Annex A) quotes a number of sources for VSL from various studies and states that the figure from the OECD meta-analysis (2012) is the one selected for its calculation of accident costs. It states that this study is the largest meta–analysis of stated preference VSL studies to date. The resulting figure is significantly higher (approximately double) the corresponding value for VSL in the 2014 Handbook, which was derived from the UNITE (2002) study, updated to average income level in 2010 prices. Country specific values were derived from HEATCO (2006). The sources for this earlier study are not clear and, being a single study rather than a meta-analysis, is less well-founded. The OECD study, with its broad scope of data, can be considered to be more robust from a scientific point of view, but the wide range of values are an explicit indication of uncertainty in the resulting average value.

The use of WTP based on stated preferences used in the OECD study is a well-established method for valuing life and has been used in many studies. These many studies enabled the OECD (2012) meta-study to be based on a large database. However, there are many potential confounding factors:

- It relies on individuals' understanding of probability and assumes a rational reaction to that probability.
- The link between low probabilities and an actual fatality may not be linear. Fatality is a binary concept (dead/alive), which lends itself only sub-optimally to fractional probabilities.
- This could lead to systematic underestimation (if the prospect of a fatal accident is too remote to contemplate rationally) or overestimation (if the horror of death is emotionally overwhelming) of the value apportioned by respondents.

The above refers to value of life when fatalities are involved. STICITE uses standard fractions of the VSL for the human cost of serious and slight injuries of 13% and 1% respectively. These are well-established figures originally extracted from ECMT (1998). Using these values requires the assumption they continue to apply after 20 years. It also requires the ratio between the value of death and injury to remain identical as VSL changes. There is no explicit research that confirms this and this assumption introduces a further element of uncertainty.

The median estimate for VSL of the OECD meta-study can be considered to provide a possible legitimate value for VSL, as can each of the individual studies on which it is based. The VSL reported by the background studies ranges from €0.02m to €197m. Excluding the top and bottom 10%, for example, the range is reduced to €0.45m to €13.4m. This indicates that reporting results using one specific value, in the case of the OECD study the median €3.6m, is not representative of the inherent uncertainty in the methodology. The suggested range of €1.8m to €5.4m represents one possible sensitivity range. However, it cannot guarantee to capture the significance of the wide range of values. For example, excluding the 10% outliers as above results in a factor of 30 between the lowest and highest values for VSL. The standard deviation of the mean values of the studies is €17m.

<u>VOLY</u>

The STICITE Handbook includes a full definition and derivation of value of life year lost. VOLY can be directly linked to VSL in the context of sudden loss of life, but the relationship breaks down when considering non-instantaneous fatalities, for example from the health effects of air pollution. For this case, the VOLY used by STICITE was derived from a meta-study, in which STICITE reviewed a database of 14 studies.

As with VSL, there is a high variation in values. The value selected by STICITE, €70,000, is an approximate median and is one possible figure, but inherently subject to high uncertainty. Many of the studies report significantly higher values, others significantly lower ones.

ANNEX IV: DETAILED ANALYSIS OF CONGESTION COSTS

A. ADDITIONAL DETAILED CONSIDERATIONS FOR EXTERNAL CONGESTION COSTS

Below, the cost curve graph from the Handbook (p88 & 217) is reproduced, with the areas representing the four above methods for calculating (non-zero) delay cost indicated. It is apparent that the graph is not to scale, since the apparent magnitude of the deadweight loss area (method 4) appears to be more than half the total delay costs (method 1), whereas in the STICITE results deadweight loss is ⅙ the value of delay costs.

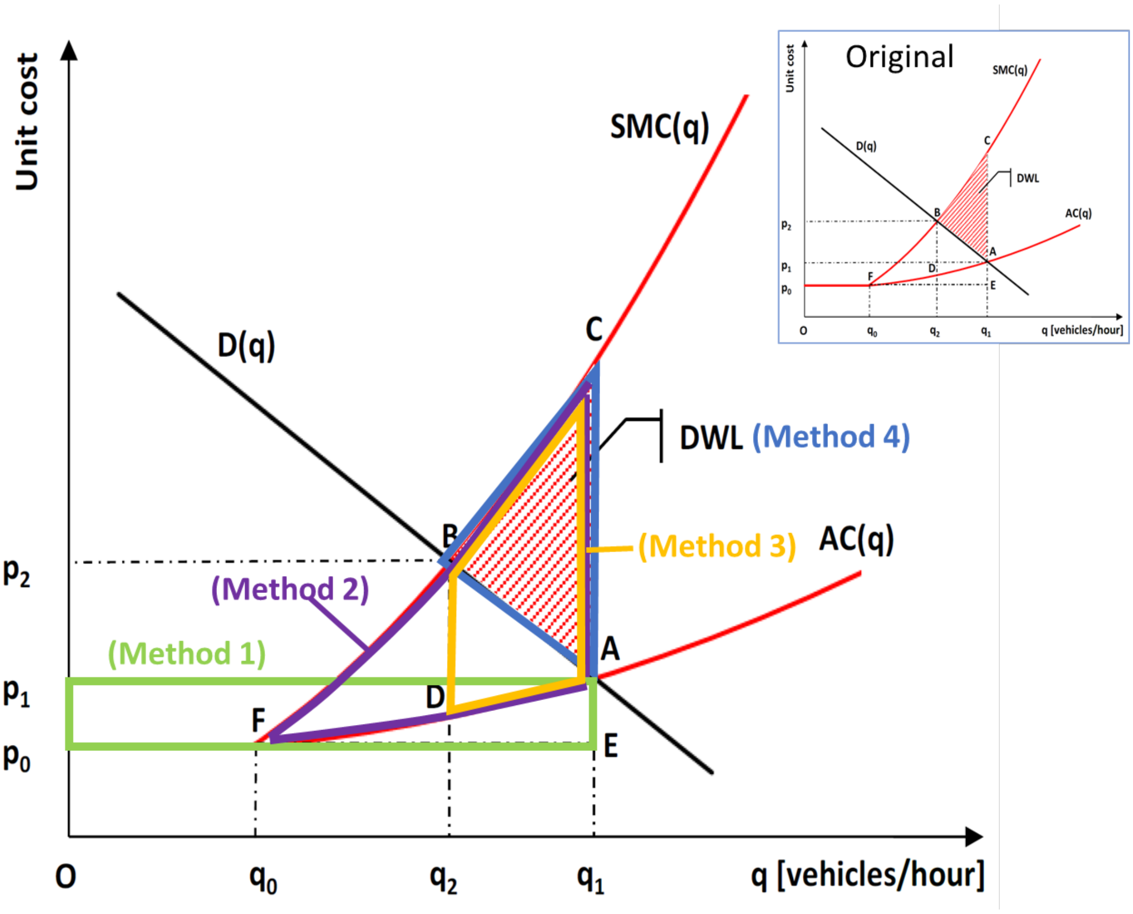


Figure 10: Road congestion chart from STICITE study

Estimates for the relative magnitudes of above different interpretations of external congestion cost are charted below. Deadweight loss is shown as column with distinct edges due the consistency of its ratio to delay cost in the STICITE results (16-17%). The columns for integrated marginal costs and marginal costs above the optimal point are shown with fade-out shading, indicating the potential ranges in the values. Delay costs is shown in outline, recognising that it is not a potential measure of external cost.

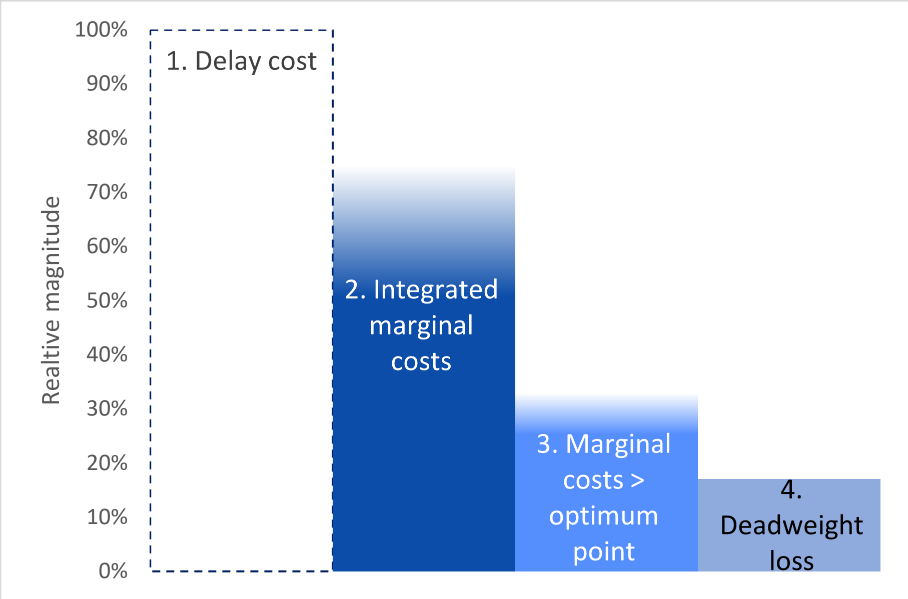


Figure 11: Estimated relative magnitudes of options for congestion cost

An additional question arises from the description and shape of the curves in the above chart. The STICITE Handbook annex p215 *states "If the flow takes any value lower or equal to q_0, the cost of travel is equal to p_0 and it corresponds to the cost of travel time"*. The equation for the cost curve and the examples of cost curves appear to contradict this.

From page 216, the AC curve equation is: $T = T_0 \cdot (1 + Par_A \cdot r^{Par_B})$. The expected shape of such a curve corresponds to the examples shown on page 217, in that they smoothly and slowly increase as the load/capacity ration increases from zero:

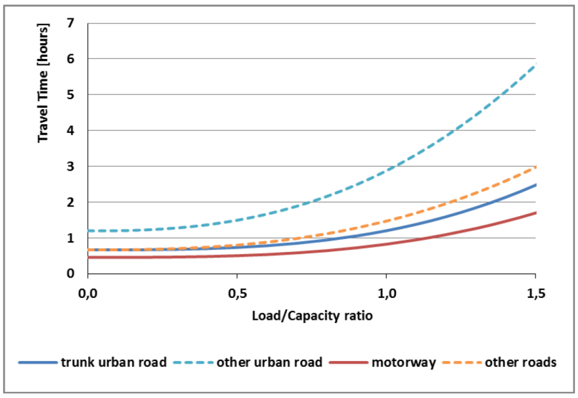


Figure 12: STICITE examples of speed-flow functions for different road types

However neither the equation nor the examples exhibit the expected flat part of the curve before q_0 as described above. This appears to imply that the equation should apply the parameter (r-1) instead of r for values of r (load/capacity ratio) above 1, and should be identical to p_0 for r<0. Without access to the STICITE background data and calculations it is not possible to determine whether this apparent discrepancy has a material impact on the results.

B. NON-ROAD MODES

The Handbook includes a discussion of congestion costs of non-road modes, identifying congestion (delay) costs and scarcity costs as external costs. Few studies have been performed to evaluate these costs, but some can provide relevant estimates.

Rail

Christidis and Brons (2016) calculated congestion costs of rail freight transport. From the background documents, the data appear to be from 2011 and the values quoted appear to be average costs, not marginal costs as shown in the handbook (p262). They appear to apply to the interurban network and are total delay cost. The EU average is quoted as €0.43/1000tkm (2016 prices).

An equivalent figure can be derived for road freight. The interurban delay cost (Handbook p247) is €0.030/vkm. Applying the average vehicle load derived from the HGV congestion costs per vkm and per tkm in the "Country data" spreadsheet, 13.6t, the corresponding figure is €2.21/1000tkm.

In this case, the rail congestion cost (2011 data) is approximately 20% of the road congestion cost (2016 data). This is comparing delay cost to delay cost. As discussed in the above section, only part of the delay cost represents the external cost of road transport. If the aggregate marginal costs are identified as the external road congestion costs, these are somewhat lower than the delay cost. The 20% could therefore be an underestimate on a like-for-like basis.

To process this further, a possible assumption is that a similar ratio between road/rail congestion applies in the case of passenger transport. The robustness of these have not been tested, but they are useful as first approximations. With these assumptions, the same >20% ratio of congestion costs could be applied to passenger rail.

Aviation

Figures for delay cost estimated by Eurocontrol indicate that congestion costs could be approximately €1.5bn in 2018, resulting in 0.2 €-cent/pkm. This compares to average interurban delay costs for cars of 1.74 €-cent/pkm (Handbook p245). Christidis and Brons (2011) however estimate the congestion costs of aviation to be negligible. Scarcity costs could (as described above) augment any evaluation.

Waterborne

GRACE (2006) estimates values for scarcity cost of inland navigation between 38 €-cent and 50 €-cent /TEU-km at Kaub and 65 €-cent to €1.25/TEU-km at Duisburg (Handbook 2019). These are local effects and do not cover the entire network. Christidis and Brons (2011) estimate the congestion costs of inland waterways to be negligible

Overall assessment

In conclusion, congestion costs for non-road modes are tangible, but a robust evaluation requires substantial further analysis. Estimates for passenger aviation and inland waterway freight indicate they could be negligible compared to road.

For rail, the quantitative estimate above for average congestion costs is not sufficiently robust to be used as a solid conclusion, but indicates that those costs are likely greater than 20% those of road transport.

ANNEX V: RAIL SUBSIDIES FOR SPAIN, FRANCE, GERMANY, ITALY, UK, BELGIUM AND AUSTRIA

The following table shows figures for operational subsidies (not including subsidies directed towards infrastructure investment) in 2016 in eight member states*, representing 81% of EU GDP. They derive from the annual reports of each country's main railway operator and are expressed in €m. The categorisation of the different costs is for added context, but is not guaranteed to be accurate. We have ensured no double-counting of the total figures.

<table>
<tr><th>Member State / Subsidy (€m)</th><th>Spain (2016)</th><th>France (2017)</th><th>Germany (2016)</th><th>Italy (2016)</th><th>UK (2016)</th><th>Belgium (2016)</th><th>Austria (2016)</th></tr>
<tr><td>National PSOs</td><td rowspan="2">561</td><td>346</td><td></td><td>248</td><td></td><td></td><td rowspan="2">741</td></tr>
<tr><td>Regional/local PSOs</td><td>4,354</td><td></td><td>2,113</td><td></td><td></td></tr>
<tr><td>Regional contribution</td><td></td><td></td><td>370</td><td></td><td></td><td></td><td>340</td></tr>
<tr><td>Operational subsidies/ ongoing losses</td><td></td><td>3,600</td><td>5,252</td><td>975</td><td>2,778</td><td>1,130</td><td></td></tr>
<tr><td>Contribution to regional trains</td><td></td><td>2,000</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Pensions</td><td></td><td>3,200†</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Other</td><td>25</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td colspan="7">€28.0bn</td></tr>
</table>

*For the Netherlands, the subsidies were found to be zero

Table 17: 2016 rail operational subsidy and PSO figures

The total is €28.0bn for the eight Member States, which represent:

- 79.6% of EU passenger rail activity
- 56.9% of EU freight rail activity

We make a conservative estimate for EU28 by rounding up to €30bn (less than above ratios).

Data sources:

Spain: Gruppo Renfe-Operadora (2017)
France: Ministère Des Transports (2018) – †pensions were explicitly included in published rail company accounts only for France
Germany: Bundesministerium der Finanzen (2019)
Italy: Ferrovie Dello Stato Italiane (2017)
UK: Office of Rail and Road (2017)
Belgium: SNCB (2017)
Austria: ÖBB (2017)

ANNEX VI: SECTOR CLASSIFICATIONS USED FOR ESTIMATE OF ECONOMIC FOOTPRINT

The Table below lists the detailed mapping of NACE Rev. 2 sector classifications from Structural Business Statistics (SBS):

Subsector	NACE REV 2 classifications
Road transport	H49.3 Other passenger land transport H49.4 Freight transport by road and removal services
Rail transport	H49.1 Passenger rail transport, interurban H49.3 Rail freight transport*
Inland vessel	H50.3 Inland passenger water transport H50.4 Inland freight water transport
Maritime transport	H50.1 Sea and coastal passenger water transport H50.2 Sea and coastal freight water transport
Aviation	H51.1 Passenger air transport H51.21 Freight air transport**
Transport related services	H52 Warehousing and support activities for transportation H53 Postal and courier activities
Manufacturing, sales and repair of road transport	C29 Manufacture of motor vehicles, trailers and semi-trailers C30.91 Manufacture of motorcycles G45 Wholesale and retail trade and repair of motor vehicles and motorcycles
Manufacturing and repair of rail transport	C30.2 Manufacture of railway locomotives and rolling stock C33.17 Repair and maintenance of other transport equipment
Manufacturing, sales and repair of maritime	C30.1 Building of ships and boats C33.15 Repair and maintenance of ships and boats G46.14 Agents involved in the sale of machinery, industrial equipment, ships and aircraft***
Manufacturing, sales and repair of aviation	C30.3 Manufacture of air and spacecraft and related machinery C33.16 Repair and maintenance of aircraft and spacecraft G46.14 Agents involved in the sale of machinery, industrial equipment, ships and aircraft***
Construction for road transport	F42.11 Construction of roads and motorways F42.13 Construction of bridges and tunnels****

Construction for railway	F42.12 Construction of railways and underground railways F42.13 Construction of bridges and tunnels****
Extraction, manufacturing and sales of fuel	G47.3 Retail sale of automotive fuel in specialised stores B06.1 Extraction of crude petroleum B09.1 Support activities for petroleum and natural gas extraction C19.2 Manufacture of refined petroleum products

Table 18: Mapping of NACE Rev. 2 sector classifications

Notes:

* Due to missing data for 2016, Rail freight transportation was proxied by the 2015 value.

** Due to confidentiality reasons freight air transport is not available. However, the larger aggregate Freight air transport and space transport is available and used as a proxy here.

*** This sector was shared amongst maritime and aviation based on the share of manufacturing and repairs of each sector

**** This sector was shared amongst the construction for road and railway using the share of construction of each sector (road and railway.

ANNEX VII: DATA ON COMPENSATION PAYMENTS FOR INJURY AND DEATH

The following table shows presents data on liability insurance payments for death and injury in 2016. The data comes from reliable sources but is not comprehensive for all EU countries.

Member State	**Compensation payments €bn**	**Source and comments**
Czech Republic	0.19	Insurance Europe
Germany	5.25	Insurance Europe
Denmark	0.14	Insurance Europe
France	4.35	CCR Re
Greece	0.19	Insurance Europe
Italy	6.10	Insurance Europe
Spain	2.74	Insurance Europe
UK	3.46	Association of British Insurers, excludes claims for death
Total (7 countries, 82% EU GDP)	**22.35**	

Table 19: Comparison of 2012 and 2016 subsidy figures for plausibility check

These figures do not include gratification payments (non-insurance compensation).

To generate an estimate for total EU, the total (€22.35bn) is scaled up according to total GDP, amounting to €27bn. Conservatively, the following figure is estimated for EU28:

<u>€25bn</u>

ANNEX VIII: MARGINAL COST COVERAGE RATIOS FROM STICITE

The following table shows marginal cost coverage ratios for all modes and vehicle types, from the STICITE "Annex I Final_marginal" spreadsheet. For each vehicle type, STICITE defines three or four cost scenarios depending on attributes of the vehicle and transport system parameters (see tables below). Congestion is excluded from the calculation of the ratios to enable comparison.

Marginal cost coverage ratios excluding congestion	**External cost scenario**			
	High	**Average**	**Low**	**Very low**
Passenger car	73%	116%	283%	166%
Bus	22%	27%	35%	55%
Coach	21%	27%	51%	
Motorcycle	24%	125%	198%	646%
High-speed train	221%	329%	324%	
Passenger electric train	80%	80%	46%	
Passenger diesel train	146%	118%	98%	
Passenger aircraft	5%	2%	0%	
LCV	60%	65%	302%	106%
HGVa	18%	56%	70%	
HGVb	37%	66%	137%	
HGVc	33%	41%	114%	
HGVd	34%	33%	124%	
Freight electric train	33%	56%	29%	
Freight diesel train	45%	51%	45%	
Inland waterway	17%	194%	38%	
Maritime	70%	0%	5%	566%

Table 20: STICITE marginal cost coverage ratios excluding congestion

STICITE descriptions of cost scenarios for passenger modes

	External cost scenario			
	High	**Representative**	**Low**	**Very low**
Passenger car				
Scenario description	— Diesel EURO 3 — CO_2 emissions: 176 g/km — Daytime — Congested traffic — Large SUV — Urban road in metropolitan area	— Average vehicle — Average daytime/night — Average congestion level — Average road	— Petrol EURO 6 — CO_2 emissions: 99 g/km — Daytime — Thin traffic — Small car — Motorway in rural area	— BEV — Daytime — Thin traffic — Motorway in rural area
Externality description	— AP*: Metropolitan area - urban road — CC**: Urban — Noise: Urban, day, dense — WTT***: Urban	— Take average values for all cost categories except: • Accidents: Rural • Noise: Suburban, day, thin	— AP: Rural motorway — CC: Motorway — Noise: Rural, day, thin — WTT: Motorway	— AP: Rural motorway — CC: Motorway — Noise: Rural, day, thin — WTT: Motorway
Bus and coach				
Scenario description	— Diesel EURO 3 — CO_2 emissions: Bus: 1155 g/km / coach: 742 g/km — Daytime — Standard bus: 15-18t / coach <=18 t — Dense traffic — Urban road in metropolitan area	— Average vehicle — Average daytime/night — Average traffic flow — Average road	— Diesel EURO 6 — CO_2 emissions: Bus 954 g/km / coach 583 g/km — Daytime — Standard 15-18t — Thin traffic — Bus: Average road / coach: motorway in rural area	— Electric bus - medium — Daytime — Thin traffic — Average road
Externality description	— AP*: Metropolitan area - urban road — CC**: Urban — Noise: Urban, day, dense — WTT***: Urban	— Take average values for all cost categories except: • Accidents: Rural • Noise: Suburban, day, thin	— AP: Rural area - rural road — CC: Other road — Noise: Rural, day, thin — WTT: Bus Other road / coach Motorway	— AP: Rural area - rural road — CC: Other road — Noise: Rural, day, thin — WTT: Motorway
Aviation				
	Embraer 170 Short-haul (500 km) High emission level High noise class Night	Average airplane Average day/night	Airbus A34-300 Long-haul (15,000 km) Low emission level Low noise class Daytime	
	Embraer 170 Short-haul (500 km) High emission level High noise class Night	Average airplane Average day/night	Airbus A34-300 Long-haul (15,000 km) Low emission level Low noise class Daytime	

Table 21: STICITE parameters for external cost scenarios of passenger modes for marginal cost coverage

STICITE descriptions of cost scenarios for freight modes

	External cost scenario			
	High	**Representative**	**Low**	**Very low**
LCV				
Scenario description	— Diesel EURO 3 — CO_2 emissions: 225 g/km — Daytime — Congested traffic — Urban road in metropolitan area	— Average vehicle — Average daytime/night — Average congestion level — Average road	— Petrol EURO 6 — CO_2 emissions: 105 g/km — Daytime — Thin traffic — Motorway in rural area	— BEV — Daytime — Thin traffic — Motorway in rural area
Externality description	— AP*: Metropolitan area - urban road — CC**: Urban — Noise: Urban, day, dense — WTT***: Urban	— Take average values for all cost categories except: • Accidents: rural • Noise: suburban, day, thin	— AP: Rural motorway — CC: Motorway — Noise: Rural, day, thin — WTT: Motorway	— AP: Rural motorway — CC: Motorway — Noise: Rural, day, thin — WTT: Motorway
HGV				
HGVa: 3.5 to 7.5t rigid HGVb: 7.5 to 16t rigid HGVc: 16 to 32t rigid HGVd: > 32t articulated	— Diesel EURO 3 — CO_2 emissions: HGVa 450 g/km HGVb 716 g/km HGVc 875 g/km HGVd 1033 g/km — Daytime — Congested traffic — Urban road in metropolitan area	— Average vehicle — Average daytime/night — Average congestion level — Average road	— Diesel EURO 6 — CO_2 emissions: HGVa 370 g/km HGVb 596 g/km HGVc 716 g/km HGVd 848 g/km — Daytime — Thin traffic — Motorway in rural area	
Externality description	— AP*: Metropolitan area - urban road — CC**: Urban — Noise: Urban, day, dense — WTT***: Urban	— Take average values for all cost categories except: • Accidents – rural • Noise: suburban, day, thin	— AP: Rural motorway — CC: Motorway — Noise: Rural, day, thin — WTT: Motorway	
Reference rail vehicle				
High-speed train	Night	Average daytime/night	Day	
Passenger electric	Regional train Daytime	Average passenger train Average daytime/night	Intercity train Daytime	
Passenger diesel	Regional train Not equipped with EGR/SCR Daytime	Average passenger train Average daytime/night	Intercity Equipped with EGR/SCR Daytime	
Freight electric	Short train (bulk) Daytime High noise level	Average freight train Average daytime/night	Long train (bulk) Daytime Low noise level	
Freight diesel	Short train (bulk) Daytime High noise level Not equipped with EGR/SCR	Average freight train Average daytime/night	Long train (bulk) Daytime Low noise level Equipped with EGR/SCR	
Freight IWT vessels				
	CEMT II (bulk) CCR-1	Average vessel	CEMT Va (bulk) CCR-2	
Maritime				
	Small Vessel (container) Tier 1 500 km	N/A	Large Vessel (container) Tier 2 15,000 km	Large Vessel (bulk) Tier 2 15,000 km

Table 22: STICITE parameters for external cost scenarios of freight modes for marginal cost coverage

ANNEX IX: MINOR DISCREPANCIES

The following are discrepancies or unresolved questions that were identified in the course of this review of the publicly available documents. They are intended as an additional constructive contribution to ensure full understanding of the STICITE study.

Reporting of cost coverage ratios

Some of the cost coverage ratios have different values between the following documents. The table below presents an overview.

Key:

Tables: The tables presented in the study documents (Study Summary and State of Play).

Annex: The Excel spreadsheet Annexes E, F, G, H.

Text: The text in the study documents (Study Summary and State of Play).

xx% - original and unchanged values
xx% - values in annex different from tables by more than 1%
xx% - values in text different from tables by more than 1%

Values from exec. Summary	Overall cost coverage			Overall cost coverage excluding fixed infra costs			Variable infrastructure and external cost coverage			Total infrastructure cost coverage			Variable infrastructure cost coverage		
Passenger transport	Tables	Annex	Text	Tables	Annex	Text	Tables	Annex	Text	Tables	Annex	Text	Tables	Annex	Text
Passenger car	51%	51%	51%	63%	63%	63%	48%	48%	48%	27%	22%	22%	417%	347%	350%
Bus	17%	17%	17%	24%	24%	24%	21%	21%	21%	3%	3%	3%	6%	5%	5%
Coach	18%	18%	18%	26%	26%	26%	23%	23%	23%	3%	3%	3%	6%	6%	5%
Motorcycle	19%	19%	19%	20%	20%	20%	15%	15%	15%	35%	28%	28%	576%	473%	470%
High speed train	26%	32%	32%	145%	181%	181%	208%	258%	250%	28%	34%	34%	394%	477%	
Electric pax train	16%	20%	20%	61%	75%	75%	70%	86%	86%*	19%	23%	23%*	160%	190%	190%*
Diesel pax train	22%	23%	23%	91%	97%	97%	101%	110%		16%	18%	18%	122%	137%	140%
Aircraft	34%	32%	32%	45%	41%	37%/41%	46%	41%	37%/41%	82%	82%	82%	247%	247%	250%
Freight transport	Tables	Annex	Text	Tables	Annex	Text	Tables	Annex	Text	Tables	Annex	Text	Tables	Annex	Text
LCV	43%	36%		53%	44%		48%	39%		11%	12%		153%	177%	
HGV	26%	26%	26%	37%	36%	36%	33%	33%	33%	14%	13%	13%	44%	43%	43%
Elec. freight train	12%	13%	13%	30%	32%	32%	35%	37%	37%	16%	17%	17%	86%	90%	90%
Diesel freight train	26%	27%	27%	55%	56%	56%	61%	62%	62%	25%	25%	25%	138%	140%	140%
IWT vessel	6%	6%	6%	12%	12%	12%	13%	13%	13%	12%	12%	12%	176%	176%	180%
Maritime vessel	4%			4%			4%		4%	127%			4571%		

Table 23: Discrepancies in cost coverage ratios reported in the STICITE documents

Some values are different by up to 25%, which is a material factor. In themselves they do not necessarily lead to different conclusions, but the magnitude of the differences can have an impact on the strength of those conclusions.

Duplicated charts

The charts in the Study Summary for “Average external and average variable infrastructure costs vs. average taxes/charges for passenger transport” and for “Average variable external and infrastructure costs vs. average variable taxes/charges for passenger Transport” are identical. These represent the data for cost coverage ratios 2 and 3 respectively.

ANNEX X: RECOMMENDATIONS FOR FURTHER STUDY

Derived from our analysis, we have determined a number of potential additional areas of study that go beyond the scope of this review. These would enhance understanding of the respective areas and provide additional insight into the key questions regarding external costs and internalisation.

Accident underreporting

As indicted in Section 4.2.2, the available data to estimate underreporting of accidents, in particular injuries, is not sufficiently mature to reach robust conclusions. Most studies are over 10 years old and the more recent quoted study has a narrow scope. In-depth analysis is necessary to determine if there have been significant changes since the 2006 study from which the data are quoted. This could potentially result in material impacts on the calculated accident costs.

Congestion costs

Further detailed investigation of the nature and extent of external congestion costs and the impacts of internalisation would enhance understanding. There remain complicated questions about the magnitude and interpretation of the external part of congestion costs. How internalisation and other measures can impact congestion in practice and achieve societal objectives is a relevant area of study. To be comprehensive, this work would require a dedicated study.

Comparable congestion cost evaluation for non-road modes

To provide relevant and workable conclusions on congestion costs, a full comparison between different modes of transport would be informative. This would build on the work outlined in the STICITE study, enabling systematic comparison with road congestion, taking into account both congestion and scarcity costs. Ideally it would link to any additional work performed to characterise congestion costs (see above).

Urban transport

Including urban transport in the scope of future study on external costs and revenues would ensure a fully comparable assessment, since urban road transport is currently included.

Subsidies

Further study to evaluate and transport subsidies and characterise their relevance to internalisation would be informative. The relevant information comes from individual Member States and is therefore in non-standard form, lacking straightforward comparability and difficult to interpret. A dedicated study would be necessary for a comprehensive treatment. The scope could also extend to urban transport, as addressed above.

ANNEX XI: CONTRIBUTIONS FROM STAKEHOLDERS DURING THE COURSE OF THE REVIEW

Outreach to industry, academia and civil society was undertaken in the course of writing this review.

One dedicated meeting was held with representatives of associations representing road users (cars, powered two-wheelers, commercial vehicles) and of academia.

Informal individual meetings, email exchanges and telephone calls were held with representatives of the other sectors referred to in the STICITE study.

Informal individual meetings were also held with representatives of two civil society organisations.