Supporting the driver in conserving energy and reducing emissions

ecoDriver

D54.1: Costs and benefits of green driving support systems

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Abstract	This report describes the methodology and results of the scaling up and cost-benefit analysis in the ecoDriver project.

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Executive Summary

Sub Project 5 (SP5) of the ecoDriver project draws on all the evaluations carried out in the project, to predict the impact of the ecoDriver systems in the future. SP5 produced results with which it is possible to compare estimates about the costs and benefits of the suggested green driving support systems on the EU-28 level in various scenarios, both for society as a whole and for sub-groups such as manufacturers and consumers. Earlier in the project, SP5 constructed a set of possible scenarios for the future depending on various road maps envisioned today. In the scenarios, the traffic mix and ecoDriver market penetration were varied, as well as the vehicle fleet mix, new vehicle purchase shares by fuel type/powertrain and the overall traffic demand by road type. The scenarios used were called Green Future, Policy Freeze and Challenging Future. Policy Freeze is the closest to a 'Business-as-Usual' scenario, whilst Green Future and Challenging Future present alternatives on either side of this. Green Future assumes high fuel prices, supportive attitudes and policies and fast technology development. Challenging Future assumes low fuel prices, unsupportive attitudes and policies and slow technology development. Market penetration rates of ecoDriver systems are assumed to vary over time and across scenarios: projections including both embedded systems and low-cost mobile-app-based systems reach between 45% (Challenging Future, for cars) and 79% (Green Future, for cars) by 2035. Projections were also done for drivers' compliance with the ecoDriver systems' advises: assuming up to 92% of the car drivers to be fully compliant by 2035 in the Green Future; and down to 60% of the car drivers to be fully non-compliant by 2035 in the Challenging Future. The impact of the ecoDriver systems on traffic flows in those scenarios was then simulated in microscopic traffic models, using small networks comprising motorways, rural roads and urban roads. Results from the field trials with the Full ecoDriver System (FeDS) and the ecoDriver smartphone app were used in the simulations, to model the changes in driving behaviour. In the final task of SP5, the results for these small networks were scaled up to the EU-28 level, and a cost-benefit analyses was carried out with the scaled-up results.

For the scaling up, data from many sources had to be combined, to produce statistics at the aggregate level needed for the evaluation of the impacts of the ecoDriver systems. This meant that data were needed that distinguished between situations in which the ecoDriver was expected to have more or less impact, such as the level of service (from free flow to congested) but also geometric characteristics such as the density of intersections and junctions. Most statistics on mileage at the EU- or country level are not that detailed, so information had to be added from other sources, such as detailed information about the road network in each NUTS 3 region in the EU, as well as the number of inhabitants of these regions and the amount of delay reported for countries and urban areas. The scenarios provided information to produce prognoses for future years.

Figures S.1-S.3 show the scaled-up effect sizes for each of the three scenarios, for the year 2035 (effects are also available for the years 2020, 2025 and 2030). The figures show the % change between a situation with and without ecoDriver. The effect on emissions and energy consumption is as intended (a decrease) but quite small at the EU-28 level. The size of the effects varies from a decrease just above 0% to about 1.7%. Effects are largest for the Green Future scenario and smallest for the Challenging

Future scenario. Rural roads contribute the most to these effects, because rural roads have the highest effect sizes and the highest share in total EU-28 mileage (as compared to motorways and urban roads).

The figures show that the safety effects are quite large compared to the environmental and traffic efficiency effects. Also, the effects are clearly the largest in the Green Future scenario. This scenario has the highest penetration and compliance rates of the three (as well as the highest share of environmentally friendly vehicles). The effect sizes at the EU-28 level are smaller than the ones found in the simulations, because ecoDriver is assumed to have no effect in congested traffic (where the ecoDriver advice is generally not relevant, e.g. advice to slow down for a lower speed limit). They are also smaller than the effects found in the field trials, because the scenarios assume lower than 100% penetration and compliance rates.

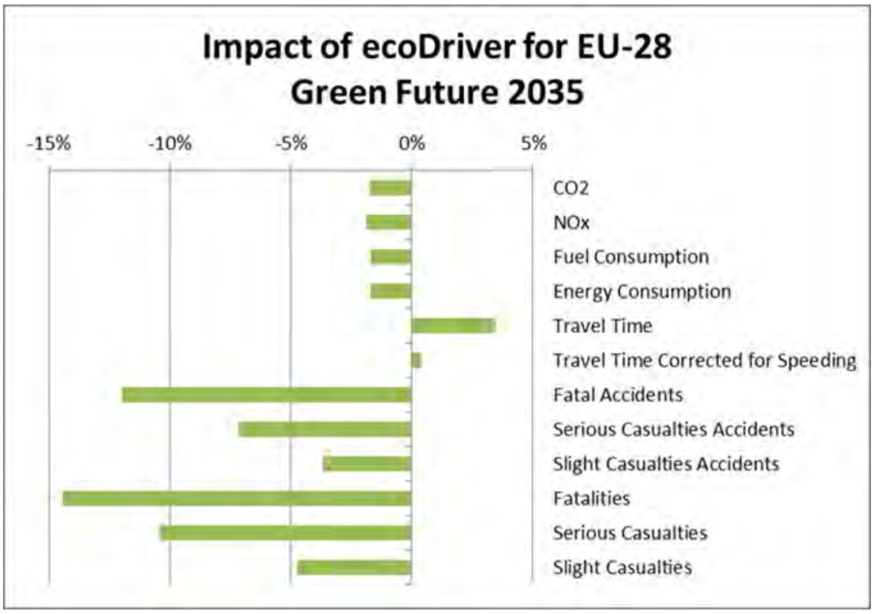

Figure S.1: Impact of ecoDriver systems for scenario Green Future 2035, for EU-28

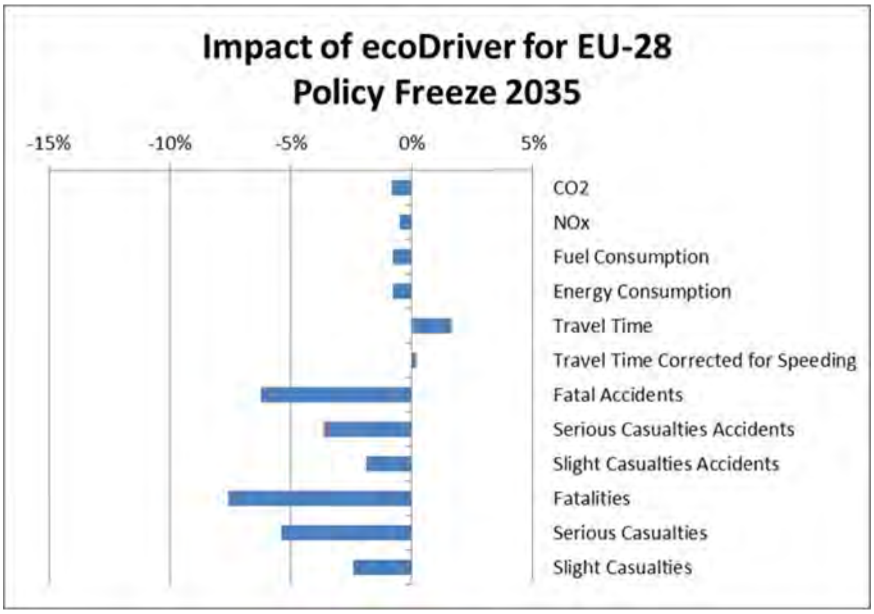

Figure S.2: Impact of ecoDriver systems for scenario Policy Freeze 2035, for EU-28

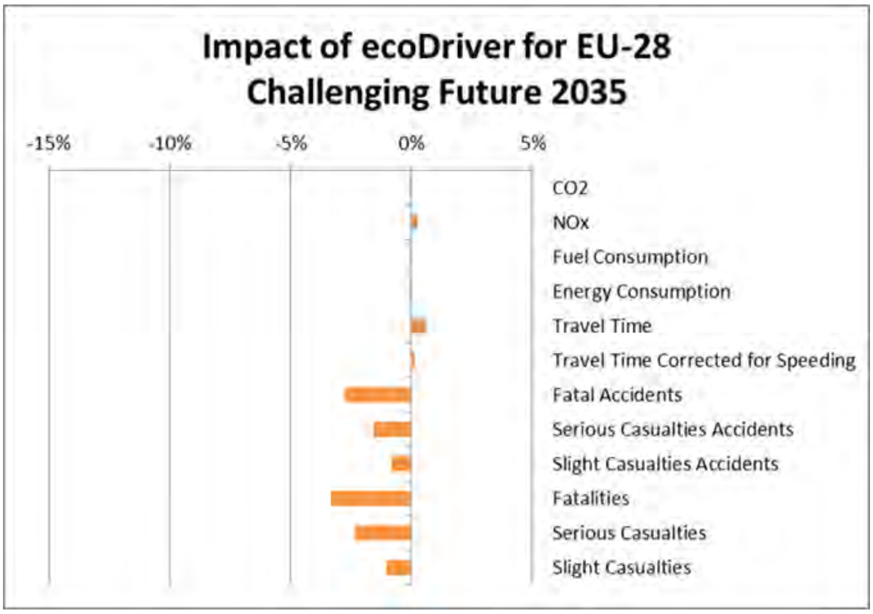

Figure S.3: Impact of ecoDriver systems for scenario Challenging Future 2035, for EU-28

The cost-benefit analysis (CBA) used established methods that have previously been used to appraise EU transport policies and projects. The approach followed the FESTA Handbook (FOT-Net, 2014, and previous versions) and adopted the latest research evidence and valuation guidance for the EU. It is a scenario-based CBA: we tested not only whether ecoDriving is a good investment in a Business-As-Usual type world (the 'Policy Freeze' scenario), but also its robustness to a widely supportive future scenario ('Green Future') or in a widely unsupportive one ('Challenging Future'). The analysis contained both a Social CBA and a Stakeholder CBA.

The overall benefit:cost ratio is considered to be good for the Policy Freeze and Green Future scenarios at around 2. For the Challenging Future scenario the costs are greater than the benefits: the BCR falls below 1. The stakeholder CBA shows that we can be reasonably confident the system is worth purchasing for drivers. This depends not only on their own fuel saving but also on whether other benefits are big enough, because there are substantial time losses which weigh on the driver and because there are some substantial benefits which accrue, in part, to 'others' on the road, i.e. the safety benefits. For buses and trucks, the case for the ecoDriver system is very positive. Also for a representative European diesel car with the typical mileage, the fuel savings would easily justify purchasing the ecoDriver system.

The results from the field trials (determined in SP4) show that the effectiveness of the ecoDriver system could be twice as high as the effects found in the simulations in SP5, if the implementation of the ecoDriver system is optimised further. Assuming that a version of the ecoDriver system can be developed that enables drivers on the road to achieve that increased level of fuel/energy and CO_2 savings, we have carried out a sensitivity analysis of the CBA results to determine what that would mean for the benefit:cost ratio and other CBA results. The impact on the Net Present Value (NPV) is strongly positive, whilst the BCR to government remains just 'good' – this is because the cost to government increases due to loss of indirect tax revenue (fuel taxes).

It is unclear if these extra savings would be achieved by driving at lower speeds (lower than found with the version of ecoDriver that we evaluated in this deliverable), which would mean that there are also other effects, such as on travel times and safety, that need to be quantified. It is also not clear whether a more effective version of the ecoDriver system would need additional hard- or software (such as a haptic gas pedal) and what this would mean for the costs of the system. However, if the ecoDriver system can be engineered to achieve higher benefits at a cost of €250 per unit for the embedded system (the 'FeDS', whilst the mobile app would have a nominal €15 charge and a correspondingly lower level of performance) then the case for several stakeholders looks stronger.

The scaling up and cost-benefit analysis provided valuable insights into the impacts of ecoDriver on the EU-28 level, and showed that in all scenarios explored ecoDriver has the potential to decrease energy use and emissions, and the number of accidents and casualties.

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Glossary of terms

Term	Description
Cost-benefit analysis	A cost-benefit analysis can be defined as a systematic process for calculating and comparing benefits and costs of a project, in this case the roll-out of different variants of the ecoDriver system in different future scenarios
Scaling up	Translating results (e.g. effects of a system) on a small or local scale to results on a larger scale (e.g. EU level)

Acronyms

Acronym	Description
BCR	Benefit:cost ratio
CBA	Cost-benefit analysis
CF	Challenging Future (scenario name)
EV	Electric vehicle
FeDS	Full ecoDriver System
HMI	Human Machine Interface
GF	Green Future (scenario name)
NPV	Net Present Value
OEM	Original Equipment Manufacturer
PF	Policy Freeze (scenario name)
PHEV	Plug-in hybrid electric vehicle
SP	Sub project
TOE	Tonne of oil equivalent
VE3	Vehicle Energy and Environmental Estimation
WP	Work package
WTP	Willingness to pay

1. Introduction

1.1 Overview of the project

The global aim of the ecoDriver project was to deliver the most effective advice to drivers on fuel efficient driving by optimising the driver-powertrain-environment feedback loop. More specifically, the focus of the project was on the interaction between technology and the driver, since the behaviour of a driver is a critical element in energy efficiency. Advice to drivers covers the whole spectrum, from previewing the upcoming situation, optimising the current driving situation, to post-drive feedback and learning. The aim of the project was to optimise human machine interfaces (HMIs) and advice to drivers for both portable devices within the vehicle which provide assistance to the driver (nomadic devices) and built-in systems, and to compare the effectiveness of each. This was addressed across a wide range of vehicles — e.g. cars, light trucks and vans, medium and heavy trucks and buses — covering both individual and collective transport. Lastly, the project did not only examine (in both the field trials and the simulations) driving with current and near-term powertrains, but also with a full range of future vehicles, including hybrid and plug-in electric vehicles.

By increasing the acceptance of eco-driving applications through intelligent HMI and advice solutions, the ecoDriver project substantially contributes to the Europe 2020 goals through a much needed reduction of gas emissions and energy usage in transport, and thereby a significant reduction in the negative impact of transport on the environment.

The detailed aims of the ecoDriver project were to:

1. Investigate how best to win the support of the driver to obtain the most energy-efficient driving style for optimal energy use, with regard to preview, the current situation, and post-drive feedback and learning
2. Assess this across a wide range of vehicles — e.g. cars, vans, light and heavy trucks and buses – covering both individual and collective transport
3. Explore and evaluate alternative HMIs and styles of advice
4. Consider driver behaviour with a wide range of current and future powertrains, including internal combustion (both petrol and diesel), hybrid and electric, and provide the optimum advice for each powertrain
5. Consider driver style, driver learning, and consider how the systems can affect driving style
6. Look at the impacts of eco-driving support on driver attention and safety
7. Look at a variety of impacts: CO_2 (carbon dioxide), NO_x (nitrogen oxide), particulates etc. and the balance between impacts
8. Consider how the observed effects on driving style would affect network-wide energy use and a variety of aspects of network performance including network efficiency
9. Consider scenarios for future powertrain adoption, and how eco-driving might affect the road networks of the future
10. Perform a cost benefit analysis considering a range of scenarios of powertrain adoption.

1.2 This deliverable

1.2.1 Scope SP5 – Scaling up and future casting

The aim of Sub Project 5 (SP5) was to predict the impact of a variety of systems and solutions in the future, drawing on all the evaluations carried out in the project. With the results of SP5 it is possible to compare estimates about the costs and benefits of the suggested green driving support systems on the EU-28 level in various scenarios, both for society as a whole and for sub-groups such as manufacturers and consumers. SP5 has constructed a set of possible scenarios for the future depending on various road maps envisioned today. The predictions for future years have been made based on available data from within and outside of the project, and on advanced microscopic traffic modelling. Thus, the predictions are well anchored in state-of-the-art knowledge. SP5 took the following steps to meet the objectives:

- Collect data needed for scaling up and developing scenarios
- Create a range of scenarios
- Assess the network implications of green driving support systems for future networks
- Predict the EU-wide impacts for a range of systems and scenarios
- Carry out a cost benefit analysis for a range of systems and scenarios

1.2.2 Scope of the report

This report is the result of WP54 of the ecoDriver project: Scaling up and cost-benefit analysis. The objective of this work package was to predict the impacts for a range of systems and scenarios on the EU level, and to carry out a cost-benefit analysis for the same range of systems and scenarios. The first task (T54.1) of the work package translated the outputs that WP53 provided (presented in D53.1 (Olstam et al., 2016)) on traffic efficiency impacts, energy consumption and emissions impacts and safety impacts on a small scale to the whole of Europe. In the second task (T54.2) all costs and benefits on the EU level were determined. This was done for all scenarios and future years considered (see paragraph 2.3); in the main text of this report, the most representative and especially interesting instances are discussed (in terms of scenarios and points in time). To determine the costs, data were collected and additionally input from stakeholders was used. To determine the benefits, the scaled-up impacts were monetised. The social cost-benefit analysis was carried out for a 20 year period from 2015 to 2034. The third task (T54.3) made use of the full social cost-benefit analysis carried out in T54.2, and looked at other perspectives, such as the user (buyer of the system) level and the producer (seller of the system) level.

1.2.3 Structure of the report

This introduction is followed by Chapter 2 that gives background information on the ecoDriver systems, the framework for scaling up and future casting, the scenarios and simulation results. This background information is a prerequisite for reading and understanding the remainder of this report. Chapter 3 contains the methodology for scaling up and cost-benefit analysis. For both scaling up and cost-benefit analysis different types of data from different sources were needed. Chapter 4 contains a description of the data collection and preparation processes. The results of the work package are given in Chapter 5 (scaling up) and Chapter 6 (cost-benefit analysis). In Chapter 7 the implications for the ecoDriver project are described. After this the references and Annexes are given.

2. Background information

This chapter contains background information on the project: information on the ecoDriver systems, the framework for scaling up and future casting, scenarios and simulation results. This background information was used as input for the scaling up and cost-benefit analysis tasks and is therefore a prerequisite for reading and understanding the remaining chapters of this report.

2.1 ecoDriver systems

The ecoDriver systems give advice to drivers on fuel-efficient driving by optimising the driver-powertrain-environment feedback loop. The system can either be embedded (built-in) or nomadic (on a portable device). The ecoDriver systems use a vehicle energy and environment estimator, that runs on-line in vehicles and utilises on-board (sensor) information and an e-horizon functionality based on digital map data (information about speed limits and speed limit changes, curves, gradients and preceding vehicles). With these data, a signal is generated for eco-friendly driver guidance, which is relayed to the driver via a human-machine interface. The driver is provided with speed and gear advice.

The ecoDriver systems have been implemented in test vehicles that drove in field trials in France, Germany, the Netherlands, Spain, Sweden and the UK. A mix of controlled and naturalistic trials was carried out, with various types of vehicles, e.g. passenger cars, trucks and buses, but also different powertrains, including hybrid, plug-in hybrid and fully electric vehicles. Nine different systems were tested in the real world trials that were conducted in SP3. Five systems were developed by OEMs (CRF, Daimler, BMW), one system by TomTom, an ecoDriver app by IFSTTAR and CTAG and the Full ecoDriver System (FeDS) by mainly CTAG and TNO. The systems differed in the information they used to provide advice and/or feedback to the driver, the way the HMI operated and the events on which advice and/or feedback was provided. This paragraph provides a coarse overview of these systems. For more detailed information (e.g., what was exactly shown in the HMI, how the systems exactly operated) the reader is referred to the underlying ecoDriver deliverables of SP1, SP2 and SP3 (available on the ecoDriver website: http://ecodriver-project.eu).

The FeDS and the nomadic ecoDriver app were simulated in micro simulation models (see paragraph 2.4 and (Olstam et al., 2016)). Detailed descriptions of the FeDS and the ecoDriver app are available in ecoDriver deliverables D22.1 (Ivens et al., 2013a) and D22.2 (Ivens et al., 2013b). A short description and some visualisations follow below.

2.1.1 Full ecoDriver System (FeDS)

The HMI of the Full ecoDriver System (FeDS) was developed within the project, mainly by CTAG, and its behaviour was developed through interactions between CTAG, TNO, IKA, VTI, and ITS Leeds. Since it was used in different vehicles the information to the driver was presented on a Samsung Galaxy Note II tablet. The main screen of the FeDS is presented in Figure 1. The speedometer was shown with the current speed and the speed advice (in green), the current gear was indicated including gear shift advice, performance of the driver was indicated through green circles against a background of a tree indicating the eco-driving performance (five filled circles indicated excellent eco-driving performance and none a poor performance). The FeDS had the possibility to distinguish eco-driving performance at different levels (the level was indicated by a bronze, silver or gold coin on which the driver's chosen 'avatar' was standing). However, the feature of different levels was not used in the real world trials. Figure 1 show a situation when current speed is at the advised speed and the current used gear is equal to the advised gear.

Figure 1: Example of HMI of the Full ecoDriver System (FeDS): Main screen of FeDS.

The advised speed was shown continuously. Advice to change speed was provided for the following events:

- approaching an intersection
- approaching a lower speed limit
- approaching a curve
- approaching a preceding vehicle

After the occurrence of an event the driver received feedback on her/his performance. This was done by rating the performance by giving stars, with five highlighted stars indicating the best performance. As an example the advice and feedback for a curve are presented in Figure 2.

Figure 2: Advice to slow down for a curve (left) and the feedback on performance with a perfect score (right).

2.1.2 EcoDriver app

The ecoDriver application was developed within the project by IFSTTAR. It shares HMI features with the FeDS as described in the previous section. The ecoDriver app provides feedback analysis on acceleration, deceleration and gear shifting behaviour but it also displays feedforward information and advice about upcoming events (junctions, sharp curves, slopes, traffic lights, roundabouts, speed limits). The main difference from the FeDS is the sensor information used to provide advice and feedback to the driver.

The main screen of the ecoDriver app is presented in Figure 3. Drivers could choose to show the performance tree or a map that was used for navigation. No speed advice was presented.

Figure 3: The main screen of the ecoDriver app with the performance tree (left) or with a map (right).

The ecoDriver app provided information, feedback and advice on the following events

- crossing an acceleration/deceleration threshold (see Figure 4)
- on time or too late gear shift (see Figure 5)

- approaching intersection
- going downhill
- approaching a curve (see Figure 6)
- approaching a pedestrian crossing
- the posted speed limit

Figure 4: Feedback on harsh acceleration (left) and deceleration (right)

Figure 5: Feedback on gear shift performance

Figure 6: Example of an advice to decelerate and the reason for deceleration (in this example a sharp curve)

2.2 Framework for scaling up and future casting

For the scaling up and future casting of the ecoDriver systems, four major work items were carried out in SP5:

- Development of scenarios (WP52)
- Traffic simulations (WP53)
- Scaling up (WP54)
- Cost-benefit analysis (WP54)

These four steps followed each other and made use of each other's output and work. Besides this, data from other SPs in the project and external data were needed. This is illustrated in Figure 7, where an overview of the work in SP5 and the data flows is given: the analysis framework. The green blocks contain the work items of SP5 and the white blocks contain input data, from within the project (white blocks on the left) and external data (white blocks on the right).

First, scenarios were developed in WP52. These scenarios describe possible futures (up to 20 years ahead) with respect to powertrain distributions, mileage, uptake of new technologies etc. – see paragraph 2.3 for a description of the scenarios. The scenarios were then used as input for the simulations in WP53. For this, the scenarios were transformed into inputs as needed by the traffic simulation models, such as penetration rates of ecoDriver equipped vehicles, compliance levels and traffic composition (with 4 vehicle classes: car, van, truck and bus). This was done for four future years: 2020, 2025, 2030 and 2035. The choice of a 20 year horizon, set out in the Description of Work, was based on a desire to capture the benefits over a period covering the expected life of the equipped vehicles and allowing for fleet turnover, whilst recognising that vehicle technology is fast-changing and a judgement that ecoDriver technology could be overtaken before the 30/40/60 year horizon usually used for infrastructure. 20 years is consistent with other in-vehicle technology assessments, e.g. the Freightliner FOT (Batelle Memorial Institute, 2003).

The simulations covered several road types. The lay-out of the (small) networks modelled was chosen such that the resulting networks could be considered representative for the European road network (a visual check was done using road map data from various countries, e.g. checking average intersection densities). Table 1 shows for which road types networks were built. First, a distinction was made between motorways, rural roads and urban roads (categories widely used, e.g. in statistics): road type level 1. Two variations of each road type were modelled, to reflect different lay-outs (for which the ecoDriver systems might give different advice or with a different frequency): road type level 2. For rural and urban roads, both flat and hilly networks were modelled. This was not done for motorways as we did not have sufficient data to model the behaviour of drivers of either equipped or unequipped vehicles on hilly motorways. For each network in Table 1, two demand levels were modelled: low demand (approximately free flow) and moderate demand (some interactions between vehicles). Congested traffic was not modelled, because the ecoDriver systems are very unlikely to generate advice in congested traffic. In the simulations, driver models with distributions of driving behaviour have been used. In theory they represent different drivers as can be found across Europe. However, we did not have data per country to verify how representative this modelled behaviour is in reality. In order to do this, data at a very detailed level would be needed.

Because of the decision to work with three scenarios, a variety of networks that we have chosen in such a way that they are reasonably representative for all kinds of European roads, and variation in driving behaviour, we believe that we have taken into account differences between countries in policy ambitions, road networks and driving styles in a sufficient way. For more information on the simulations, see (Olstam et al., 2016). For the scaling up (and subsequently the CBA), an effect size of 0% was assumed for all situations not modelled.

Table 1: Road networks modelled

Road type (level 1)	Road type (level 2)	Hilliness
Motorways	Interurban	Flat
	Urban	Flat
Rural roads	High intersection density	Flat
	High intersection density	Hilly
	Low intersection density	Flat
	Low intersection density	Hilly
Urban roads	Compact	Flat
	Compact	Hilly
	Spacious	Flat
	Spacious	Hilly

For the modelling of green driving support systems, results on driver behaviour and use from SP4 were used. The traffic simulations enabled us to draw conclusions on a traffic flow level. Three types of impacts were calculated with the output from the traffic simulations: environmental, traffic safety and traffic performance (or traffic efficiency) impacts. The results of the simulations are summarised in section 2.4.

The outputs of the traffic simulations (impacts on a small scale) served as input for the scaling up in T54.1. The results were translated to the whole of Europe (EU-28). This scaling up was done based on statistical data, for example vehicle kilometres by road type.

The last step in SP5 was the cost-benefit analysis (T54.2). In this task all costs and benefits for EU on a societal level (as well as for some specific stakeholder perspectives) were determined.

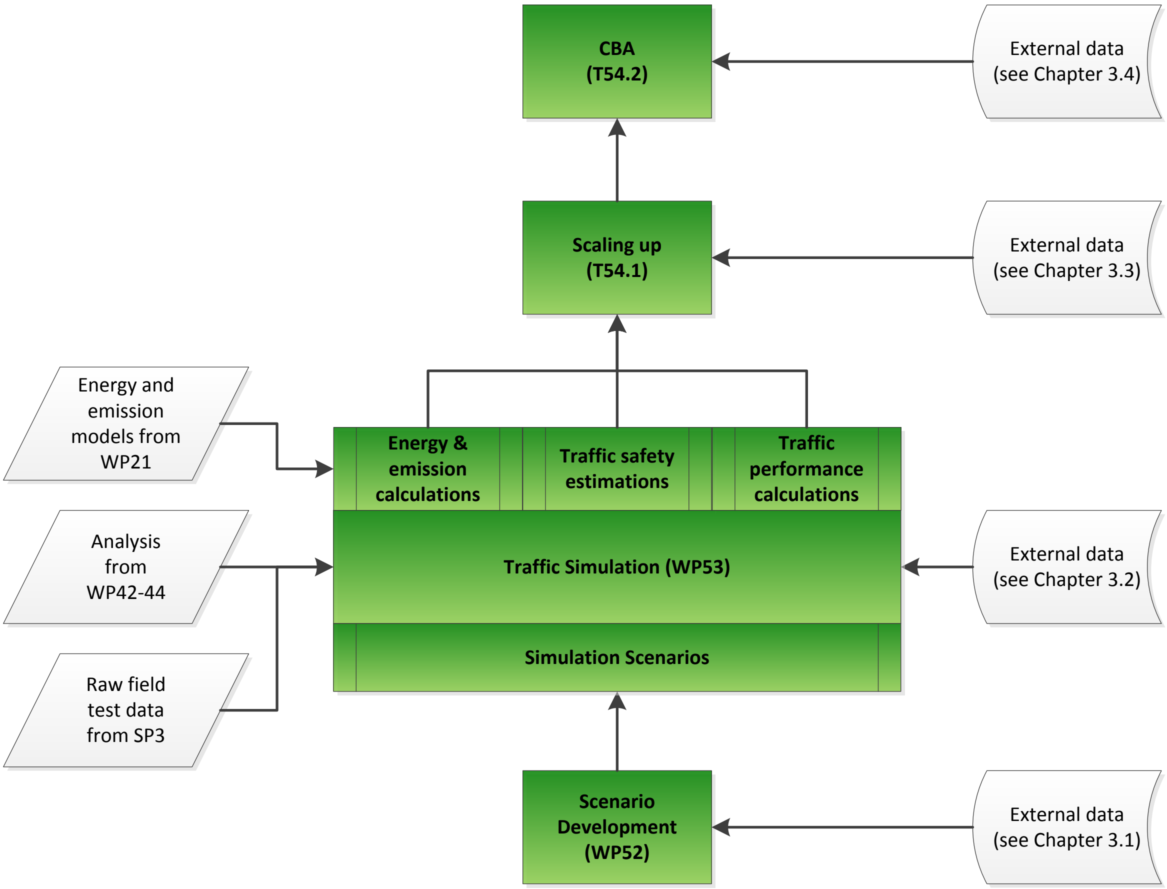


Figure 7: Overview SP5 analysis framework and data flow

2.3 Scenarios

The simulation of future traffic (WP53) and the scaling up and CBA (WP54) both required projections of future vehicle fleet, traffic and market penetration of ecoDriver systems. WP52 developed a set of scenarios to meet these needs, including qualitative and quantitative descriptions of the scenarios (Jopson et al, 2015). The scenarios are based on the research team’s synthesis of the evidence emerging from data collection work, a set of focus groups held across different countries (Table 2), and original stated preference (SP) analysis examining consumers' preferences for ecoDriver systems (Jopson et al, 2015).

Table 2: Focus groups

Country	Topic/Market Segment
UK	Passenger systems
UK	Freight systems
Sweden	Energy policy
Italy	Technical feasibility
Netherlands	Lease/fleet systems
Netherlands	Vehicle equipment and manufacturers

2.3.1 Contextual scenarios

Three overarching scenarios were developed: these were called ‘Green Future’ (GF), ‘Policy Freeze’ (PF) and ‘Challenging Future’ (CF). They cover a range of assumptions about the level of support for green driving, given: the outlook for fuel prices over the next 20 years; the pace of technological development in vehicle efficiency; drivers’ acceptance and likely uptake of systems; and wider policy and economic contexts. ‘Policy Freeze’ is the closest to a ‘Business-as-Usual’ scenario, whilst ‘Green Future’ and ‘Challenging Future’ present alternatives on either side of this, in terms of the factors cited above – see Table 3.

Table 3: Contextual scenarios in ecoDriver

Scenario	Fuel price outlook	Supportive attitudes and policy	Technology development
Green Future	High	Yes	Faster
Policy Freeze	Central	No	Slower
Challenging Future	Low	No	Slower

For the traffic simulations (WP53), the key data requirement was the future traffic mix, by road type, vehicle type and powertrain/fuel type. Table 4 gives an example of the scenario results: this is the urban traffic mix in the 'Green Future' scenario. The results for the other road types (rural roads and motorways) and contextual scenarios were given in Jopson et al (2015). Note the relatively strong growth of hybrids and EV/PHEV cars in this scenario, towards 23.7% of car km in the year 2035. This corresponds to 61% of new car purchases being hybrid/EV/PHEV by 2035 (Figure 8). For comparison, Norway – probably the most advanced market for electrified cars – had a market share of 20.7% in these categories in 2014 (comprising 12.6% EVs, 1.2% PHEVs and 6.9% hybrids) (ICCT, 2015).

Table 4: Projected traffic shares by road type and vehicle type, 2015-2035, ‘Green Future’ scenario, urban (non-motorway) roads, % of vehicle km

Vehicle type	Fuel type	2015	2020	2025	2030	2035
Car	Petrol	55.3%	49.6%	45.4%	41.1%	34.3%
	Diesel	43.7%	48.4%	50.0%	48.6%	42.0%
	Hybrid	0.7%	1.5%	3.4%	7.8%	18.2%
	Gas	0.1%	0.1%	0.0%	0.0%	0.0%
	EV	0.1%	0.3%	0.8%	1.9%	4.1%
	PHEV	0.0%	0.1%	0.3%	0.6%	1.4%
	Other	0.0%	0.0%	0.0%	0.0%	0.0%
	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Van	Petrol	2.7%	2.1%	1.7%	1.5%	1.3%
	Diesel	97.0%	97.5%	97.7%	97.2%	95.4%
	Gas	0.2%	0.1%	0.1%	0.1%	0.0%
	EV	0.1%	0.2%	0.4%	0.9%	2.2%
	Hybrid+Other	0.0%	0.0%	0.1%	0.4%	1.1%
	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Truck	Diesel	100.0%	100.0%	99.9%	99.7%	99.2%
	Hybrid	0.0%	0.0%	0.0%	0.0%	0.0%
	EV	0.0%	0.0%	0.1%	0.3%	0.8%
	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%
Bus	Diesel	99.7%	99.4%	98.7%	97.0%	92.7%
	Hybrid	0.2%	0.5%	1.1%	2.6%	6.3%
	Gas	0.0%	0.1%	0.1%	0.1%	0.1%
	EV	0.0%	0.0%	0.1%	0.3%	0.9%
	SUBTOTAL	100.0%	100.0%	100.0%	100.0%	100.0%

Key: EV - full electric vehicle; PHEV - plug-in hybrid electric vehicle.

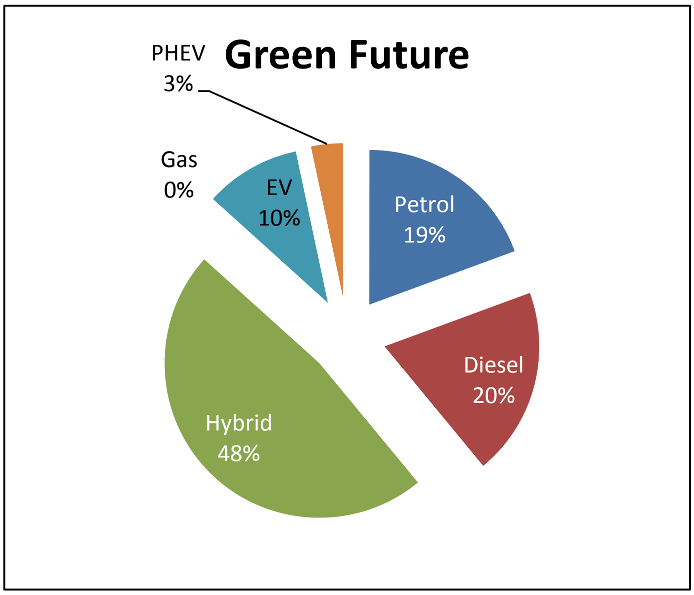


Figure 8: Shares of new car purchases by fuel type in the Green Future scenario, 2035

A significant step towards developing the projected traffic mix was to develop a projection of the *vehicle fleet*, across cars, vans, trucks and buses. This was done with aid of detailed historic data series, transportation elasticities from the literature, and projections of key factors such as real GDP, population and fuel prices, and also constraints imposed by the capacity of the network through increasing travel time and delay. An elementary scrappage model was combined with projections of new vehicle purchases based on evidence from the earlier focus groups and the SP survey (Jopson et al., 2015).

2.3.2 Market penetration of ecoDriver systems

For the CBA, it was also important to have predictions of the take-up of ecoDriver systems, in order to compare the 'with ecoDriver' and 'without ecoDriver' scenarios. The take-up of ecoDriver systems was assumed to be influenced by their availability on one hand and the demand for them on the other. Key aspects of equipment availability are: the ownership of smartphones, which enables use of the mobile app; the presence of the full ecoDriver system (FeDS) pre-fitted to vehicles; and the prices associated with each option. We assumed that the FeDS is not available for retrofit to existing vehicles: this was considered and rejected as a possibility within reasonable cost limits. We also assumed that the ecoDriver mobile app is itself essentially free of charge (a nominal charge of €15 was assumed) – focus groups found that this was expected by the market, and take-up would be deterred otherwise. The lifetime cost of the FeDS was assumed to be €250 based on an analysis of available data (see section 4.3 for more detail). Figure 9 and Figure 10 show the results in terms of shares of the vehicle fleet.

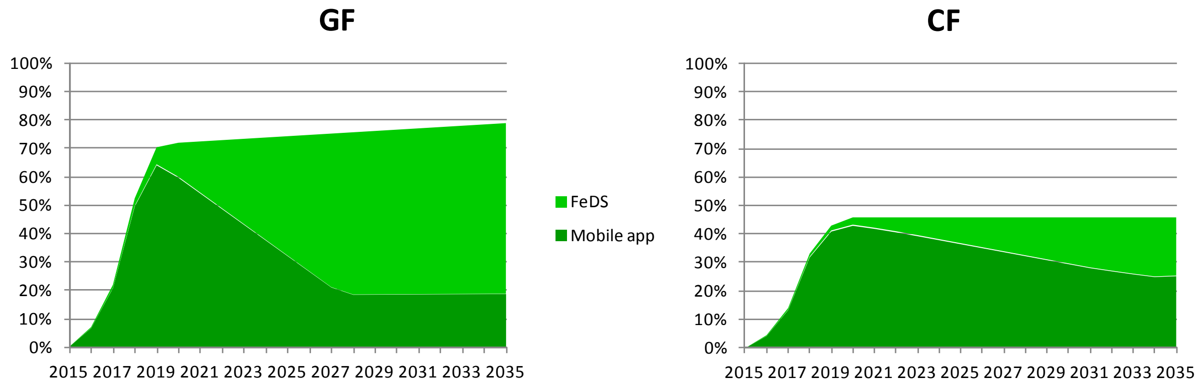


Figure 9: Projected market penetration of ecoDriver systems, Green Future and Challenging Future scenarios, use by car drivers, 2035

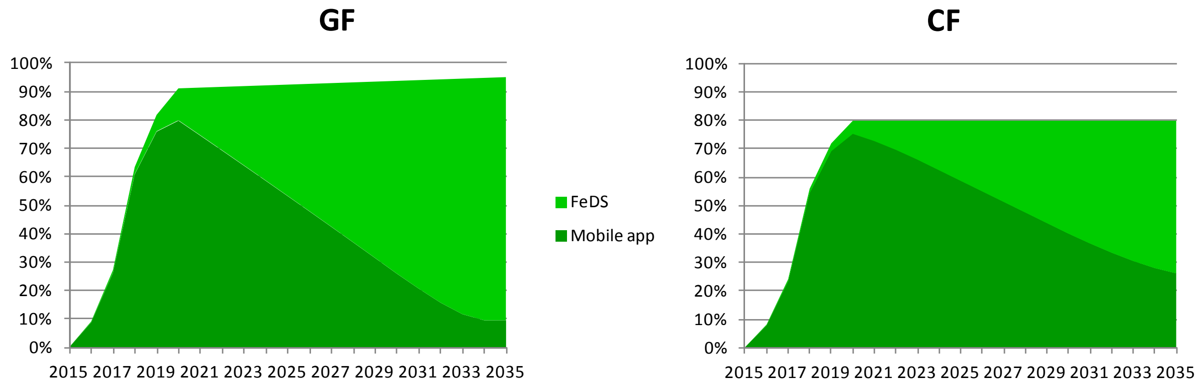


Figure 10: Projected market penetration of ecoDriver systems, Green Future and Challenging Future scenarios, use by goods and bus drivers, 2035

It is not sufficient for an ecoDriver system to be fitted to the vehicle – the driver must choose to use it (or conversely choose not to switch it off if that option is available). In our survey, 38% of car drivers indicated they would not use an ecoDriver system if fitted in the current situation (we assumed this would shift substantially in the Green Future). The Focus Groups suggested the benefits are greater and the commercial imperative to fit and use ecoDriving systems is stronger in the commercial vehicle market (goods vehicles and buses). These factors are reflected in Figures 9 & 10 above.

In the early years, mobile app take-up is strongest, because the main user requirement is simply ownership of a smartphone, and smartphone ownership is rising through 80% (2015), 90% (2017) and expected to reach saturation at around 92% by 2018 (Jopson et al., 2015). By contrast, the FeDS takes longer to integrate into the vehicle fleet. However, the FeDS offers an advantage in fuel savings, which is attractive to most users – except those who drive a low mileage or have attitudes that are resistant to the use of in-vehicle technologies to improve driving efficiency. Consequently over time the FeDS becomes dominant in the Green Future. In the Challenging Future, the FeDS share is smaller, since private car drivers are assumed to maintain their current attitudes such that 38% will not use an ecoDriver system if fitted. For goods vehicles and buses, ecoDriver systems are assumed to be purchased purely on cost saving grounds. These vehicles also have high annual mileages. This leads to higher market penetration for these vehicle types. Take-up is not instantaneous for the mobile app or the FeDS: instead there is assumed to be an S-shaped product take-off curve in the first 5-9 years starting from 2015. Combined with the mobile app's early years advantage, this results in an n-shaped profile of market share for the mobile app, rising initially and then falling as the FeDS replaces it in the fleet.

2.3.3 Other outputs

The scenario analysis produced a range of outputs. In addition to the traffic mix and ecoDriver market penetration, the results included:

- vehicle fleet mix;
- new vehicle purchase shares by fuel type/powertrain;
- overall traffic demand by road type.

Results were set out in the WP52 report (Jopson et al, 2015).

2.4 Simulation results

2.4.1 Simulation approach

The traffic system impacts of the scenarios were quantified by means of traffic simulation modelling on the microscopic (vehicle) level, for small networks. A set of different road environments, i.e. motorway corridors, rural roads and urban street networks, flat and hilly, with different levels of traffic demands, was modelled and multiple simulation runs were carried out. To facilitate analysis of the impacts of different implementation paths in the scenarios, runs were also carried out for future years, with penetration rates of ecoDriver increasing over time, and with varying vehicle fleet compositions and compliance rates as consistent with the scenarios. For each scenario – future year combination, the with ecoDriver case was compared to the without ecoDriver case, making it possible to examine the specific effect of the ecoDriver system. The scenarios were assumed to have a common starting point in 2015 for which the penetration rates of ecoDriver systems were assumed to be zero. The performance indicators that have been produced by the traffic simulations and that have been used by the scaling up and cost-benefit analysis are given in Table 5.

Table 5: Performance indicators used in ecoDriver (simulations, scaling up and cost-benefit analysis)

Performance indicator	Unit	Impact category
CO_2	grams (g)	Environment
NO_x	grams (g)	Environment
Fuel consumption	litres (l)	Environment
Energy consumption	kilojoule (kJ)	Environment
Travel time	seconds (s)	Traffic efficiency
Travel time corrected for speeding	seconds (s)	Traffic efficiency
Fatal accidents	-	Safety
Serious casualty accidents	-	Safety
Slight casualty accidents	-	Safety
Fatalities	-	Safety
Serious casualties	-	Safety
Slight casualties	-	Safety

Note that two indicators for travel time have been included in Table 5. This is because of the way travel times are used in CBAs. The ecoDriver system influences the vehicles' speeds. If for instance in the 'without' case some drivers were exceeding the speed limit and in the 'with' case they do not, this results in extra travel time which is a disbenefit. In social CBAs, there exists two different approaches to how travel times can be included in the analysis (van Wee, 2011). The first approach is to use the actual travel time, this implies that driving faster than the speed limit counts as a benefit compared to driving at the speed limit. The second approach is to discard travel time benefits arising from speeding. Part of the travel time changes when comparing the 'with ecoDriver' case to the 'without ecoDriver' case do indeed come from exceeding the speed limit. Therefore we have added the performance indicator 'travel time corrected for speeding'. This indicator is calculated by cutting off speeds that are above the speed limit. The 'travel time corrected for speeding' was used in the social CBA.

Some more information about the set-up of the traffic simulations and networks used can be found in section 2.2. Detailed explanation and results are given in Deliverable D53.1 (Olstam et al., 2016). Below a brief summary of the most important simulation results for the scaling up and CBA can be found. N.B. Non-significant effects have been put to zero.

2.4.2 Simulation results

The simulation results showed that there are marked differences between road types and vehicle classes. These are caused by the differences in speed limits, overtaking possibilities and intersection densities. The changes are largest on rural roads, somewhat lower on motorways and on urban roads only safety effects were found. This can be explained by the fact that all types of advice (speed, gear and upcoming lower speed limit) are given and may influence drivers on rural roads. Motorway driving commonly implies driving at the highest gear, thus gear advice is not frequent. The number of speed limit changes is also less on motorways. It appears that the main contributing factor on motorways is the (continuous) speed advice. Urban road driving implies more frequent gear changes while the possibility to freely choose the speed (and to exceed the speed limit) is more limited. The main contributing factor on urban roads is therefore the gear advice.

Another reason for the larger effects on rural roads is the limited overtaking possibilities, which mean that equipped and highly compliant drivers tend to become platoon leaders more frequently than on motorways. As platoon leaders they do not only decrease their own speed but also the speed of the other vehicles in the platoon. On motorways the effect on surrounding non-equipped vehicles can be the opposite, sometimes resulting in a more dynamic driving behaviour of the drivers without the ecoDriver system, such as decelerating for the ecoDriver equipped vehicles with lower speed and accelerating for overtaking manoeuvres.

For urban roads, the effects on environmental indicators (CO_2, fuel consumption, energy consumption) and on travel times were not significant. The reason for this was the influence of signalised intersections (the main source for accelerations in the urban networks). The urban results have therefore not been included in the following figures.

Figure 11 shows the CO_2 results for motorways and rural roads, for cars, vans and trucks (buses were not simulated explicitly for these road types, as their share is very low, but they were assumed to behave similarly to how trucks behave), and for the flat networks with low demand. The scenario considered is the Green Future scenario, in 2035. This is the scenario with the largest effect sizes (because of relatively high penetration rates and compliance). The CO_2 emissions decreased on all road types; the largest decrease found was over 8%. On motorways, the largest effects can be found for trucks due to a substantial decrease in speed (in the without case, most trucks are assumed to drive at speeds over the speed limit of 80 km/h; for cars and vans a much smaller share of vehicles is assumed to drive at speeds over the prevailing speed limit). On rural roads, the largest effects are for cars and vans. Overall, the effects are larger for rural roads, as cars have by far the highest share in the traffic composition (for motorways, the car share is approximately 85%).

For fuel consumption and energy consumption, the effects are very similar. For NO_x, the effects are somewhat different, because in the motorways simulations some unexpected and rather large increases in emissions were found for trucks. See Deliverable D53.1 (Olstam et al., 2016) for further discussion of the NO_x results. The NO_x results have been included in the scaling up and CBA (and the uncertainties about the NO_x results have been accounted for in a sensitivity analysis).

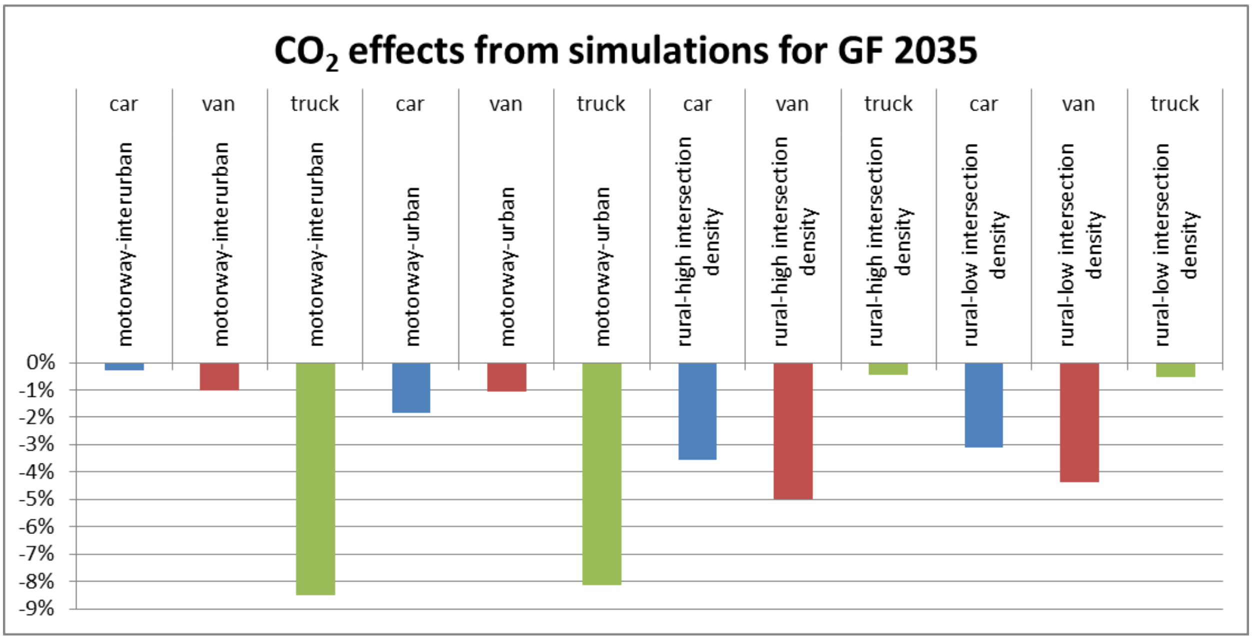


Figure 11: CO_2 effects from the simulations, motorways and rural roads (car/van/truck, flat, low demand)

For hilly roads, the effects are in the same order of magnitude as for flat roads. When comparing low and moderate demand situations, the effects are slightly smaller for moderate demand situations on rural roads. For motorways, the differences between low and moderate demand are very small.

Figure 12 shows the uncorrected travel time effects. The travel times increase in all cases. On motorways, truck travel times are most affected (because of the reduced speed). On rural roads, all vehicle classes are affected. When corrected for speeding, the travel time effects are much smaller (going from several % when uncorrected to almost 0% when corrected).

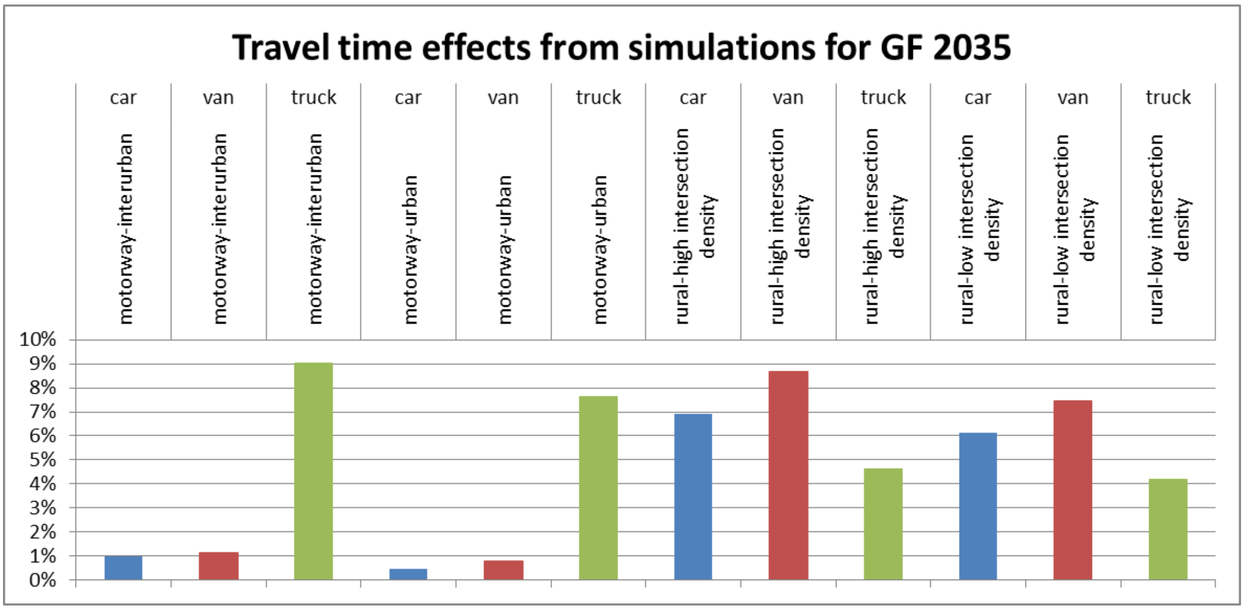


Figure 12: Travel time effects from the simulations, motorways and rural roads (car/van/truck, flat, low demand)

Figure 13 shows the safety effects. These were calculated using the Power model (Elvik et al., 2004) for all vehicle classes combined. The safety effects are large, compared to the other indicators, and are largest on rural roads, with the number of fatal accidents/fatalities being reduced the most (20-25%). Since there are no significant effects of the ecoDriver system on speeds for urban compact roads, there are no safety effects on these roads.

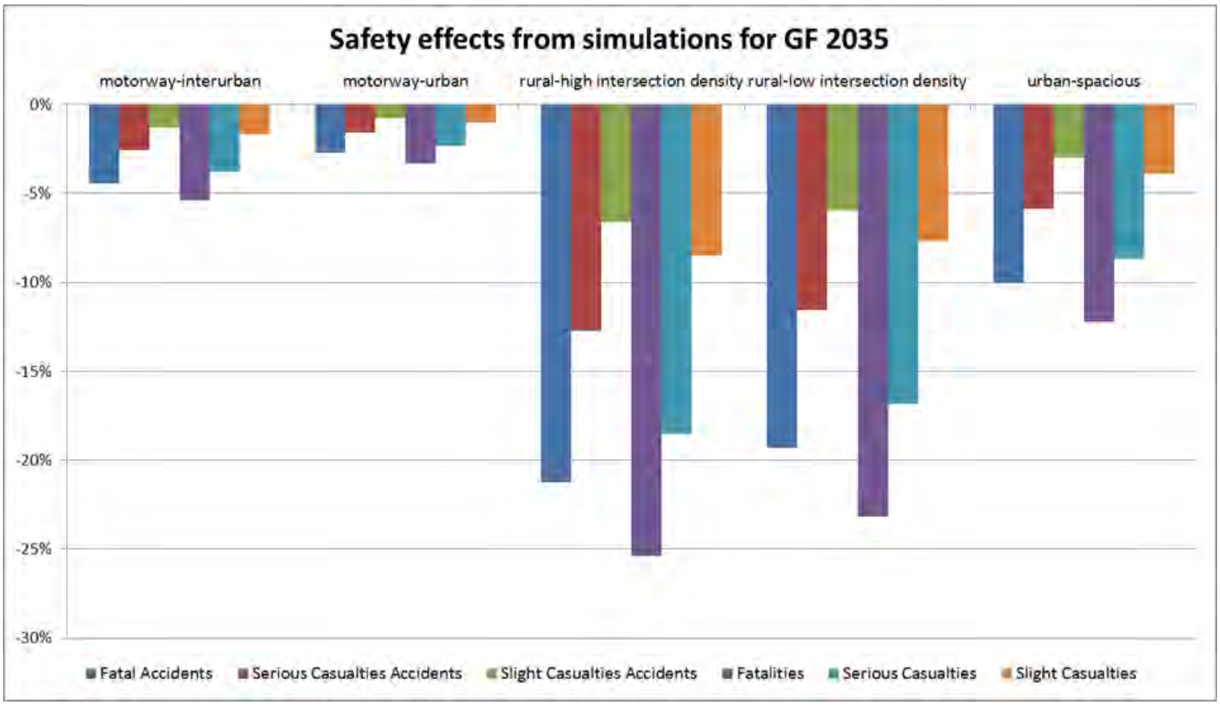


Figure 13: Safety effects from the simulations on motorways, rural roads and urban spacious roads (car/van/truck/bus, flat, low demand)

In general, the effect sizes increase over time. This is because the penetration rates increase, and in some, but not all cases also the compliance rates. The fleet composition sometimes influences how much the effect grows over the years as well (not all vehicle types have the same effects from the ecoDriver systems). As an example, Figure 14 shows how the CO_2 effects change over time in the three scenarios. All scenarios show the same tendencies, but with different effect sizes.

Challenging Future has the smallest effects, as it has the lowest penetration and compliance rates. The compliance rate even decreases after 2030. This decrease in compliance is due to the assumption of lack of system and map updates in the ecoDriver systems in the Challenging future scenario, see the scenario descriptions in Deliverable D52.1 (Jopson et al., 2015)).

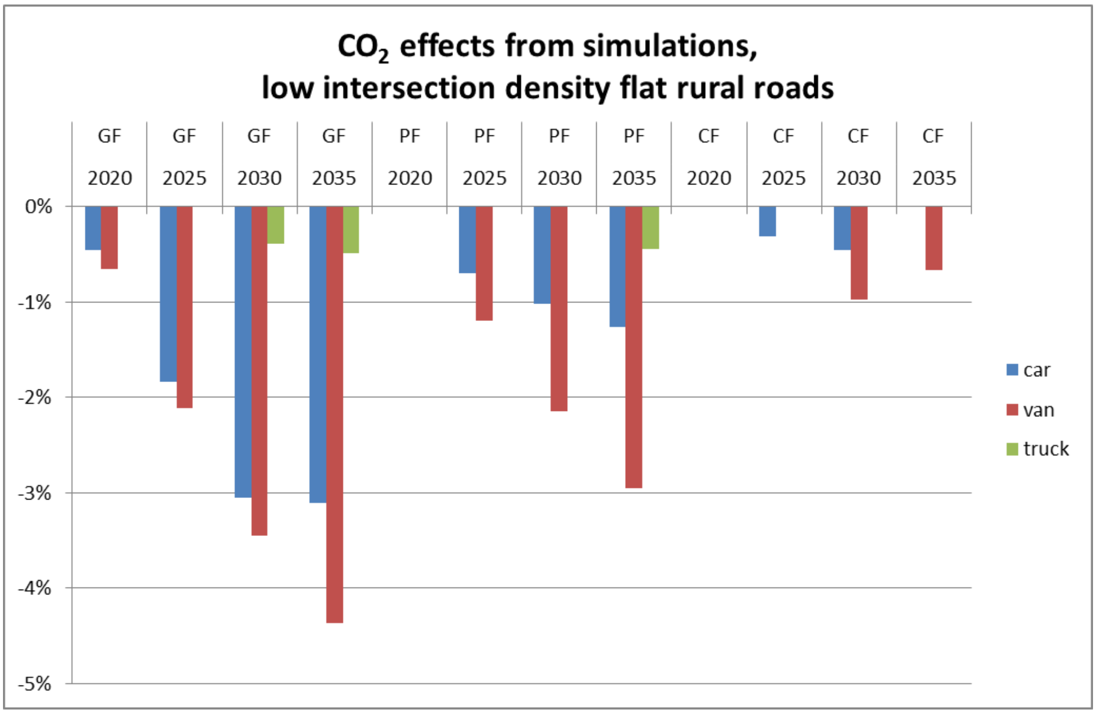


Figure 14: CO$_2$ effects over the years, all scenarios, rural roads

3. Methodology

This chapter contains the methodologies for scaling up and CBA, including explanation on the tools that were used for quantification.

3.1 Methodology for scaling up

3.1.1 General concept

Scaling up translates results on a small scale (outputs from WP53 on traffic efficiency, energy consumption and emissions, and safety) to the whole of Europe, for the 12 scenario – future year combinations. In this way the EU-wide impacts for the selected scenarios are predicted. The reason that this step needs to be made is that experimental conditions (in this case in the traffic simulations) do not necessarily match with, or completely cover, the “real world” situation. For instance, the most interesting traffic situations (from the ecoDriver perspective) may have been overrepresented in the simulations. This is corrected for in the scaling up process. The results of the scaling up are expressed as the difference between the scenario without ecoDriver system and the scenario with ecoDriver system.

After the simulation results were processed and various performance indicators were derived, changes in the indicators (effect sizes) considered in the cost-benefit analysis were made available for the small scale networks that were used in the simulations. For the scaling up, effect sizes from the simulations as well as data on the (current and expected future) situation without ecoDriver at the EU-28 level were needed. This concerned data on mileage and situational variables (road type, traffic situation (demand levels), etc.). Simulation results were (intentionally) also split for these situational variables. That is, indicators were calculated for low and moderate demand situations on flat and hilly urban and rural roads and motorways, for all scenarios (the ecoDriver system was assumed to have no effect in congested traffic). That gave us the relative changes which could be multiplied by the mileage at EU level under the same conditions, so that overall effect sizes (on EU-28 level) could be determined.

For example (fictitious numbers):

- In one scenario/future year combination, we find a decrease of energy consumption of 10% on flat urban motorways, during moderate traffic demand.
- The share of kilometres driven on this type of road during moderate traffic demand periods is 7% of the total number of kilometres driven in a year.
- If no effects were found in other situations, the total effect (taking into account all kilometres driven) is 0.1*0.07=0.007, or 0.7%.

This weighted multiplication needed to be carried out for all performance indicators considered.

To carry out scaling up for ecoDriver, mileage data for the whole of Europe (EU-28) needed to be split up by the relevant situational variables as shown in Table 6. Some of the variables described in Table 6 vary from scenario to scenario: (distribution of mileage over) road types and traffic demand. There are also variables that were kept constant over scenarios and future years. (Distribution of mileage over) hilliness is an obvious example, and also the shares of vehicle classes were kept constant.

There are other situational variables that could possibly have an effect on the potential impacts of the ecoDriver systems. An (obvious) example is weather; during bad weather (e.g. heavy rain, snow, slippery roads) people generally drive with lower speeds, so the impacts of ecoDriver could be smaller. Recent investigations in UK show that although driver behaviour varies with weather, the mean, standard deviation, and 5th and 95th percentile of speed and acceleration are mainly affected during more extreme weather conditions such as heavy rain (Pellecuer et al., 2016). In the simulations generic European circumstances were used. And even if different weather types would have been included in the simulations, it would have been quite a challenge to find good data on this on the European level for scaling up. To deal with variation in driver behaviour (due to differen driver characteristics, different road and weather conditions and possible other circumstances) in the simulations desired speed distributions that reflect different conditions have been used.

Table 6: Situational variables by which mileage data needs to be split up

Variable	**Classes**
Road types	1 Motorways • urban • interurban 2 Rural roads • low intersection density • high intersection density 3 Urban roads • spacious cities • compact cities
Terrain	1 Hilly 2 Flat
Traffic demand	1 Low traffic demand 2 Moderate traffic demand 3 Congestion
Vehicle class	1 Passenger car 2 Van 3 Bus 4 Truck

Ideally mileage data for all combinations of situational variables is used, so this makes for 6 x 2 x 3 x 4 = 144 ‘mileage numbers’ that are needed. The simulations in WP53 were set up in such a way that the required effect sizes for all combinations were calculated and could be aggregated to the desired level.

Scaling up using mileage statistics as described above is applicable for ecoDriver systems because:

- Rerouting effects are not expected because ecoDriver functions in a very similar way on every road type.
- Second order effects (i.e. latent demand induced by the improvement of the service level, caused by an ITS application) are expected to be small to negligible, as travel times increase slightly, which will likely cancel out any effects of reduced fuel/energy costs.

Interaction effects (ecoDriver equipped vehicles influencing driving behaviour of other vehicles) are expected to be small, but are an integral part of the microscopic simulations. Microscopic simulations take into account risk taking (in lane changing) and other behavioural modifications. The changes in speed of the equipped drivers are not so large that we expect other (non-equipped) drivers to behave very differently from how they normally drive.

The results of the use of ecoDriver systems in a certain area are expected to be valid in comparable situations elsewhere, considering the case that the system is implemented there in the same degree. Not taken into account in this scaling up method is the fact that driving behaviour differs for different countries, which could influence the effect sizes. This means that we have worked with driver models that can be considered to include various driving behaviours (desired speeds and accelerations, following behaviour etc.) as can be found across Europe.

Apart from effect sizes at the EU-28 level, the cost-benefit analysis also needs absolute numbers at that level, so these were also collected.

Sensitivity analyses

For the scaling up analysis, a large amount of data was collected, as is described in Chapter 4. In some cases, the desired categorisation of data was not available (e.g. mileage figures distinguishing between flat and hilly roads) and assumptions had to be made. Some sensitivity analyses were carried out to test the impact of assumptions for specific variables on the outcomes. In paragraph 4.1.3 the sensitivity analyses are specified.

3.1.2 SCENIC tool for scaling up

A tool called SCENIC was used to scale up the local impacts of the ecoDriver systems (the results of the simulations) to the EU-28 level. SCENIC offers a structured and consistent method for scaling up local impacts to higher-level regions in time and space, and other situations. SCENIC was developed at TNO (Van Noort & Soekroella, 2014).

The general setup of the tool is as follows:

- The tool assumes that the impacts of an ITS are known for one or more *local scenarios*. These are called the *local impacts*. A local scenario describes a *situation*, which is a set of circumstances characterized by the values of several *situational variables*. The situational variables used to construct local scenarios for ecoDriver are road type, terrain and traffic demand (see also Table 6). Typically, the impacts are known only for a small region in time and space. In the case of ecoDriver, these are the effect sizes resulting from the simulations of different networks of limited size in future scenarios.

- As output, the tool provides the impacts of this ITS for a *target scenario*. These are called the *target impacts*. The target region can be a much larger region in time and space, and may cover a range of values for the situational variables. The user chooses the target scenario. In the case of ecoDriver, this is the EU-28 level and covers the period of a year.
- Both local impacts and target impacts are given as changes in certain *performance indicators*. The same performance indicators are used for input and output, and the tool works irrespective of the choice of indicators. The performance indicators for ecoDriver are given later in this paragraph in Table 7.
- Each performance indicator corresponds to a certain traffic problem, which has a certain *problem size* in the target scenario. In the case of ecoDriver, the problem sizes are the EU-28 mileage figures for the different scenarios and future years, split into 6 road types, 2 terrain types and 3 traffic demand levels (the situational variables). In order to translate the local impacts into target impacts, *external data* are needed to weight the effect sizes found for the local scenarios to obtain the total effect sizes in the target scenarios.

Figure 15 shows how the SCENIC tool calculates the target impacts. The required aggregated input data consist of the problem size in the target scenario for each situation (that is, for each combination of values of the situational variables), the local impact and the target scenario choice. The impact of the ITS in the target scenario is calculated as the weighted average of the impact of the ITS in local scenarios, where the weights are given by these problem sizes. The tool has various ways to handle missing data, or mismatches between the situations where the local impacts are known, and the situations for which the problem sizes are known. This was not in issue in ecoDriver, because the simulations had been set up in such a way that all necessary input data for the scaling up (and subsequently the CBA) was produced.

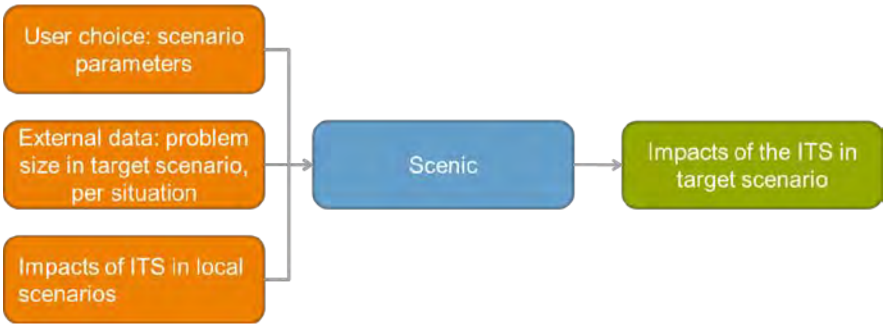


Figure 15: Conceptual model of the tool (inputs are in orange, outputs are in green)

There is no restriction on which performance indicators or situational variables can be used. All indicators can be measured as a total or average over a scenario, and some can also be measured per driven kilometre, hour or per vehicle. Table 7 shows the performance indicators used in the simulations, scaling up and cost-benefit analysis.

Table 7: Performance indicators used in ecoDriver (simulations, scaling up and cost-benefit analysis)

Performance indicator	Unit	Impact category
CO_2	grams (g)	Environment

Performance indicator	Unit	Impact category
NO_x	grams (g)	Environment
Fuel consumption	litres (l)	Environment
Energy consumption	kilojoule (kJ)	Environment
Travel time	seconds (s)	Traffic efficiency
Travel time corrected for speeding	seconds (s)	Traffic efficiency
Fatal accidents	-	Safety
Serious casualty accidents	-	Safety
Slight casualty accidents	-	Safety
Fatalities	-	Safety
Serious casualties	-	Safety
Slight casualties	-	Safety

3.2 Methodology for cost-benefit analysis

As a starting point, the cost-benefit analysis (CBA) used established methods that have previously been used to appraise EU transport policies and projects. The approach followed the FESTA Handbook (FOT-Net, 2014, and previous versions) and adopted the latest research evidence and valuation guidance for EU.

The CBA that was carried out is a scenario-based CBA: we tested not only whether ecoDriving is a good investment in a Business-As-Usual type world (‘Policy Freeze’), but also whether it is robust to a widely supportive future scenario (‘Green Future’) or in a widely unsupportive one (‘Challenging Future’). These scenarios were described in D52.1 (Jopson et al, 2015) and are outlined in section 2.3 above. The CBA also incorporated sensitivity tests to specific variables which the project team had identified as uncertain.

Finally, the analysis contains both a Social CBA and a Stakeholder CBA - we expand on this in this section.

3.2.1 CBA assumptions, parameters and values

2015 was chosen as the base year for prices, values and discounting in the CBA, as it is up-to-date, and convenient for a policy analysis starting from 2015 - as in ecoDriver. Hence the general price level in the CBA was 2015 constant prices, and future costs and benefits were discounted to 2015. A 20-year appraisal period was chosen to reflect the period over which ecoDriver systems might be expected to offer benefits if introduced.

The social discount rate was set at 3% real, consistent with FESTA (FOT-Net, 2014), (Ricardo-AEA et al., 2014) and (Bickel et al., 2006). Own estimates were made of the ideal social discount rate, which found a rate of 3.1% real, very close to the EU preferred rate. The official EU Impact Assessment Guidelines (European Commission, 2009) set down a rate of 4% for all impact assessments of policies. Since 2009, some of the drivers of social discount rates have changed, in particular economic growth and expectations of future real growth have declined, and interest rates (not a direct determinant of social discount rates but a comparator) have fallen markedly. On balance, we decided to use 4% real as a sensitivity test to the main 3% social discount rate.

Where necessary, values from countries outside the euro area are converted from national currencies to euros using Purchasing Power Parity (PPP) exchange rates sourced from OECD data (OECD, 2015). Real GDP growth data was sourced from Eurostat (Eurostat, 2015b) and the EU28 HICP index (Eurostat, 2015) was used for general price inflation.

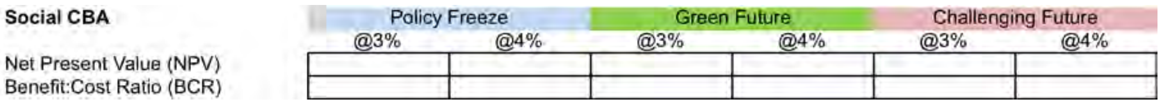
The financial benefits of ecoDriver systems at the individual driver level were first quantified in the scenario analysis (Jopson et al, 2015). Many of the benefits of ecoDriver systems, however, are in the form of externalities, including:

- safety improvements;
- CO_2 and NO_x emissions reduction;
- changes in travel time.

These require estimates of the marginal value of changes in each variable, which were sourced from the latest European research and valuation guidance, in particular (Ricardo-AEA et al., 2014), "Update of the Handbook on External Costs of Transport". Evolution of the CO_2 values over time was based on DECC (2014a). National differences in the value of safety improvements, travel time savings and NOx were taken into account, using the values in Ricardo-AEA et al. (2014).

3.2.2 Social and Stakeholder CBA

The social CBA framework is the familiar one from cost-benefit analysis (CBA) worldwide. The goal is to demonstrate firstly that the intervention is worthwhile when discounted at the prevailing social discount rate, and secondly that it offers good value for money. Net Present Value (NPV) is used as the indicator of social value in absolute terms. Good value for money is a relative concept, and the benefit:cost ratio (BCR) indicator allows for comparisons with other available interventions. The denominator of the BCR is defined as the cost to government - i.e. the focus is on obtaining the greatest value from public expenditure, see Figure 16. The @3% and @4% columns in this figure relate to the two test discount rates identified above.



Social CBA	Policy Freeze		Green Future		Challenging Future	
	@3%	@4%	@3%	@4%	@3%	@4%
Net Present Value (NPV)						
Benefit:Cost Ratio (BCR)						

Figure 16: Social CBA framework

The stakeholder CBA framework is designed to illuminate the case for ecoDriver systems in more detail, in particular to examine whether each of the key groups - road users; the general population; industry (OEMs, etc.); and government - each stand to gain or lose from the intervention. This information helps to assess whether any adjustments are needed to the financial regime around ecoDriving systems in order to ensure that they are attractive to each group. See Figure 17 for the stakeholder CBA framework.

Stakeholder CBA	Policy Freeze		Green Future		Challenging Future	
Road users	@3%	@4%	@3%	@4%	@3%	@4%
Energy cost savings						
eD system costs						
Time savings						
Safety benefits (internal)						
Safety benefits (external)						
NET PRESENT VALUE						
General population	@3%	@4%	@3%	@4%	@3%	@4%
CO2 reduction						
NOx reduction						
Industry - OEMs	@3%	@4%	@3%	@4%	@3%	@4%
Revenues						
Costs						
Margin						
NET PRESENT VALUE						
Government	@3%	@4%	@3%	@4%	@3%	@4%
Revenues						
Costs						
NET PRESENT VALUE						

Figure 17: Stakeholder CBA framework

4. Data collection and preparation

4.1 External data for scaling up

As described in Section 3.1, what is needed for scaling up is mileage data split up by different combinations of situational variables (6 road types, 2 terrain types, 3 traffic demand levels and 4 vehicle classes). These data cannot all be found in one source. A number of sources has been combined and assumptions have been made to obtain the data that are needed.

4.1.1 Mileage data

In Figure 19, an overview is presented of how the mileage data, split up by the combination of situational variables (the box at the right side of the bottom of the figure), was obtained from different sources and in different steps. The four boxes at the right side of the figure show the mileage data split up by a few situational variables (upper right box) to split up by all situational variables (lower right box). In this paragraph all steps are explained, per box at the right side of the figure. In the end we arrive at data at NUTS 3 level. More about the NUTS classification is explained in the textbox below. Figure 18 shows the NUTS 3 regions in Europe (for an idea about their sizes). We have chosen to use NUTS 3 level as aggregation level, because this allowed us to take specific regional characteristics into account, such as hilliness and the level of urbanization (from very rural to metropolitan).

The 'Nomenclature of Territorial Units for Statistics (NUTS) is a geocode standard for referencing the subdivisions of countries for statistical purposes. The standard is developed and regulated by the EU, and thus only covers the member states of the EU in detail. For each EU member country, a hierarchy of three NUTS levels is established by Eurostat. A NUTS code begins with a two-letter code referencing the country. The subdivision of the country is then referred to with one number. A second or third subdivision level is referred to with another number each.

The newest classification is named NUTS 2013, and this was published 1 January 2015. It lists 98 regions at NUTS 1, 276 regions at NUTS 2 and 1342 regions at NUTS 3 level. The NUTS 3 level is what we use in ecoDriver for the mileage data. The average size of the regions in NUTS 3 level lies between 150,000 and 800,000 inhabitants. To give some examples, Belgium has about 50 NUTS 3 regions, France has about 100, Germany has over 400 and Slovakia has about 10.

In Figure 19, the terms 'road type 1' and 'road type 2' are used. These terms are explained in Table 8.

Table 8: Road types

Road type 1	Road type 2
Motorways	Interurban motorways
	Urban motorways
Rural roads	High intersection density rural roads
	Low intersection density rural roads
Urban roads	Compact urban roads
	Spacious urban roads

Figure 18: NUTS 3 regions in Europe

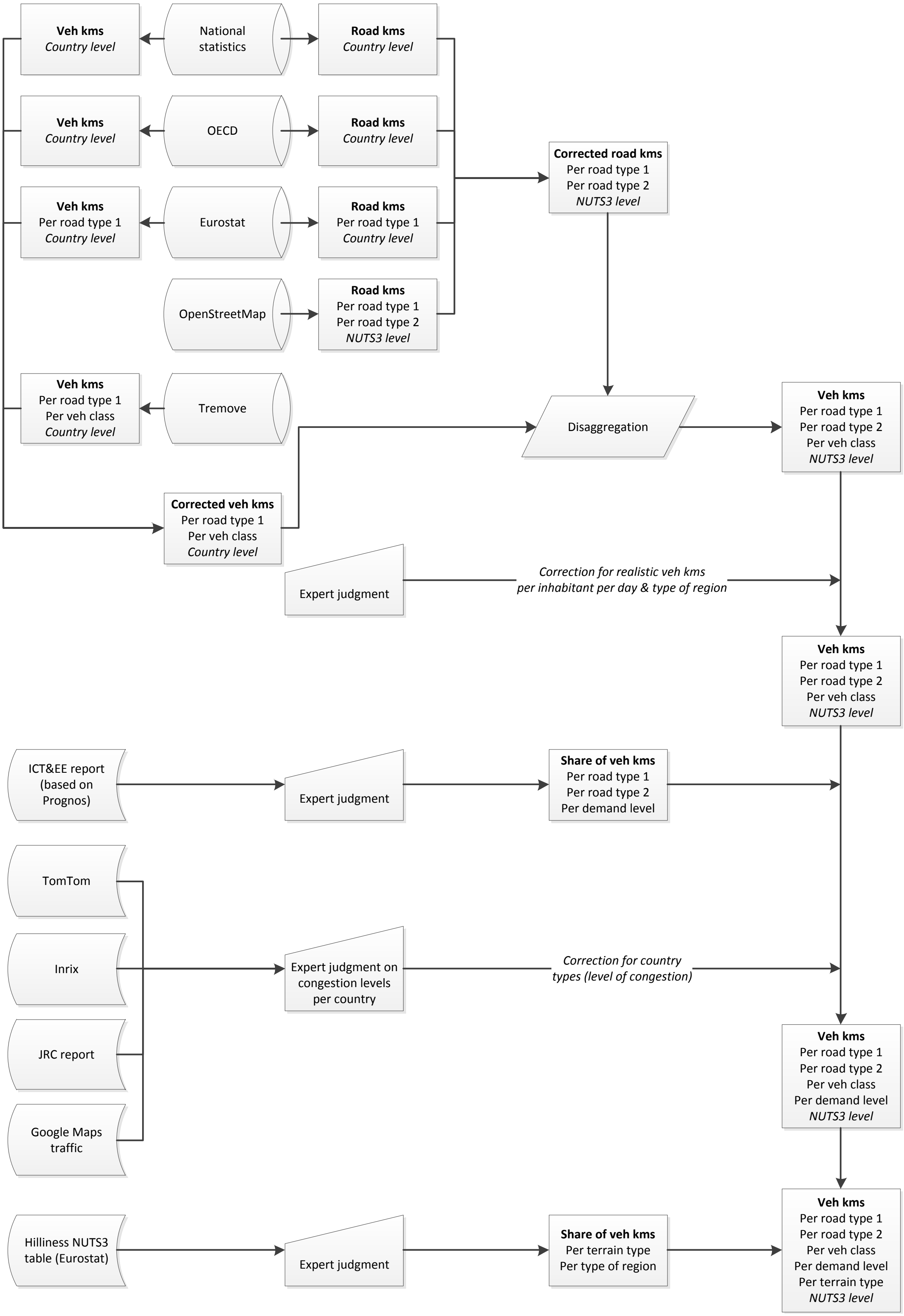


Figure 19: Overview of steps taken to obtain mileage data on EU-28 level split up by situational variables

As a first step, mileage data was split into road types (6) and vehicle classes (4), at NUTS 3 level (the upper two boxes on the right-hand side of Figure 19). For this a combination of sources was used, as can be seen in Figure 19.

The base data we started to work with was from TREMOVE[1] (Transport & Mobility Leuven, 2010), because TREMOVE offered data at the disaggregation level closest to what we needed: mileage data split up by 'road type 1' (i.e. motorways, rural roads and urban roads), by vehicle class and by country (also projections for future years). Some checks and corrections to these data were made based on national statistics, and statistics from the Organisation for Economic Co-operation and Development (OECD) (OECD, 2013) and Eurostat (Eurostat, 2015a).

To be able to split up mileage data by 'road type 2' (i.e. the subcategorization of road types – urban and interurban motorways, high and low intersection density rural roads and compact and spacious cities) and disaggregate to NUTS 3 level, other information was needed. These data were not directly available, but could be derived from information about road kilometres (road lengths). The base data we used here was OpenStreetMap (OpenStreetMap, 2015) where road kilometres are available for different road types and speed limits on NUTS 3 level. These road types and speed limits were converted to the ecoDriver road types, see Annex B. Checks and corrections on these data were made based on information about road kilometres on country level from national statistics, and statistics from the Organisation for Economic Co-operation and Development (OECD) (OECD, 2013) and Eurostat (Eurostat, 2015a). For example, comparison of OpenStreetMap and Eurostat data on the length of the motorway network showed that Eurostat seems to be more accurate, but incomplete. OpenStreetMap seems to overestimate the length, but it is not clear if this is from double counting of some sections or another cause.

Vehicle kilometres on the country level split into motorways, rural roads and urban roads and vehicle class on the one hand, and road kilometres on NUTS 3 level split into urban and interurban motorways and high and low intersection density rural roads on the other hand, were then combined and disaggregated to result in vehicle kilometres split up by road types and vehicle class on NUTS 3 level. An assumption we made is that the distribution of road kilometres over road types and NUTS 3 regions can be applied directly to vehicle kilometres. We thought this assumption was reasonable for rural roads, since high and low intersection density rural roads have similar numbers of lanes. For interurban and urban motorways this is not necessarily the case, but we had no reliable data on differences in number of lanes and traffic volumes to correct for this. For urban roads, we could not find good information on how to distinguish compact and spacious cities (or actually compact and spacious roads, since cities are almost never 100% compact or 100% spacious). Based on visual inspection (GoogleMaps) we assumed vehicle kilometres are split equally over these two groups of cities. One more check and correction to these data was made: it was calculated per NUTS 3 region whether the number of vehicle kilometres per inhabitant per day per type of region (urban or rural region or in between) is realistic. See Annex C for more details about this correction.

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[1] TREMOVE is a policy assessment model to study the effects of different transport and environment policies on the emissions of the transport sector. The model estimates amongst others the transport demand, modal shifts and vehicle stock renewal for policies as road pricing, public transport pricing, etc. The model covers passenger and freight transport in 31 countries and covers the period 1995-2030.

In the second step the mileage data was split up further into demand levels (low, moderate and congested). As base data use was made of the final report of the project Impact of Information and Communication Technologies on Energy Efficiency in Road Transport (Klunder et al., 2009) which refers to (Forschungsgesellschaft für Strassen- und Verkehrswesen e.V., 2001), (Infras/IWW, 2004) and own calculations. This report presents a table with an estimation of distribution of vehicle kilometres in the EU-15 over road types (motorways, rural roads and urban roads) and amount of congestion (free flow, heavy traffic and congestion). We have used this table as a starting point. Based on more recent information about traffic jams and congestion from the TomTom traffic index for cities (TomTom, 2015), the Inrix Urban Mobility Scorecard for countries and metropolitan areas (Inrix, 2015), a report on road congestion in European countries (JRC, 2012) and Google Maps Traffic (Google Maps, 2015), an expert judgment was made on congestion levels per country, and three country groups were distinguished: countries with a lot of congestion, countries with a moderate amount of congestion and countries with no or little congestion. For each of the groups the base table with distribution of vehicle kilometres over road types and amount of congestion was adjusted. The tables and country groups can be found in Table 9 and Annex D and F.

Table 9: Country groups distinguished for the scaling up

Group	**Countries**
Most congested, relatively low growth in mileage	Belgium, Germany, The Netherlands, United Kingdom
Moderately congested, moderate growth in mileage	Spain, France, Ireland, Italy, Luxembourg, Poland, Portugal
Least congested, moderate growth in mileage	Austria, Cyprus, Denmark, Finland, Malta, Sweden
Least congested, high growth in mileage	Bulgaria, Czech Republic, Estonia, Greece, Croatia, Hungary, Lithuania, Latvia, Romania, Slovenia, Slovakia

In the third and last step, information about terrain type is added. This was obtained from Eurostat (Eurostat, 2015a) where information about the 'hilliness' of a region is available at NUTS 3 level. This information was translated to an estimation of the distribution of vehicle kilometres over hilly and flat roads. See Annex E for the details.

4.1.2 Adjustments to mileage data for scenarios and future years

What is described in the previous paragraph produced the 'base' distribution of mileage over the desired combination of situational variables: the distribution in 2015. For the different scenarios and future years, adjustments were made to the 2015 distribution, based on the scenario descriptions in D52.1 (Jopson et al., 2015).

First, it is expected that mileage will grow over the years, and this growth is different for the different scenarios and road types (motorways, rural roads and urban roads). Also, it is assumed that the growth in mileage will be different for different groups of countries. Detailed numbers on the mileage growth can be found in Annex F.

Second, it is expected that the distribution of mileage over the different demand levels changes over the years for the different scenarios, because of the growth in mileage. Here the country groups are taken into account as well. A number of rules are developed for the changes in 2035, and for the years between 2015 and 2035, linear interpolation is applied. The rules and resulting numbers can be found in Annex D.

4.1.3 Sensitivity analyses

In the process of obtaining and selecting the mileage data as desired, assumptions were made. To test the impact of certain assumptions for specific variables on the outcomes, sensitivity analyses were carried out. This paragraph contains a list of sensitivity analyses. All sensitivity analyses were carried out for the Green Future 2035 scenario, since the results turned out to be the largest in that scenario (see paragraph 2.4). The sensitivity tests were chosen to be quite 'extreme', in order to test whether this results in a large change in the outcomes.
Results on the sensitivity analyses can be found in Chapter 5.

1. ***Sensitivity analysis on the distribution of mileage over road types (motorways, rural roads and urban roads)***

The shares of vehicle kilometres over the different road types were based on TREMOVE. However, the TREMOVE data showed very high shares of vehicle kilometres on rural roads (about 55%) and lower shares on urban roads (about 29%) and motorways (about 17%). For some countries, for example the Netherlands, national statistics showed that this was not realistic. Therefore it was chosen to carry out a sensitivity analysis on this, in which the share of vehicle kilometres on rural roads is lowered to 35%, and the shares on urban roads and motorways are raised to 35% and 30%, respectively.

2. ***Sensitivity analysis on the distribution of mileage over vehicle classes (cars, vans, trucks, buses)***

The shares of vehicle kilometres over the different vehicle classes was based on TREMOVE and is kept constant over the different scenario-future year combinations: almost 85% for cars, 5.5% for vans, 8.5% for trucks and more than 1% for buses. It can be debated whether the share of vehicle kilometres for trucks increases. To test what this means for the results, we have increased the shares of trucks and vans at the expense of cars. The distribution used in the sensitivity analysis is then: almost 76% for cars, 8% for vans, 15% for trucks and more than 1% for buses.

3. ***Sensitivity analysis on the distribution of mileage over detailed road types (urban and interurban motorways, high and low intersection density rural roads and compact and spacious cities)***

The distribution of vehicle kilometers over 'detailed' road types is based on information about road kilometres from OpenStreetMap for motorways and rural roads, and based on a very simple assumption for urban roads. This results in the following shares:

- Motorways: 84% on interurban roads and 16% on urban roads
- Rural roads: about 12% on high intersection density roads and about 88% on low intersection density roads
- Urban roads: 50% on compact city roads and 50% on spacious city roads

This was kept constant over the different scenarios and future years. Since the trend is that cities are growing and the share of people living in cities is growing, it can be expected that there is an increase in shares of kilometres driven on urban motorways and high intersection density rural roads, and – since new cities and new cities road are generally of the spacious kind, at least in terms of road geometry – in spacious cities. The new shares that were used in the sensitivity analysis are:

- Motorways: 70% on interurban roads and 30% on urban roads
- Rural roads: 22% on high intersection density roads and 78% on low intersection density roads
- Urban roads: 30% on compact city roads and 70% on spacious city roads

4. ***Sensitivity analysis on the distribution of mileage over demand levels (low, moderate and congested)***

The distribution of vehicle kilometers over demand levels was based on different (and some rather old) sources and assumptions, and there is much uncertainty in these numbers. The base distribution for the Green Future 2035 scenario is:

- Motorways: 44% low demand, 42% moderate demand, 14% congested
- Rural roads: 92% low demand, 6% moderate demand, 2% congested
- Urban roads: 27% low demand, 46% moderate demand, 28% congested

Since we are very unsure about how realistic our numbers are, we have carried out two sensitivity analyses on this topic, one where we have assumed less congestion (0%), and one where we have assumed more congestion.

a. No congestion. We have transferred the kilometres driven in congestion to kilometres driven in moderate demand. The shares are then:
    - Motorways: 44% low demand, 56% moderate demand
    - Rural roads: 92% low demand, 8% moderate demand
    - Urban roads: 27% low demand, 73% moderate demand
b. More congestion. We have increased the amount of vehicle kilometres driven in congestion, at the expense of kilometres driven in low and moderate demand (50-50, except for rural roads where the share of kilometres driven in moderate demand was quite low). The shares are then:
    - Motorways: 36% low demand, 34% moderate demand, 30% congested
    - Rural roads: 70% low demand, 15% moderate demand, 15% congested
    - Urban roads: 15.5% low demand, 34.5% moderated demand, 50% congested

The only situational variable that we did not carry out a sensitivity analysis on, is the terrain type (hilly and flat). The shares on hilly roads are very low and we do not expect that this really influences the results. Also, we do not expect that they could be much higher than what we assumed.

4.1.4 Conclusions about the data used

To give some more insight into the data that was used, this paragraph contains some figures illustrating mileage figures for the EU-28. Figure 20 shows the total number of vehicle kilometres, for the different scenarios and future years. Growth in mileage is largest in the Challenging Future scenario (it almost doubles) and smallest in the Green Future scenario. Figure 21 shows the indexed growth (2015 = 100) for the different country groups.

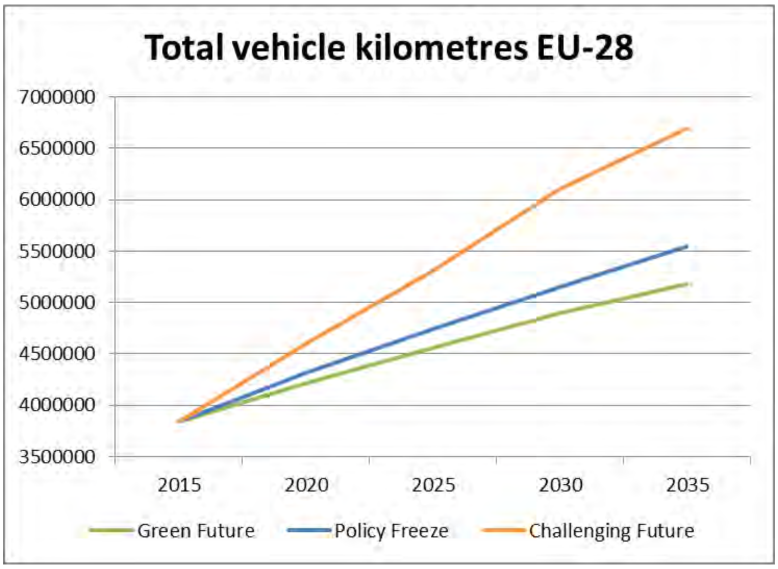

Figure 20: Total number of vehicle kilometres for the EU-28 (x 1,000,000), for the different scenario-future year combinations

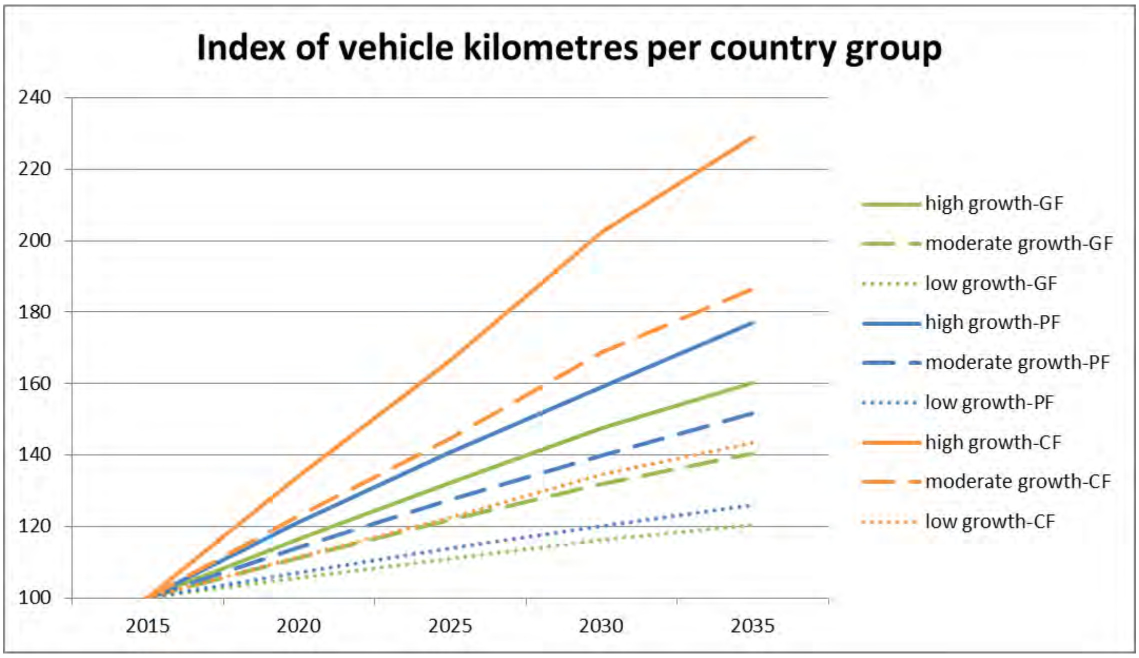

Figure 21: Indexed vehicle kilometres (2015 = 100) for the different country groups (low growth, moderate growth and high growth), for the different scenario-future year combinations

Figure 22 shows the distribution of vehicle kilometres over the different road types in 2015. The scenarios do not show much change in this for future years. Almost half of the kilometres is driven on rural roads with a low intersection density. The share of kilometres driven on motorways is smallest. On these data a sensitivity analysis was carried out, see paragraph 4.1.3.

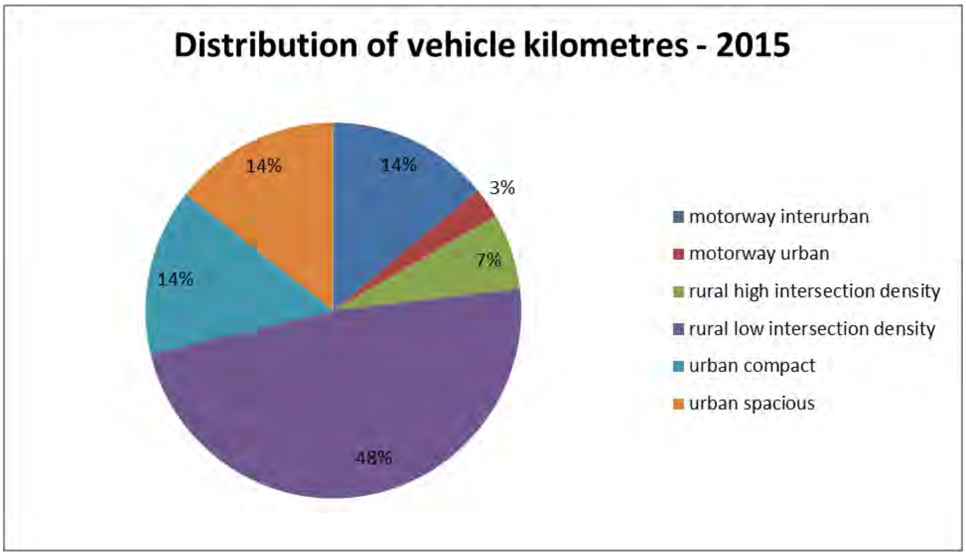

Figure 22: Distribution of vehicle kilometres over different roads types for 2015

Figure 23 shows the shares of kilometres driven in congestion for the different road types in two cases: 2015 (the situation with the least congestion) and 2035 Challenging Future (the scenario with the most congestion). Figure 24 shows the absolute amount of congestion (in vehicle kilometres driven) for the same two cases. The Challenging Future scenario had the largest growth in vehicle kilometres. Due to the growth in vehicle kilometres, the absolute amount of congestion increases as well as the share of congestion. The roads with the most congestion (absolutely and relatively) are urban roads, followed by motorways. Rural roads have the least congestion, especially rural roads with low intersection density experience almost no congestion (when compared to the amount of kilometres driven there). The growth in congestion (absolute amount) is largest on rural roads with low intersection density (almost four times as high in CF 2035 compared to 2015) and smallest on rural roads with high intersection density (just over three times as high in CF 2035 compared to 2015). Also on this data a sensitivity analysis was carried out.

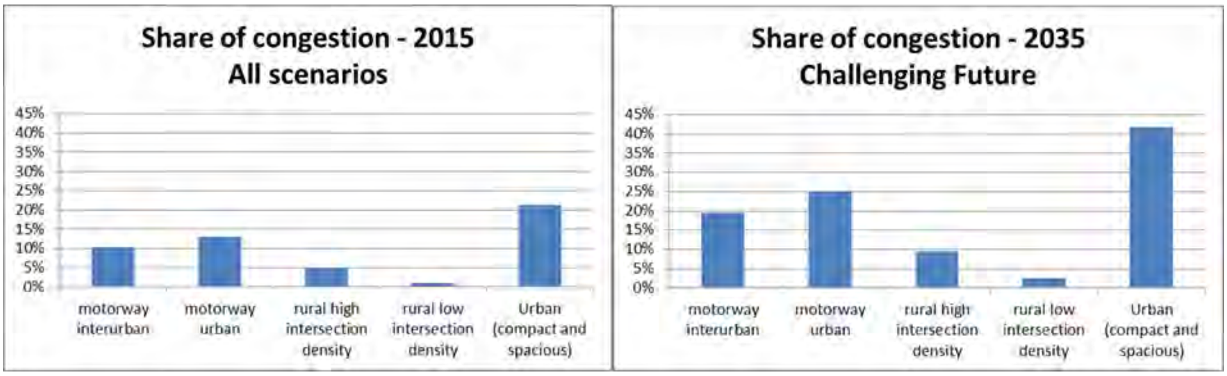

Figure 23: Shares of congestion per road type, for 2015 and 2035 Challenging Future (the scenario with most congestion)

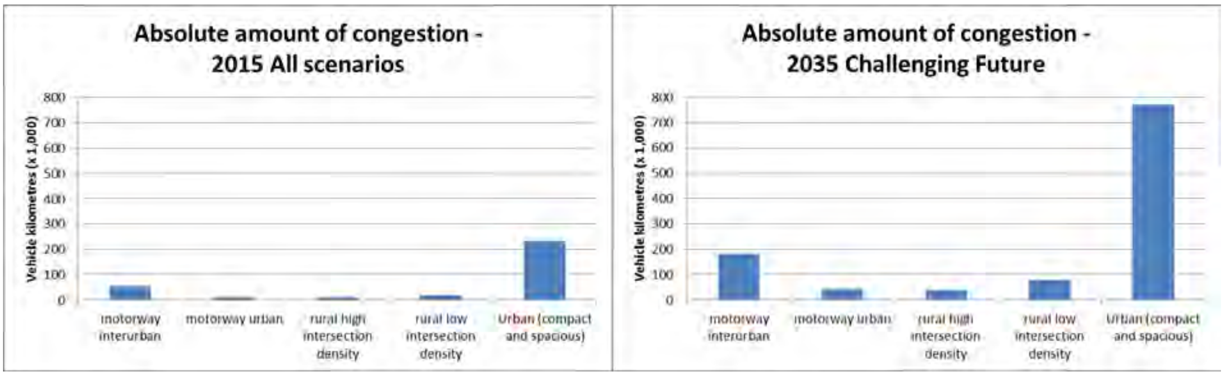

Figure 24: Absolute amount of congestion per road type, for 2015 and 2035 Challenging Future

Finally, Figure 25 shows the distribution of vehicle kilometres over the two terrain types (hilly and flat) for the different road types. The mileage on hilly roads is very low. This distribution is kept constant for future years.

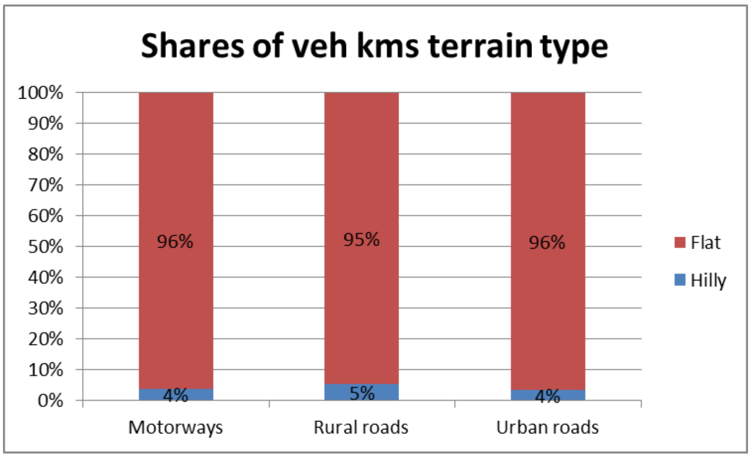

Figure 25: Distribution of vehicle kilometres over terrain type, per road type, for all scenario-future year combinations

4.2 Absolute numbers for the CBA

For all scenario-future year combinations, absolute numbers were determined for the entire EU-28. These absolute numbers were used in the CBA to 'undergo' the effect sizes. In Annex A a complete table with all numbers is given. In Table 10 the absolute numbers for 2015 and indices for 2035 (as compared to 2015) are given. Below the table, it is explained how the absolute numbers were determined, per indicator, including which sources were used.

Table 10: Absolute numbers 2015 and indexed numbers 2035 scenarios (2015 = 100)

Indicator	Absolute value 2015	Indexed number 2035 Green Future	Indexed number 2035 Policy Freeze	Indexed number 2035 Challenging Future
Vehicle kilometres (x 1,000,000)	3,842,886	135	144	174
CO_2 (x 1,000 tonnes)	813,942	122	133	161
NO_x (x 1,000 tonnes)	2,910	56	62	75
Energy consumption (x 1,000,000 kJ)	$1.17*10^{10}$	124	135	164
Travel times (x 1,000,000 hours)	69,383	139	150	187
Fatalities	21,954	35	37	45
Serious casualties	122,044	56	59	70
Slight casualties	914,942	54	57	68

Vehicle kilometres

For the current situation (2015) the vehicle kilometres were obtained from TREMOVE, and the scenario information from D52.1 (Jopson et al., 2015) was used to obtain the numbers for each future scenario. The numbers for future years were checked these against the TREMOVE forecasts. This comparison (see Figure 26 below) showed that the ecoDriver scenarios assume a higher growth than TREMOVE does (and than the EU has experienced over the last 15 years, see (European Commission, 2015a)). This does not matter for the scenario study in ecoDriver, where we compare the with and without ecoDriver case for each scenario and then compare between scenarios.

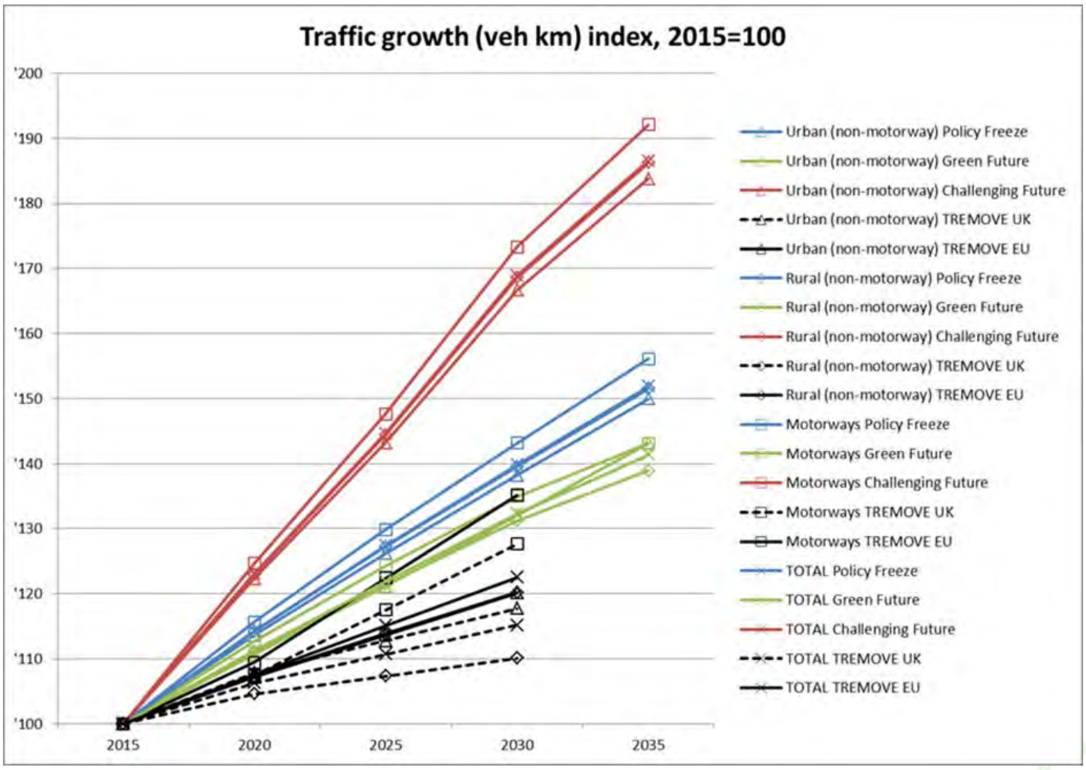

Figure 26: Growth in vehicle kilometres for the different scenarios and the TREMOVE forecasts

Travel times

No data on this was found in TREMOVE, Eurostat or other European statistics. Therefore, we have calculated travel times from the vehicle kilometres, using assumptions on average travel times (per road type, demand level and vehicle class) by assuming an average speed of the speed limit or below the speed limit. These assumptions can be found in Annex G. The effects of ecoDriver with and without correction for speeding were applied to the absolute travel times.

CO_2 emissions, NO_x emissions and energy consumption

Eurostat provides numbers for CO_2 emissions, NO_x emissions and energy consumption from road transport. Their newest numbers are from 2013: 838,920,000 tonnes CO_2, 3,429,764 tonnes NO_x and 284,982,500 TOE (tonne of oil equivalent) energy consumption. We used the trend that can be seen in the numbers (there is a small decline over the years) to estimate the numbers for 2015. For 2015 this gives average emission factors of 207 g CO_2/km and 0.74 g NO_x/km, and an average energy consumption of about 3000 kJ/vehkm. These numbers seem reasonable and have the same order of magnitude as the numbers deduced from TREMOVE.

TREMOVE data was consequently used to calculate average emission factors for the EU-28 for the different vehicle classes, road types and demand levels used in ecoDriver. The calculated average values from TREMOVE for EU-28 for 2015 are 214.5 g CO_2/km for a petrol car and 190.4 g CO_2/km for a diesel car. This is highly comparable to the average CO_2 emission factors applied for company reporting for cars registered in Britain between 1998 and 2013 (209.6 g CO_2/km for petrol cars and 191.9 g CO_2/km for diesel cars including an uplift factor for accessories) (DECC, 2014b).

We assume that the base scenario in TREMOVE is comparable to the Policy Freeze scenario in ecoDriver so that the emission factors calculated for the base scenario were directly applied to the vehicle km data for Policy Freeze. Data for the years 2015 and 2025 was interpolated from the data available in TREMOVE (2000, 2010, 2020, 2030), and the 2035 values were obtained through a simple trend function. For the Green Future and Challenging Future scenarios those base scenario emission factors were then scaled relative to the change in vehicle mix between the Green Future/Challenging Future and the Policy Freeze scenario, differentiated by vehicle class (car, van, truck, bus) and road type (motorway, rural, urban). It is assumed that the technologies for individual vehicle types (e.g. petrol cars) are the same between the scenarios, and changes are purely due to differences in traffic mix. Emission factors for hybrid vehicles are not directly available from TREMOVE, so were calculated relative to those of conventional engines based on factors deducted from (Murrels and Pang, 2013). The well-to-tank energy consumption and CO_2 emissions for an electric vehicle are assumed to be half of those of a conventional petrol car, based on typical EPA (Environmental Protection Agency) ratings for the US market and research studies (Howey et al., 2011), see (Hacker et al., 2009) for an overview. It is assumed that the energy mix for production of electricity remains constant over time. Exemplary resulting reductions of average emission factors are shown in Table 11.

Table 11: Average emission factor reductions 2035 compared to the Policy Freeze Scenario

Road Type	Vehicle class	CO_2 GF	CO_2 CF	NO_x GF	NO_x CF
Motorways	Car	99.32%	100.08%	89.70%	101.56%
	Van	99.54%	100.00%	99.20%	99.99%
	Truck	100.00%	100.00%	100.00%	100.00%
	Bus	100.00%	100.00%	100.00%	100.00%
Rural roads	Car	96.00%	100.68%	88.89%	101.71%
	Van	99.78%	100.00%	99.33%	99.99%
	Truck	99.62%	100.01%	99.23%	100.02%
	Bus	98.28%	100.10%	97.89%	100.11%
Urban roads	Car	90.69%	101.85%	83.91%	102.66%
	Van	98.43%	100.06%	97.27%	100.06%
	Truck	99.62%	100.01%	99.23%	100.02%
	Bus	98.42%	100.08%	97.99%	100.10%

Fuel consumption

Fuel consumption data for the EU-28 is not directly available from published statistics or TREMOVE data. However, TREMOVE allows differentiating energy consumption by type of fuel (petrol, diesel, CNG, LPG). This split of energy consumption was applied to the overall results for all scenarios, differentiated by road type (motorways, rural roads, urban roads). Fuel consumption was subsequently calculated by applying energy densities for the different fuel types.

Safety numbers

For the CBA, most of the safety benefits attach to casualties rather than accidents. Therefore these are the numbers that we focused on. Sources that we used for the base data on safety were EU transport in figures – statistical pocketbook 2015 (European Commission, 2015a) and the Annual accident report 2015 (European Commission, 2015b), which provide numbers up till 2013. These reports rely on the CARE database of EU road accidents and all safety figures we found are for road transport, therefore including slow modes and motorcycles. Since these seemed to be the only numbers available, we used them as they were.

To determine the numbers for 2015 and for the future years 2020 to 2035, we did the following:

- ***Fatalities***: we used the number of fatalities in 2013 and used the (decreasing) trend to make an estimation for 2015. We sourced projections for 2020 and 2030 in the Policy Freeze/Business-as-Usual scenario from the DRIVE C2X Project Deliverable D11.4 (Malone et al, 2014). We then used trends from (Hancox et al.,2015) to interpolate and extrapolate to the other years. GF and CF scenarious were based simply on varying the number of casualties in proportion with the amount of road traffic.
- ***Serious and slight casualties***: numbers of injuries were sourced at the EU-28 level from (Malone et al., 2014). Attribution between serious and slight injuries was based on UK data since

information was lacking at the EU-28 level (DfT, 2015). Again trends from (Hancox et al., 2015) were used to complete the missing years.

4.3 Cost data

The CBA required inputs on the cost of ecoDriver systems – both the nomadic and the embedded versions. These costs form part of the 'Cost' side of the CBA both for the social CBA and the stakeholder CBA. In the stakeholder CBA they play a key role in demonstrating that the technology is a win-win for each of the key groups we identify as being affected: drivers; OEMs; public authorities; and others.
In order to provide cost estimates for the ecoDriver systems, we adopted the following process:

i. Derive benchmark costs using:
    - as background, cost data in the US ITS Cost Database (US DOT, 2015), which is the leading source on this topic;
    - evidence on consumers' willingness-to-pay for ecoDriver systems and the magnitude of the expected cost-savings, gathered in WP52 and SP4;
ii. Invite comment from industrial partners on the estimates produced, including plausibility and additional factors to be taken into account.
iii. Take feedback from participants in the ecoDriver special session at the ITS Congress 2015.
iv. Use the feedback received to refine the costs, and include it in the CBA.

4.3.1 Costs for ecoDriver systems

Benchmark costs: US ITS Cost Database

The US ITS Cost Database is a resource covering the capital, operating and maintenance costs of ITS deployments. The cost data are intended to inform "project cost estimates during the planning or preliminary design phase, and for policy studies and cost-benefit analyses" (US DOT, 2015). As such it is well suited for present purposes, with the caveat that it is based on US market conditions. Note that the European vehicle market is larger than the American market (Table 12), so assumptions about economies of scale in production in the US should be valid also in Europe.

Table 12: New passenger car registrations or sales by region, Europe and the Americas, 2014

Region	***New passenger car registrations or sales***
Europe	**16,060,143**
EU28+EFTA	13,013,515
EU15+EFTA	12,113,882
Americas	**13,179,280**
North America (NAFTA)	9,188,369
US	7,689,619
Canada	755,500
Mexico	745,250

Source: (Organisation Internationale des Constructeurs d'Automobiles, 2015)

A good example of the methodologies adopted by studies in the database is the analysis of in-vehicle technologies for crash prevention published by the Minnesota Department of Transportation in 2009 (Pitale et al., 2009). This uses S-shaped curves for market penetration over time as we did in D52.1 (Jopson et al, 2015) – these play a large role in determining costs since the unit costs of manufacturing fall as the volume of production increases. The study also considers production cost and willingness-to-pay. The authors cite US-based survey research from 2007 which found that 42% of respondents would potentially purchase a lane departure warning system (LDWS), but this declined to 9% when a specific price of $500 was given (Pitale et al., 2009: 81). The market pricing context is shown in Table 13Table 13 – an LDWS system alone is priced at $295 by Cadillac, whilst other OEMS chose to bundle it with other systems.

Table 13: Market prices of LDWS systems in 2009, converted to current €

COMPANY	PACKAGE	COST, $ (2009)	COST, € (2014)
Volvo	Collision avoidance package, Adaptive Cruise Control, Collision Warning with Auto Brake, Distance Alert Lane Departure Warning, Driver Alert Control	1,695	1,411
Cadillac (GM)	Lane departure warning system	295	245
Infiniti (Nissan)	Bose® Studio Surround® sound system with digital 5.1-channel decoding, 14 speakers and multi-media drive Intelligent Cruise Control Brake Assist with Preview Lane Departure Prevention and Lane Departure Warning systems	2,800	2,330
BMW	BMW Driver Assistance Package –Blind spot detection, Lane departure warning, High beam assistant	1,350	1,123

Source: (Pitale et al., 2009), Table 4.2; exchange rates and inflation index from (OECD, 2015)

Production costs tend to decline over a system's lifetime as take-up and the scale of production increases. After an initial period of rapid unit cost reduction, unit costs then tend to flatten-off, until investment is needed to increase capacity of the production line – appearing as steps up in the curve followed by further reductions – or until further efficiencies are introduced into production processes – these would appear as steps down in the near-horizontal part of the curve. Figure 27 shows an example data plot from (Pitale et al., 2009) taken from engine manufacturing data.

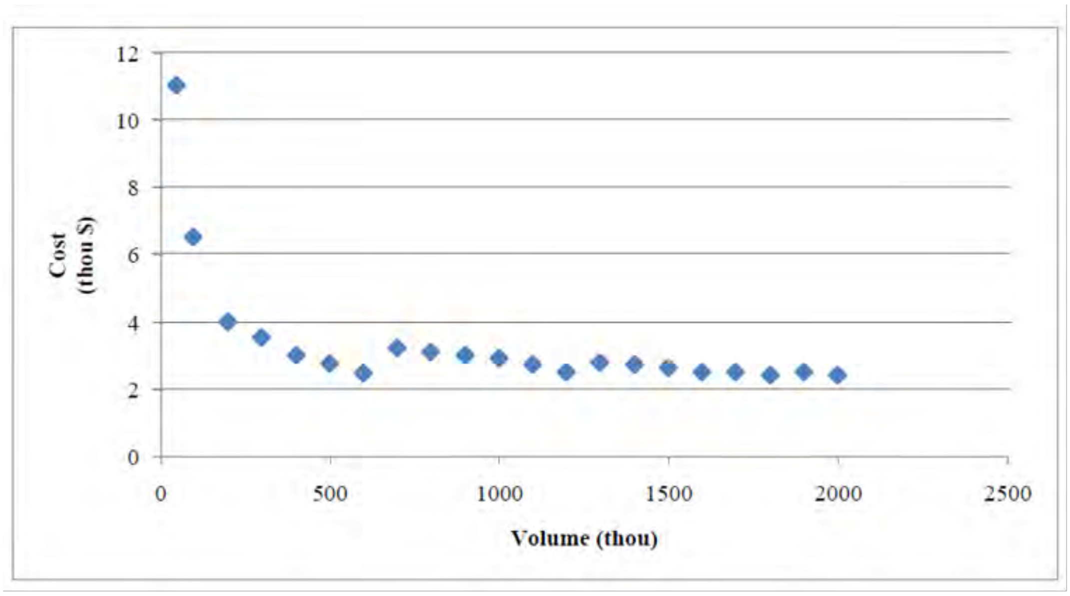

Figure 27: Cost-volume relationship. Source: (Pitale et al., 2009), Fig 7.1

Figure 28 shows the production cost model used in the same study for the LDWS system analysis. Based on the information obtained, the authors chose to use $500 as a starting cost in 2010, declining to an end cost of $200, after 20 years of production, in the higher cost estimate, or £150 in the lower estimate.

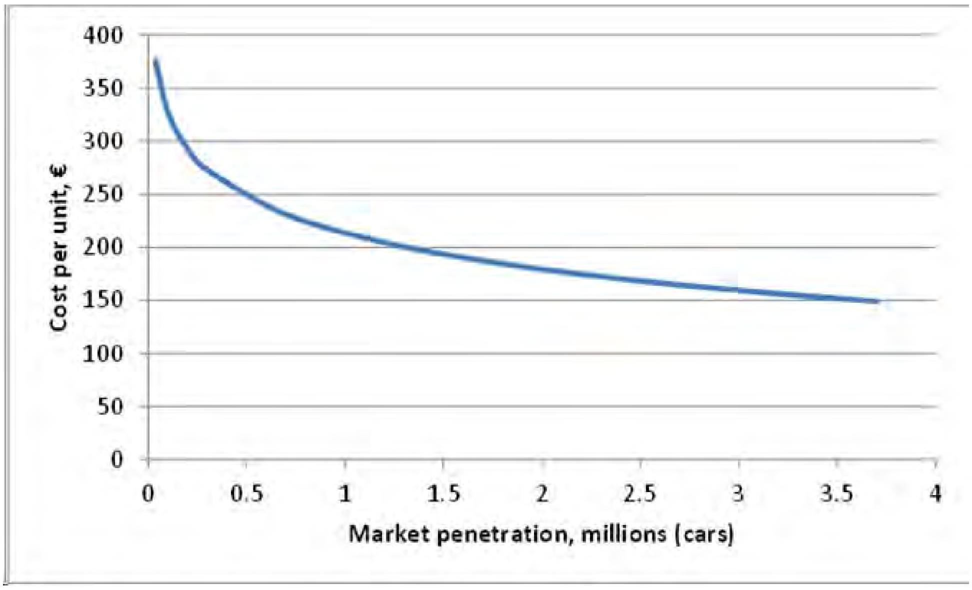

Figure 28: Cost model used for LDWS systems in Minnesota, €/unit vs market penetration (lower estimate). Source: adapted from (Pitale et al., 2009), Fig 7.4

Other in-vehicle technologies are included in the ITS Cost Database, and Table 14 gives a summary of these including 2014 Euro equivalents.

Table 14: Costs of in-vehicle technologies from the US ITS Cost Database

Unit Cost Item	Unit Costs, $ (2014)		Unit Costs, € (2014)		Description
	Capital	Operation & Maint-enance /annum	Capital Cost	Operation & Maint-enance /annum	
Sensors for lateral control	500-700	10-13	377-528	8-10	Includes lane sensors in vehicle and lateral sensors millimetre wave radar.
Mayday Sensor and Processor	90-400	2-10	68-302	2-8	Collision detector sensor and interface for Mayday processor. Software is COTS.
Sensors for Longitudinal Control	200-300	4-10	151-226	3-8	Longitudinal sensors millimetre wave radar.
Advanced Steering Control	300-400	6-10	226-302	5-8	Advanced steering control ("hands off" driving). Software is COTS.
Advanced Cruise Control	90-180	2-4	68-136	2-3	Adaptive cruise control (automatic braking and accelerating)
Intersection Collision Avoidance Processor, Software	170-330	4-7	128-249	3-5	Software/processor for infrastructure transmitted information, interface to in-vehicle signing and audio system, software and processor to link to longitudinal and lateral vehicle control modules based on input signal from vehicle intersection collision warning equipment package. Software is COTS.
Driver and Vehicle Safety Monitoring System	400-1000	20-40	302-754	15-30	Safety collection processor and software, driver condition sensors, six vehicle condition sensors, and vehicle data storage. Software is COTS.
Pre-Crash Safety System	700-1300	20-40	528-980	15-30	Vehicle condition sensors, vehicle performance sensors, software/processor, interface, pre-crash safety systems deployment actuators. Software is COTS.

Notes: costs are adjusted within ITS Cost Database from the study year to 2014 using sector-specific cost indices; conversion to € is at an exchange rate of 0.754 €/$, which is reflective of market and PPP exchange rates in 2014. Exchange rates in 2015 have been exceptional and the year is not complete, so 2014 was chosen as a base for the reported data. At present, € price inflation from 2014-2015 is approximately 0%. The CBA will still use a 2015 base.

Recent market information

Recent information describing new-to-market driver assistance systems from Toyota indicates pricing at around $300 in compact cars (€226), $500 (€377) in midsize and larger models, and $500-635 (€377-479) in Lexus high-end models, for a package including automatic braking, lane departure alert technology and other safety electronics (Automotive News, 2015). Given that these systems are likely more expensive – for a given volume – to the OEM than the FeDS, then it seems likely that a €250 price or something close to it is achievable, subject to sufficient volume being achieved.

Hardware and Software for the ecoDriver system

The ecoDriver FeDS unit comprises the following hardware and software components (information provided by project partners):

- Hardware (see Figure 29):
    - Computer: to run the software listed below; would be integrated into the vehicle for the production version;
    - Samsung Galaxy Note 2: acts as the user interface; the HMI application is installed on it; would be integrated into the vehicle for the production version;
    - Radar: placed in the front of the vehicle in order to detect vehicles ahead;
    - CAN Interface VN1610: CAN to USB interface that allows to collect information from the CAN buses of the vehicle as inputs to the ecoDriver system;
    - Wi-Fi router: to communicate the smartphone with the HMI application with the software installed in the computer; would be integrated into the vehicle for the production version;
    - [CTAG Data logger: device to collect data from the CAN bus for analysis of data – however this item is not relevant to the production version of the unit, it is for evaluation purposes only].
- Software:
    - The HMI application;
    - The Vehicle Energy and Environmental Estimation (VE3); this algorithm predicts energy consumption and manages the data from the CAN bus and radar;
    - The Vehicle model, that calculates the energy consumption of the vehicle under specific situations; it is an input to the VE3;
    - ADASRP, the map database from NAVTEQ that provides data about the electronic Horizon. It is an input of the VE3.

Note that the system does not include any actuators – all the outputs are audio/visual.

The approximate cost of the equipment for the evaluation prototype installed during the project is €7,780[2], however this is not representative of the cost in mass production (see Table 14), where the components would be more integrated into the vehicle and would be engineered to a price point closer to the numbers in the previous section, in order to be competitive with / comparable to other similar products on the market.

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[2] Components: Samsung Galaxy Note 2 150€; Computer 500€; CANVN1610 80€; Radar 7000€; Smartphone accessories (charger, holder..) 20€; Wifi router 30€.

Figure 29: ecoDriver vehicle adaptations for the prototype

We have separately considered the operation and maintenance costs. These would be primarily the costs of providing software updates, including any map/other data costs, updates to the connections to sensors and outputs, and updates to algorithms used in generating advice to the driver. We estimate these would be approximately €2-10/annum per unit, and we assume these costs would be included by the OEM in the initial purchase price.

4.3.2 Consumers' willingness-to-pay

The OEM has to decide how to price the system. Assuming the OEM is aiming for the system to make a positive contribution to profitability in the medium term, it has to be concerned not only with production costs – which can be varied to some extent by engineering the design of the system to a price-point – but also with consumers' willingness-to-pay (WTP) for the service offered by the ecoDriver system. Therefore another source of information relevant to costing ecoDriver systems is the willingness-to-pay (WTP) survey research reported in D52.1 (Jopson et al, 2015).

This research found that among respondents for whom price played a key role in car choice (the group of most interest for the analysis) the mean incremental WTP for the FeDS was €742. By comparison, the mean lifecycle cost saving to be expected from reduced fuel consumption due to the FeDS was €405, based on a 3% incremental fuel saving compared with the mobile app. Taking these numbers at face value, the difference could be explained by:

- a possible halo effect, where the individual valued the green benefits of the system in reducing CO_2 and other pollutants;
- risk aversion, given the recent history of sudden and large fuel price increases – so that the value of a more efficient car is not only the expected fuel saving but also the value of some protection against unexpected future price rises;
- annual mileages driven per vehicle have been declining in recent years, and this could lead to an overstatement of WTP by individuals basing their judgement on past data.

Given that it is uncertain what influence each of these, and other factors, have had in the gap between WTP and the estimated cost saving, we took a cautious approach, using the lifecycle cost saving to measure consumers' mean valuation of the FeDS.

Bearing in mind the gradual turnover of the vehicle fleet, and the desire of the OEM to increase the scale of production in order to drive costs down, we focused on price-points at which the FeDS would be attractive to 50% or more of the potential users. This is determined by the mileage driven by each user, and there is a wide distribution of mileages. The results are shown in Table 15, which relates the price of the FeDS to the % of potential users who would expect to gain from it, i.e. WTP > FeDS incremental cost to the consumer. 100% here corresponds to those who own a smartphone: it was decided during the scenario projections work to assume that individuals who did not own a smartphone would likely be in the category of those who did not wish to have any form of driver assistance device in their vehicle.

Table 15: Consumers' willingness-to-pay for the FeDS system (SP5 data)

FeDS price, €	**% consumers**
150	91
250	78
350	63

Source: Scenario Projections analysis; survey year 2014.

Further willingness-to-pay evidence is taken from the simple direct questions to drivers that were included in the ecoDriver trials (SP4). The questions asked was: "How much would you be willing to pay for the ecoDriver system if it were an optional feature on a new car?". The results are summarised in Table 16.

Table 16: Consumers' willingness-to-pay for the FeDS system (SP4 field trial data)

Purchase:	**€ 137 + Software Updates: € 11 (annual)**
TOTAL (lifetime)	€227-247 (sample size N=170) slightly less across other system types

These results increase our confidence that €250 lifetime cost is a suitable estimate of WTP in the market for an embedded (FeDS) system. Of course not all consumers would be willing to pay this amount, some would choose the low-cost mobile app and some no system at all, but based on the available evidence the proportion who would choose the FeDS under these conditions (3% additional fuel saving; roughly €150 inital cost plus lifetime updates) is substantial, and consistent with the costs of in-vehicle systems listed in Table 13. (Note that for comparison, in VW's current range there are models where a Bluemotion version saving 7.5% of fuel consumption is offered at a €500 premium. Scaled to 3% that suggests a €200 premium, again in the same broad range).

Another comparator is the iMobility Challenge study (Öörni et al., 2014), which investigated awareness of eco-driving systems and whether respondents would like to have such a system in their next car. The survey did not state how much fuel the system would save, and only 19% of respondents had any experience of an eco-driving system of some type. The survey found that 54% of respondents would like to have an eco-driving system in their next car. Willingness-to-pay responses varied widely as usual: 11% were WTP in excess of €300; 10% were WTP €201-300; 13% were WTP €101-200; and 19% were WTP €1-100. Whilst these results do suggest lower WTP than in ecoDriver, this was for a system with unstated performance. Overall the results seem usefully indicative of positive WTP for eco-driving across at least 50% of drivers, even without specific knowledge of the size of savings achievable.

4.3.3 Conclusions: Taking account of costs and willingness-to-pay

A comparison with the marketed in-vehicle systems listed above, suggests that the ecoDriver FeDS system may be priced in the range €150-400 lifetime cost, with a possible central estimate of €250 at 2014 prices.

At €150, 91% of consumers would opt for the FeDS, however the focus groups and the production cost estimates above cast some doubt on whether the cost of the FeDS could come down that low. Instead a decision was made to assume that the FeDS would be aimed at the €250 price point, for a unit which is attractive to 78% of consumers. This gives a target for the OEMs to engineer the cost to, in mass production.

The OEM has to decide how to price the FeDS-type system over its lifetime, aiming to make a positive contribution to profitability. In the face of considerable uncertainty, the OEM may test the market in the early years to learn about potential demand. The OEM may initially target the system at high-end models, and accept a smaller sales volume at a higher price. However, we think it is more likely given the number of similar/related systems already on the market, that the systems would be rolled out across vehicle types, as in the Toyota case. OEMs would likely set prices which are consistent with lifecycle production costs plus margin, based on market projections. Therefore we have focused on the average sales price in real terms (2014 prices) over the appraisal period (2015-2034), which we have set at €250.

We have assumed that for the nomadic version of the ecoDriver system, only a basic smartphone holder for use in the car is required, and the lifetime cost to the user would be €15. The nomadic version of the system is conceived as a smartphone app which would be free or very low-cost to download, but offering reduced integration with the vehicle and lower performance. For the OEM it would serve to introduce consumers to the system. The willingness-to-pay estimates above are consistent with the incremental performance of the built-in FeDS-type system as compared with the smartphone app. The increment was assumed to be a 3% fuel saving.

The total cost to the OEM would also include the costs of software updates, which are partly common to the FeDS and the nomadic system, and partly specific to the FeDS given its additional integration with vehicle sensors and systems. At approximately €2-10 per annum per unit based on Table 14, this would sum to €16-81 over a 12 year lifecycle – the maximum we can envisage for this type of system. We suggest that in view of the WTP estimates above, the OEM would engineer the FeDS unit to a €250 price point inclusive of the software updates.

4.4 Conclusions regarding the data collection

The data needed for the scaling up and future casting of the effects of the ecoDriver system generally required a lower aggregation level –i.e. greater detail– than is used in most EU and national statistics. Also, the Eurostat data was rather incomplete in many of the datasets used. There are other (publicly available) datasets that can be used (each with their own strengths and weaknesses), but many assumptions had to be made. These assumptions were all checked using data from smaller geographical areas (and national/regional statistics) but it was not feasible to check the data for all of the EU-28.
The OpenStreetMap data was very useful for the purpose of the work in ecoDriver. Visual checks of the maps in various locations well known by the researchers showed that the road categorisation is generally very good. However, in some cases the aggregated numbers turned out to be quite strange, and it is not clear where the errors in the data came from.
Sensitivity analyses were done to check the impact of variations in our assumptions.

The combination of data sources - review material, focus groups, SP surveys, field trial feedback, the US ITS Cost database and current market information - was very useful in reaching a view of the lifetime cost of the ecoDriver system. Ultimately a decision is needed to engineer the system to a price point. What we have done is indicate at about what level that price point should be: our starting point was a €250 lifetime cost including any software updates, for an embedded 'FeDS'-type system.

5. Scaling up results

5.1 Effect sizes for selected scenarios

For all scenarios the scaled up results were calculated with SCENIC. This resulted – for each scenario-future year combination – in a % change for each indicator: this is the effect of the ecoDriver system (compared to no ecoDriver system) in the EU-28, for all road types and vehicle classes. A detailed table with all results can be found in Annex H. This paragraph contains a number of graphs with the results per indicator and per scenario.

5.1.1 Environmental results

Figure 30 and Figure 31 show the environmental results: the impact of ecoDriver on CO_2 and NO_x emissions and on fuel and energy consumption. The results for CO_2, fuel consumption and energy consumption are very similar (but not exactly the same, due to the presence of hybrid and electric vehicles). What can be seen in the figures is that there is a small positive impact of ecoDriver on the environmental indicators: CO_2 and fuel and energy consumption decrease. The size of the effects varies from a decrease just above 0% to over about 1.7%. Effects are largest for the Green Future scenario and smallest for the Challenging Future scenario. In most cases, effects are larger for future years. The only scenario this does not hold for is Challenging Future 2035. This is due to a lower compliance rate for 2035 (compared to 2030). In Green Future, the CO_2 emissions effect is almost the same for 2030 and 2035. The effect sizes found in the simulations were higher for 2035, but the share of vehicle kilometres in congested traffic conditions is higher in 2035 (and in congested traffic, the ecoDriver effect is assumed to be 0%).

For NO_x emissions, the effects vary, due to reasons discussed in paragraph 2.4. In two scenarios, small increases can be found.

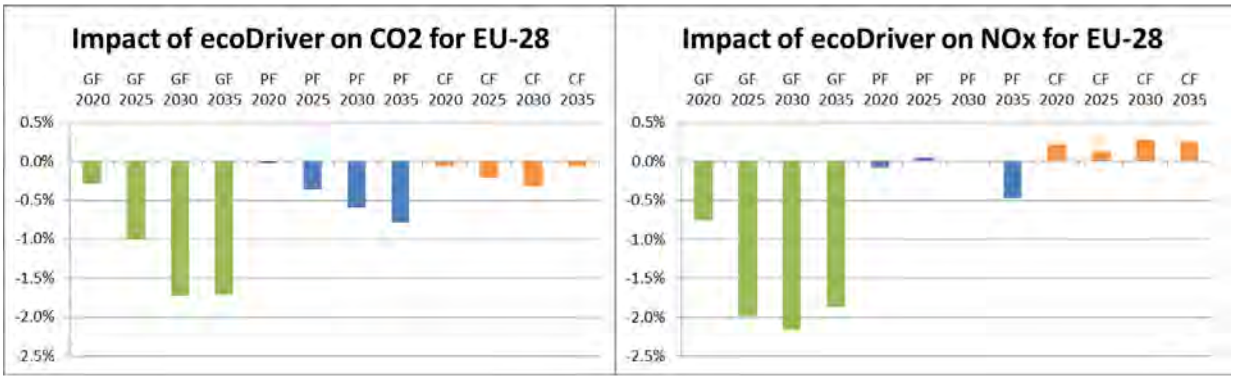

Figure 30: Impact of ecoDriver systems on CO_2 and NO_x emissions for EU-28

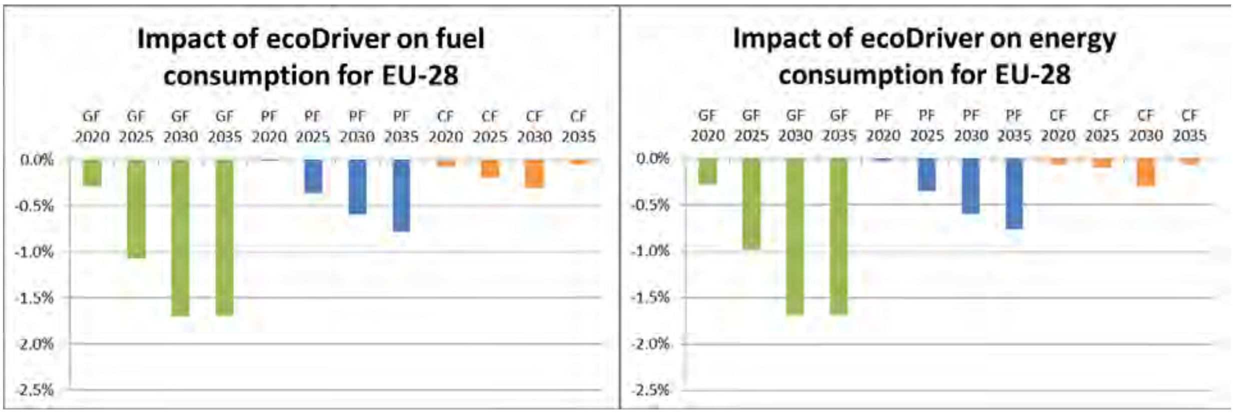

Figure 31: Impact of ecoDriver systems on fuel and energy consumption for EU-28

5.1.2 Traffic efficiency results

Figure 32 shows the traffic efficiency results: the impact of ecoDriver on travel times and travel times corrected for speeding. In the figure a negative impact of ecoDriver on throughput can be seen: travel times are increasing. This is due to the lower speed with which the ecoDriver vehicles drive. If we look at the travel time corrected for speeding (the argumentation for this is given at the end of paragraph 3.1.2) we see that the effect is very small: below 0.5%. Just as for the environmental results, the effects are largest for the Green Future scenario and smallest for the Challenging Future scenario. In most cases, effects are larger for future years.

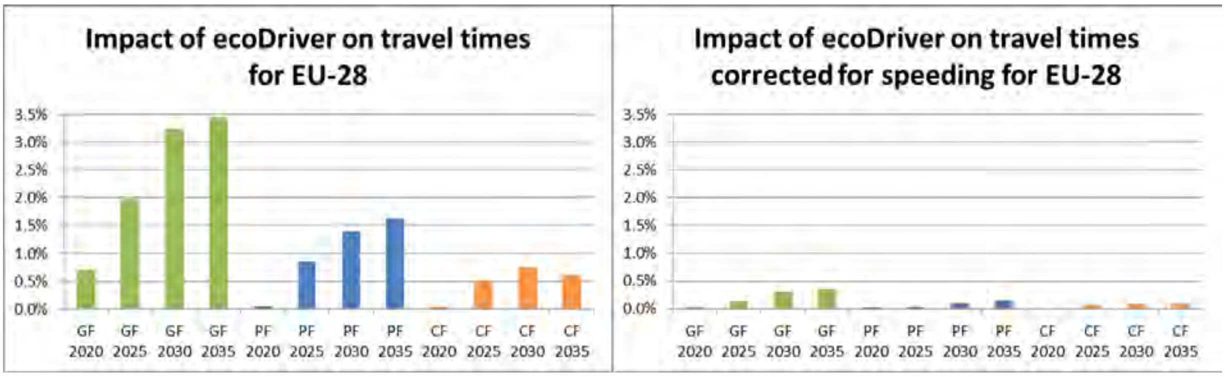

Figure 32: Impact of ecoDriver systems on travel times and travel times corrected for speeding for EU-28

5.1.3 Safety results

Figure 33, Figure 34 and Figure 35 show the safety results: the impact of ecoDriver on fatal, serious and slight casualty accidents, and on fatalities, serious and slight casualties. There are large positive effects of ecoDriver because of the lower speeds of the ecoDriver vehicles (and in some cases, other vehicles as well): all safety indicators show quite a large decrease (a few orders of magnitude larger than the effects for the other indicators). Again, the effects are largest for the Green Future scenarios, and effects are larger for future years.

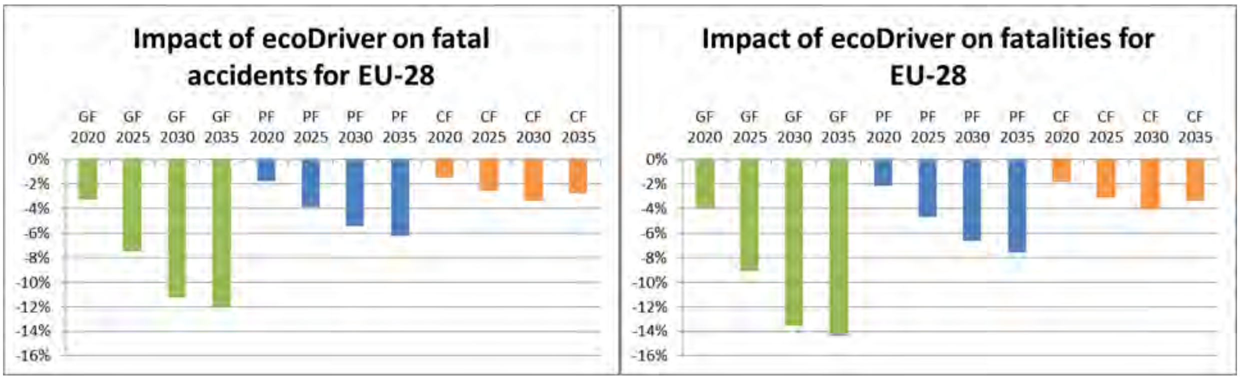

Figure 33: Impact of ecoDriver systems on fatal accidents and fatalities for EU-28

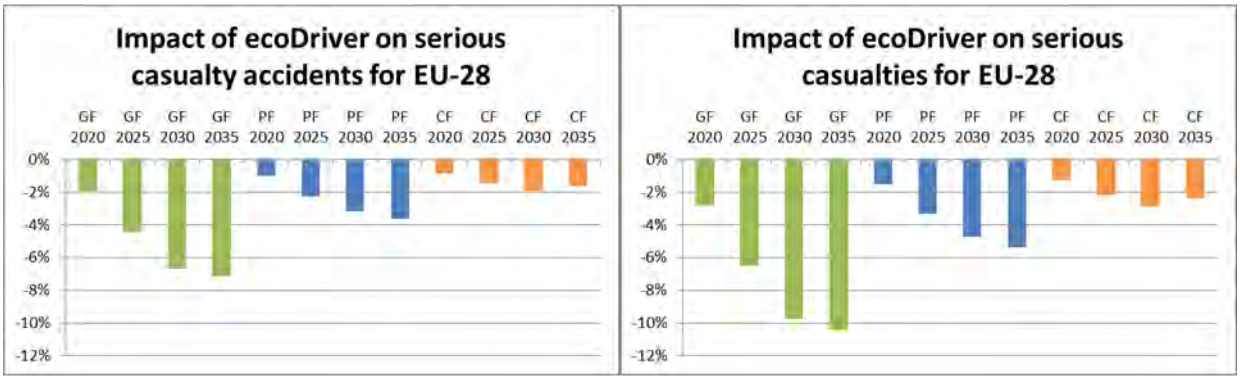

Figure 34: Impact of ecoDriver systems on serious casualty accidents and serious casualties for EU-28

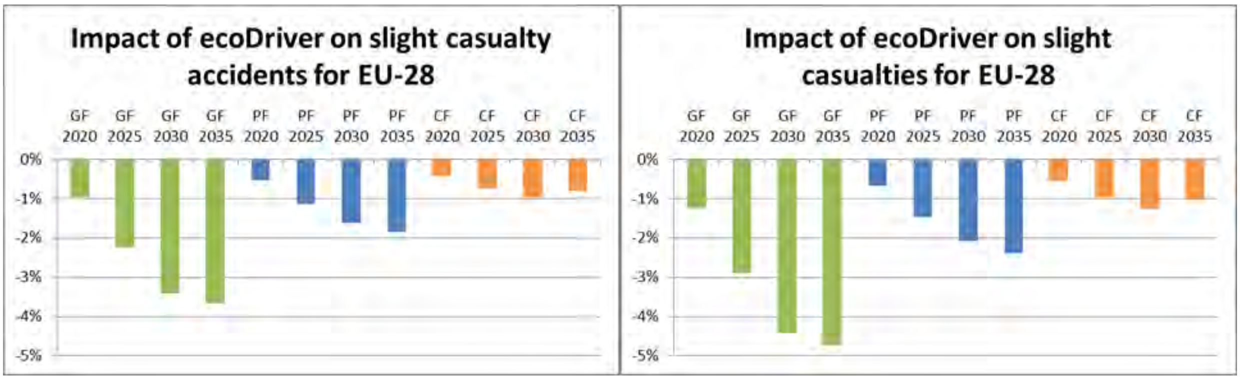

Figure 35: Impact of ecoDriver systems on slight casualty accidents and slight casualties for EU-28

5.1.4 Results per scenario

Figure 36, Figure 37 and Figure 38 show the impacts of ecoDriver for all indicators in one figure, per scenario for the year 2035. Scales have been kept the same across the scenarios. These graphs clearly show that the safety effects (in terms of % change) are quite large compared to the environmental and traffic efficiency effects.

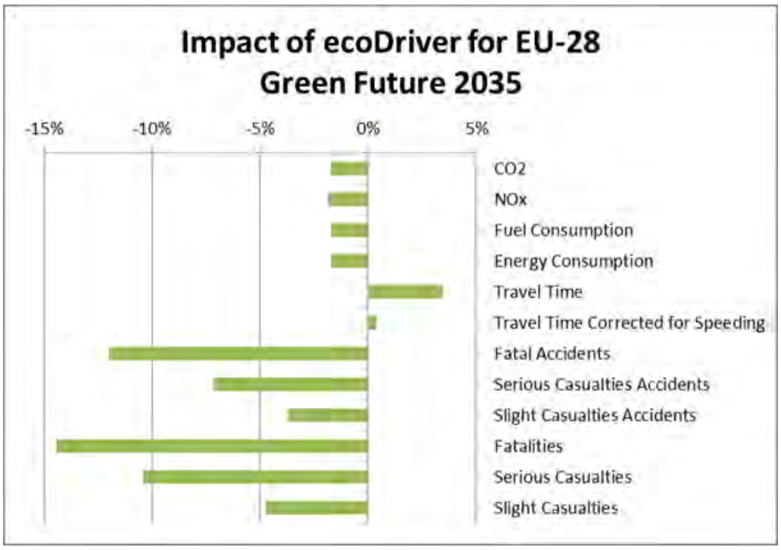

Figure 36: Impact of ecoDriver systems for scenario Green Future 2035, for EU-28

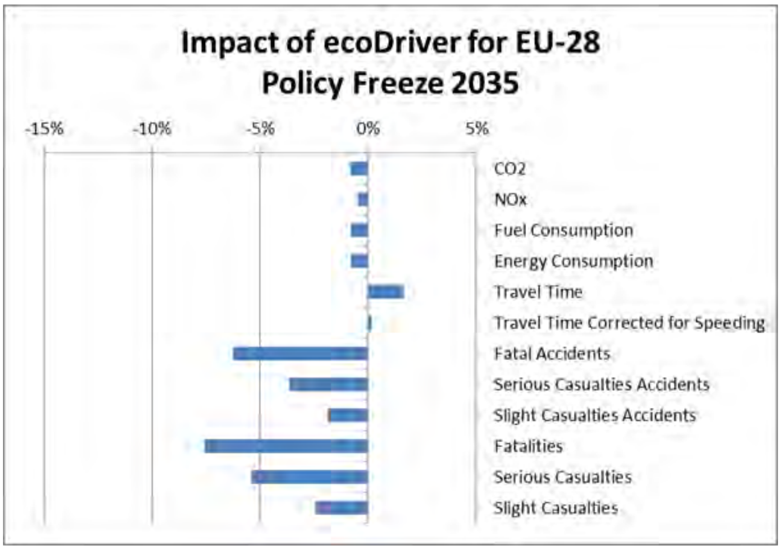

Figure 37: Impact of ecoDriver systems for scenario Policy Freeze 2035, for EU-28

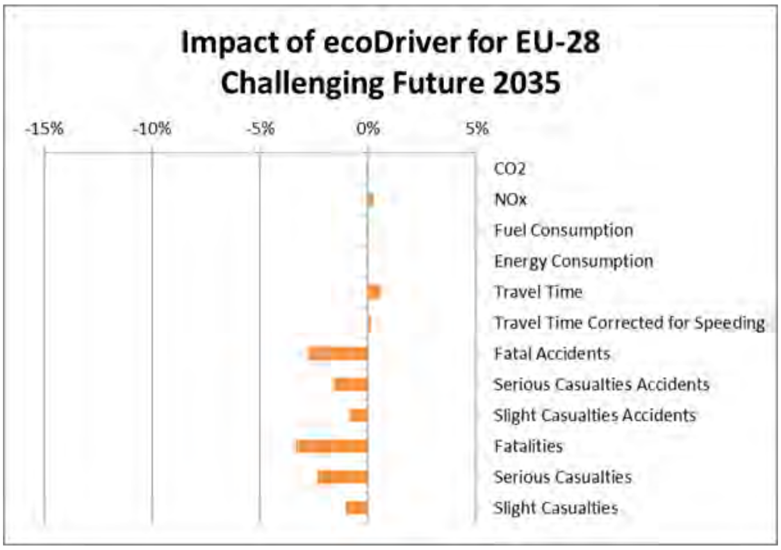

Figure 38: Impact of ecoDriver systems for scenario Challenging Future 2035, for EU-28

Not visible in these scaled-up results, but clear from the underlying data (and as mentioned in paragraph 2.4), is that the effects are the largest on rural roads. As rural roads have a high share in the total mileage in the EU-28 (over 50% of all kilometres driven) these roads also contribute the most to the overall effects of the ecoDriver systems at the EU-28 level.

5.2 Results of the sensitivity analyses

Paragraph 4.1.3 explained which sensitivity analyses were carried out. Detailed results of the sensitivity analyses can be found in Annex I. All sensitivity analyses were carried out on the Green Future 2035 scenario, since the impacts of ecoDriver are largest for that scenario-future year combination. This paragraph contains a summary (in words) of the results. A comparison has been made with the 'regular' Green Future 2035 scenario. The results are:

1. The sensitivity analysis on the distribution of mileage over road types (higher share on motorways and urban roads, lower share on rural roads) showed smaller effects for the adjusted distribution, which is because the effects were largest on rural roads and the share of kilometres driven on rural roads was reduced.
2. The sensitivity analysis on the distribution of mileage over vehicle classes (higher share for vans and trucks, lower share for cars) showed similar effects for both distributions, except for NO_x (there the effects were smaller with the adjusted distribution). This is logical because the emissions of NO_x are quite different for different vehicle classes.
3. The sensitivity analysis on the distribution of mileage over detailed road types (higher share for urban motorways, high intersection density rural roads and spacious cities) showed very similar results (effects were slightly larger with the adjusted distribution).
4. The sensitivity analysis on the distribution of mileage over demand levels was done in two ways.
    a. Zero share for congestion, higher share for moderate demand: this analysis shows effects that are a little bit larger in that case. This is logical because in congestion there is no effect of ecoDriver.
    b. Higher share for congestion, lower share for low and moderate demand: this analysis shows results that are a bit smaller in that case. This is logical because of the same reason as under a).

Overall, the differences between the sensitivity analysis scenarios and the 'regular' Green Future 2035 scenario are not substantial. The largest difference in effects is encountered in the first sensitivity analysis. It was decided not to take into account the results of the scaling up sensitivity analyses in the cost-benefit analysis.

5.3 Discussion of the scaling up results

The results of the scaling up based on the simulation results show that the effect of the ecoDriver system on the target indicators is as intended, but small. For CO_2 emissions and fuel/energy consumption the effects are in most scenario-future years combinations less than -1%. In the most positive case (Green Future 2035) the effect is about -1.7%.

Travel times increase, by up to 3.5% (for a 30 minute trip this means an extra travel time of just over a minute). When corrected for speeding, the effect is much smaller (up to 0.5%).

The safety effects are substantial, because of the decrease in speed. Fatalities and serious casualties are decreased by up to 14.5% and just over 10%; slight casualties are decreased by up to 4.7%.

The scaling up to the EU-28 level reduced the effects found in the simulations. The main reason for this is that no effects were assumed for congested traffic, as in that case driving is highly influenced by the surrounding traffic and speeds are (well) below the speed limit, leaving very little to no room for the ecoDriver system to affect driving behaviour.

The effects found in the simulations were highest for rural roads. These are the roads with the highest share in total mileage in the EU-28 (which is positive for the overall effect).

All scaling up results for the 'regular' scenarios (not the results of the sensitivity analysis) are input for the cost-benefit analysis.

To put the scaling up results in a broader perspective and compare them with results from other projects, we have compared the findings to evaluations carried out for similar systems in other projects. In eIMPACT (Wilmink et al., 2008), safety and traffic efficiency effects were estimated for several systems, of which the SpeedAlert system is the most similar to the ecoDriver system. The safety effects at a penetration rate of 100% were estimated to be -8.7% for fatalities and -6.2% for injuries, which is not very different from the results found with ecoDriver. Traffic efficiency effects were also in line with the results with ecoDriver. Environmental impacts were estimated to be positive (but not quantified).

In DRIVE C2X (Malone et al., 2014), several cooperative systems were evaluated, of which the in-vehicle signage system (speed limits version) was somewhat similar to the ecoDriving system (it is an informing rather than an advisory system, with an audible signal when the driver exceeds the speed limit). Safety effects for 100% penetration rate were in the range of -1 to -3% in 2020 and -5 to -15% in 2030 for fatalities and -1 to -2.5% for 2020 and -3 to -10% for 2030 for injuries. In the field trials, vehicles were found to have driven 4.1% slower (averaged over all road types). Within ecoDriver, an effect of this size was only found in the Green Future 2035 scenario. Effects on CO_2 emissions were calculated to be in the range -1 to -2%.

In the EuroFOT project (Benmimoun et al., 2012), two systems somewhat similar to the ecoDriver system were evaluated: Speed Regulation, which included a speed limiter (voluntary) and cruise control (not active at the same time), and the Fuel Efficiency Advisor, which shows the fuel consumption of the vehicle real-time, to support fuel-efficient or eco-driving. This is an advisory system for trucks which could be not be switched off.

No results are given for the safety effects. In the field operational tests (FOTs), the following results were found for the speed limiter: a change in travel time/speed of between 0.8 and 2.4%, a reduction of fuel consumption of -1.5% on motorways to -5.2% on urban roads (rural roads: -3.8%). Scaling up the field operational test results using the usage rate derived from the FOT data (<3% of the time), a potential effect on fuel consumption of -0.26% could be achieved in the European passenger vehicle fleet.

Only environmental effects were determined for the Fuel Efficiency Advisor. A reduction of 1.9% in fuel consumption (not significant, trucks only) was found in the field operational test.

In the eCoMove project, several systems aiming at reducing energy consumption and CO_2 emissions were evaluated. (Wilmink & Niebel, 2014) reported that the extent of the effects depended on the traffic situation, the road network, and the driver, and that the effects on fuel consumption / CO_2 emissions of co-operative driving support functions tested in the field and in driving simulator studies ranged between 4-25%. Simulations were also carried out, showing effect sizes of up to 12%, but the simulations looked at traffic control applications which are not comparable to the ecoDriver system. No scaling up was carried out, due to a focus of the project on development and testing and the lack of suitable data at the EU level.

6. Cost-benefit analysis results

6.1 Benefits

The benefits of ecoDriver systems are shown in Table 17 for the Policy Freeze (business-as-usual) scenario. These include the fuel and energy cost savings to road users, the emissions reductions, the safety benefits and finally the travel time increases – a net *dis*benefit which we must include to give a complete assessment of the impact on users.

Table 17: Benefits of ecoDriver systems 2015-2035, PF scenario, Present Values, 2015 prices and values

	Policy Freeze	
Road users	@3% discount	@4% discount
Energy cost savings	28,868,532,822	25,209,843,994
eD system costs	-28,008,733,314	-24,674,292,986
Time savings	-11,170,334,051	-9,682,549,879
Safety benefits (internal)	20,578,499,898	18,403,803,486
Safety benefits (external)	11,095,332,591	9,922,799,117
General population	@3% discount	@4% discount
CO2 reduction	5,174,770,545	4,507,569,203
NOx reduction	157,856,798	139,584,839

Overall, the introduction of ecoDriver systems produces benefits of about €26.7 billion over 20 years at a 3% discount rate (and €23.8 billion at 4%) at the EU-28 level. The energy cost savings are roughly offset by the cost to road users of the ecoDriver system in the Policy Freeze scenario. This reflects the relatively small, approximately 0-0.8% annual energy savings predicted over the period 2015-2035 in this scenario, and the fixed price of the ecoDriving system. Previous studies, for example the impact assessment of the EU Transport White Paper (European Commission, 2011a), indicated larger potential energy savings from eco-driving, e.g.: "1.6% for cars and motorcycles; 2.1% for buses; 3.2% for vans; 1.9% for medium and heavy trucks; 2.2% for passenger rail and 1.3% for freight rail" (p52), and in other scenarios ecoDriver does achieve a greater energy savings – see Green Future below.

Table 18 shows the results for the other two scenarios. We see that the differences in fuel prices, attitudes to ecoDriving and other scenario assumptions (Table 3) make a substantial difference to the benefits. In particular, the Green Future scenario produces a 1.7% energy saving, and hence a substantially larger net benefit: €89.8 billion at 3% (and €79.9 billion at 4%). The Green Future also exhibits very large safety benefits: €61.2 billion at 3% (€54.7 billion at 4%). Whilst the primary motivation for ecoDriver was the savings in fuel and CO$_2$, the reasons for undertaking a wider CBA are illustrated by the strength of its safety impact.

The Challenging Future is very different in the opposite sense: only a 0.3% energy saving at the most; comparatively small net benefits (€3.5 billion at 3%, €3.6 billion at 4%). Among the factors in this are: the low fuel prices which reduce any savings; relatively low take-up of ecoDriver systems when available; and relatively low compliance with advice. The NO$_x$ increase that emerged in this test gave the analysts cause for concern, and a sentivity test was set up to remove NO$_x$ from the CBA – we report on this test with the main results in section 6.3 below.

Table 18: Benefits of ecoDriver systems 2015-2035, GF&CF scenarios, PVs, 2015 prices and values

	Green Future		Challenging Future	
Road users	@3% discount	@4% discount	@3% discount	@4% discount
Energy cost savings	86,348,939,703	75,862,087,776	8,602,786,622	7,621,119,849
eD system costs	-46,396,957,348	-40,975,738,182	-18,836,533,696	-16,588,459,811
Time savings	-29,253,804,031	-25,522,077,856	-12,096,215,775	-10,560,605,100
Safety benefits (internal)	38,743,706,355	34,627,792,494	14,676,712,023	13,184,111,191
Safety benefits (external)	20,789,460,876	18,580,905,263	7,856,577,873	7,057,575,027
General population	@3% discount	@4% discount	@3% discount	@4% discount
CO2 reduction	13,533,700,653	11,874,569,391	2,612,842,773	2,311,502,672
NOx reduction	4,415,923,462	3,964,452,628	-697,972,617	-631,208,873

6.2 Costs

The net cost to government from the introduction of ecoDriver systems consists mainly of the loss of indirect tax revenues from reduced fuel consumption. This is because governments receive substantial revenue from taxes and duties on fuel and energy. For example the current average shares of taxation in the consumer prices of diesel, petrol, autogas and electricity are: 0.5; 0.57; 0.28; and 0.33 (European Environment Agency, 2015; European Commission, 2011b; Eurostat, 2015c).

Table 19: Net costs to government, PF scenario, Present Values, 2015 prices and values

		Policy Freeze	
Government		@3% discount	@4% discount
Revenues		-15,158,620,581	-13,237,790,830
Costs		0	0
NET PRESENT VALUE		-15,158,620,581	-13,237,790,830

Differences in the energy price trajectory between scenarios have a profound effect on the cost to government (Table 20), partly because the energy price trajectories, which were based on a synthesis of international forecasts, are so divergent: by 2035 the range of underlying oil prices assumed was €75/barrel (CF) to €190/barrel (GF) (Jopson et al, 2015).

Table 20: Net costs to government, GF&CF scenarios, Present Values, 2015 prices and values

	Green Future		Challenging Future	
Government	@3% discount	@4% discount	@3% discount	@4% discount
Revenues	-45,013,901,750	-39,553,461,393	-4,520,556,901	-4,005,032,212
Costs	0	0	0	0
NET PRESENT VALUE	-45,013,901,750	-39,553,461,393	-4,520,556,901	-4,005,032,212

The impact on industry is the cost of developing and supplying vehicles fitted with ecoDriver systems, net of the revenue gained: the difference is labelled “margin” in Table 21. The take-up of ecoDriver systems influences the total cost of supplying the fleet – Table 21 shows these predicted costs across the three scenarios.

Table 21: Costs to industry, All scenarios, Present Values, 2015 prices and values

	Policy Freeze		Green Future		Challenging Future	
Industry - OEMs	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Costs	-26,328,209,315	-23,193,835,407	-43,613,139,907	-38,517,193,891	-17,706,341,674	-15,593,152,222
Margin	-1,680,523,999	-1,480,457,579	-2,783,817,441	-2,458,544,291	-1,130,192,022	-995,307,589

The margin is assumed to be 6% of industry revenues on sales of ecoDriver systems: this value was chosen in view of evidence that 8% is an appropriate cost of capital (nominal) in the automotive industry (KPMG, 2015), whilst the medium-term European Central Bank inflation forecast is tending back towards the long term 2% level (ECB, 2016). Therefore in each ecoDriver scenario and policy test, we have factored in a normal return for the industry–OEM.

6.3 Benefit-cost ratios

The Social cost benefit analysis (CBA) is reported in the form of two summary measures – NPV and BCR – each presented for the 3% or 4% discount rate, and for each of the PF, GF and CF scenarios:

Table 22: Social CBA results, Present Values, 2015 prices and values

Social CBA	Policy Freeze		Green Future		Challenging Future	
	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Net Present Value (NPV)	11,537,304,708	10,588,966,944	43,167,067,921	38,858,530,122	-2,402,359,699	-1,610,997,257
Benefit:Cost Ratio (BCR)	1.76	1.80	1.96	1.98	0.47	0.60

The overall benefit:cost ratio (BCR) of just below two in the Green Future scenario appears reasonable – it would be on the margin of being classified as 'good' in the UK (DfT, 2013). Indeed it is comparable with some major national-level infrastructure projects that have recently been approved (HS2 and Crossrail).

The Challenging Future scenario in particular shows how sensitive the BCR is to differences in benefits and in the cost to government (the denominator); note that the BCR drops somewhat below 2 in the Policy Freeze scenario (still in the mid-range of 'medium' value for money), whilst in the Challenging Future, the costs are greater than the benefits: NPV<0 and the BCR falls below 1.0. There is a risk here to the robustness of the appraisal results. Therefore we investigated what was causing the difference in outturn between the CF scenario and the others.

One specific issue is the NO_x performance of the ecoDriving system in the CF scenario. The NO_x benefits are negative – i.e. the amount of NO_x emitted appears to increase when the ecoDriving system is introduced. This seems counterintuitive, and if we exclude the NO_x calculations and provide a sensitivity test without it we obtain different, and slightly improved, results for the CF scenario (Table 23). Nevertheless the NPV remains negative.

Table 23: Social CBA results – sensitivity test excluding NO_x, Present Values, 2015 prices and values

Social CBA	Policy Freeze		Green Future		Challenging Future	
	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Net Present Value (NPV)	11,379,447,910	10,449,382,105	38,751,144,459	34,894,077,494	-1,704,387,082	-979,788,384
Benefit:Cost Ratio (BCR)	1.75	1.79	1.86	1.88	0.62	0.76

Another sensitivity test arises from WP43: the results from the field trials showed that the effectiveness of the ecoDriver system may approximately double (Borgarello, 2016; Saint Pierre et al., 2016), if the results from the most successful tests can be followed-through into implementation (how this could be achieved was not investigated in this workpackage). In that case, fuel savings and CO_2 emissions will also double with a positive effect on BCR. A caveat is that there may be effects on speed – it is unclear at the moment what the effects on safety and time losses are. We present a sensitivity test showing the implications for the Social CBA.

Table 24: Sensitivity test to increased ecoDriver system effectiveness – social CBA results, Present Values, 2015 prices and values

Social CBA		Policy Freeze		Green Future		Challenging Future	
		@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Net Present Value (NPV)		30,421,987,493	27,068,589,311	98,035,806,528	87,041,725,896	4,292,712,794	4,316,593,051
Benefit:Cost Ratio (BCR)		2.00	2.02	2.09	2.10	1.47	1.54

In this case, the BCR appears fairly robust (greater than 1.45 in all scenarios and greater than 2 in the PF and GF) to the increase in effect size and the consequences for the benefit and cost sides of the CBA – the cost side is affected through changes in government indirect tax revenues from fuel duty, VAT, etc. The NPV shows that in terms of absolute value to the EU population, a doubly effective ecoDriver system has markedly greater value than the system emerging from the scaling up.

It also needs to be borne in mind that more effective ecoDriver systems could potentially have higher costs – e.g. a haptic pedal. Therefore a key finding is that if the system can be engineered to achieve higher benefits at €250 cost, then the social case for ecoDriver systems looks strong – especially in NPV terms.

6.4 Cost-benefit analysis from different perspectives

The stakeholder CBA (Table 25, Table 26) shows there is an issue for drivers: whether the system is worth purchasing depends not only on their own fuel saving but on whether other benefits are big enough – this is because there are substantial time losses which weigh on the driver and because there are some substantial benefits which accrue, in part, to 'others' on the road, i.e. safety benefits. The allocation of the safety benefits between externalities and internal benefits to drivers is therefore very important to ascertain the overall Internal benefit.

This CBA has used the weighting from Ricardo-AEA et al (2014)[3], which was based on a synthesis of research including the UNITE studies (Lindberg, 2001; Sommer et al, 2002). It can now be seen from Table 25 (row labelled "of which, Internal") that even with the central estimate of ecoDriver fuel savings, there is a net gain to drivers in terms of their internal benefits: €11.3 billion net benefits, as a result of

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[3] car 0.76 internal; van and truck 0.22 internal; bus 0.16 internal

ecoDriver systems costing drivers €29 billion. The worst case from the driver perspective across all the scenarios tested is the Challenging Future.

Table 25: Stakeholder CBA results, Present Values, 2015 prices and values

	Policy Freeze		Green Future		Challenging Future	
Road users	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Energy cost savings	28,868,532,822	25,209,843,994	86,348,939,703	75,862,087,776	8,602,786,622	7,621,119,849
eD system costs	-28,008,733,314	-24,674,292,986	-46,396,957,348	-40,975,738,182	-18,836,533,696	-16,588,459,811
Time savings	-11,170,334,051	-9,682,549,879	-29,253,804,031	-25,522,077,856	-12,096,215,775	-10,560,605,100
Safety benefits (internal)	20,578,499,898	18,403,803,486	38,743,706,355	34,627,792,494	14,676,712,023	13,184,111,191
Safety benefits (external)	11,095,332,591	9,922,799,117	20,789,460,876	18,580,905,263	7,856,577,873	7,057,575,027
NET PRESENT VALUE	21,363,297,946	19,179,603,731	70,231,345,555	62,572,969,495	203,327,046	713,741,156
...of which, Internal	10,267,965,356	9,256,804,615	49,441,884,679	43,992,064,233	-7,653,250,826	-6,343,833,871
...of which, External	11,095,332,591	9,922,799,117	20,789,460,876	18,580,905,263	7,856,577,873	7,057,575,027
General population	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
CO2 reduction	5,174,770,545	4,507,569,203	13,533,700,653	11,874,569,391	2,612,842,773	2,311,502,672
NOx reduction	157,856,798	139,584,839	4,415,923,462	3,964,452,628	-697,972,617	-631,208,873
	Policy Freeze		Green Future		Challenging Future	
Industry - OEMs	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Costs	-26,328,209,315	-23,193,835,407	-43,613,139,907	-38,517,193,891	-17,706,341,674	-15,593,152,222
Margin	-1,680,523,999	-1,480,457,579	-2,783,817,441	-2,458,544,291	-1,130,192,022	-995,307,589
NET PRESENT VALUE	0	0	0	0	0	0
	Policy Freeze		Green Future		Challenging Future	
Government	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Revenues	-15,158,620,581	-13,237,790,830	-45,013,901,750	-39,553,461,393	-4,520,556,901	-4,005,032,212
Costs	0	0	0	0	0	0
NET PRESENT VALUE	-15,158,620,581	-13,237,790,830	-45,013,901,750	-39,553,461,393	-4,520,556,901	-4,005,032,212

Table 26: Sensitivity test to increased ecoDriver system effectiveness – Stakeholder CBA results, Present Values, 2015 prices and values

Stakeholder group:	Policy Freeze		Green Future		Challenging Future	
Road users	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Energy cost savings	57,737,065,644	50,419,687,989	172,697,879,407	151,724,175,552	17,205,573,243	15,242,239,698
eD system costs	-28,008,733,314	-24,674,292,986	-46,396,957,348	-40,975,738,182	-18,836,533,696	-16,588,459,811
Time savings	-11,170,334,051	-9,682,549,879	-29,253,804,031	-25,522,077,856	-12,096,215,775	-10,560,605,100
Safety benefits (internal)	20,578,499,898	18,403,803,486	38,743,706,355	34,627,792,494	14,676,712,023	13,184,111,191
Safety benefits (external)	11,095,332,591	9,922,799,117	20,789,460,876	18,580,905,263	7,856,577,873	7,057,575,027
NET PRESENT VALUE	50,231,830,768	44,389,447,726	156,580,285,259	138,435,057,271	8,806,113,668	8,334,861,005
...of which, Internal	39,136,498,178	34,466,648,609	135,790,824,382	119,854,152,009	949,535,795	1,277,285,978
...of which, External	11,095,332,591	9,922,799,117	20,789,460,876	18,580,905,263	7,856,577,873	7,057,575,027
General population	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
CO2 reduction	10,349,541,089	9,015,138,406	27,067,401,307	23,749,138,781	5,225,685,546	4,623,005,343
NOx reduction	157,856,798	139,584,839	4,415,923,462	3,964,452,628	-697,972,617	-631,208,873
Industry - OEMs	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Costs	-26,328,209,315	-23,193,835,407	-43,613,139,907	-38,517,193,891	-17,706,341,674	-15,593,152,222
Margin	-1,680,523,999	-1,480,457,579	-2,783,817,441	-2,458,544,291	-1,130,192,022	-995,307,589
NET PRESENT VALUE	0	0	0	0	0	0
Government	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Revenues	-30,317,241,162	-26,475,581,659	-90,027,803,499	-79,106,922,785	-9,041,113,802	-8,010,064,424
Costs	0	0	0	0	0	0
NET PRESENT VALUE	-30,317,241,162	-26,475,581,659	-90,027,803,499	-79,106,922,785	-9,041,113,802	-8,010,064,424

One way to summarise the impact of ecoDriver systems on the driver is by calculating a ‘road user BCR’, which contains the Internal benefits to the users from Table 25 and Table 26 net of the ecoDriver system costs (Table 27). This highlights the finding that if the ecoDriver effectiveness was greater (precisely doubled), then the impact of the system would have a reassuringly ‘high’ BCR in the ‘Green Future’ and a solidly ‘medium’ BCR in the ‘Policy Freeze’. The ‘Challenging Future’ would remain a more marginal scenario for the introduction of ecoDriver systems.

Table 27: Road User BCR

Road User BCR	Policy Freeze		Green Future		Challenging Future	
	@3% discount	@4% discount	@3% discount	@4% discount	@3% discount	@4% discount
Main Test	1.37	1.38	2.07	2.07	0.59	0.62
Sensitivity test: 2x ecoDriver effectiveness	2.40	2.40	3.93	3.93	1.05	1.08

We have also conducted a stakeholder analysis on an individual level, focusing on the fuel saving set against the cost of the ecoDriver system so that a ‘break-even annual km’ figure emerges – in other words how far does a driver have to drive each year for the embedded system to pay for itself at €250, and at different levels of fuel saving (%)? The results are shown in Table 28. This demonstrates that for buses and trucks, the case for the ecoDriver system is overwhelming. Also for a representative European diesel fleet car, if the 5% fuel saving is achieved, then the ‘break-even’ annual km is approximately one-sixth of the typical annual km for such a car. Adoption should be widespread – subject only to some resistance among a small percentage of drivers who do not wish to have such a device in their car. At a 0.8% fuel saving the system will be attractive to only approximately half of the fleet drivers. For an average private petrol car, the driver would need to drive at least 29,400 km/annum (18,270 miles) in the Policy Freeze scenario to justify purchasing the system at a 0.8% fuel saving. This is far above the mean of 12,700 km/annum for such cars , so we would expect adoption to be limited in that case. Conversely, with a 5% fuel saving, any private driver who drives a distance greater than 4,700 km annually should obtain a benefit from the ecoDriver system: we know from UK data that only 13% of cars are driven less than this distance annually. Adoption, and success, of the ecoDriver system is therefore closely tied to the precise fuel saving delivered.

Table 28: Annual km at which a €250 ecoDriver system becomes worthwhile

Breakeven annual km	Policy Freeze				Green Future				Challenging Future			
	Car		Bus	Truck	Car		Bus	Truck	Car		Bus	Truck
	Private,	Fleet,	Diesel	Artic.	Private,	Fleet,	Diesel	Artic.	Private,	Fleet,	Diesel	Artic.
	Petrol	Diesel		>33t GVW	Petrol	Diesel		>33t GVW	Petrol	Diesel		>33t GVW
5% fuel saving	4,700	4,780	470	760	5,400	5,150	440	710	5,080	5,160	590	900
1.7% fuel saving	13,850	14,050	1,390	2,250	15,900	15,200	1,280	2,080	14,950	15,210	1,730	2,650
0.8% fuel saving	29,400	29,850	2,960	4,780	31,800	32,300	2,720	4,430	31,800	32,330	3,660	5,630
Typical annual km	*12,700*	*29,900*	*52,500*	*80,000*	*12,700*	*29,900*	*52,500*	*80,000*	*12,700*	*29,900*	*52,500*	*80,000*
Life expectancy, years	14	14	17.7	13.6	12	12	17.7	13.6	16	16	17.7	13.6

Assumptions: petrol car 6.6 l/100km (real world); diesel car 5.6 l/100km (real world); bus 46 l/km (real world); HGV artic.>33t GVW 36 l/100km (real world). Note the differences in fleet turnover/vehicle life expectancy in each scenario to some extent counteract the differences in fuel prices between scenarios, so the relationship between GF, PF and CF may not be exactly as expected.

6.5 Discussion of the cost-benefit analysis results

In the social cost-benefit analysis, the introduction of ecoDriver systems has a positive Net Present Value under most scenario assumptions. The only exception is the Challenging Future scenario, where the benefits are outweighed by the costs. This reflects the relatively small energy saving impact (up to

0.8%) under this scenario, the fact that the system costs per user are fixed across different levels of effectiveness, and the somewhat counterintuitive increase in NO_x emissions in this scenario. A sensitivity test was conducted to remove the NO_x effect, however the NPV remains negative in the CF scenario. It would be valuable to understand the underlying reason for the unexpected sign on the NO_x effect, however resolving this would not necessarily turn the NPV positive in the Challenging Future scenario.

The fact that current conditions in Europe resemble the Challenging Future scenario – in terms of fuel prices and economic growth particularly – creates something of a hurdle to the case for ecoDriver systems. The balance between energy cost savings and the costs of the ecoDriver system are rather skewed towards the latter in this scenario. In the other scenarios tested, the energy savings do outweigh the cost of the system, in a Present Value calculation at either a 3% or a 4% discount rate.

One way of moving beyond this finding for the Challenging Future scenario is to posit an increase in the effectiveness of the ecoDriver system, compared with the energy saving impacts modelled. For example, a sensitivity test was conducted to doubling the ecoDriver system's effectiveness in reducing energy consumption across the network. The stakeholder CBA results show that in this test the energy saving benefits alone do not outweigh the costs of the system, but when account is taken of the other positive impacts including internal safety benefits, the net internal effect on road users is positive. Then, when account is taken of the external benefits, we observe that the social benefit:cost ratio (BCR) for the Challenging Future scenario changes from around 0.5 to just over 1.0.

For the other scenarios, Policy Freeze and Green Future, the pattern of benefits and costs is as follows:

- The energy cost savings outweigh the costs of the ecoDriver system;
- When other effects on road users are included, there is a large benefit in terms of road safety, some of which accrues to the drivers themselves (internal) and some to other road users and wider society. There is also a disbenefit in terms of travel time losses, but the net effect of the energy savings and safety improvements net of time losses, is positive overall for drivers and for road users as a whole.
- We calculated a 'road user BCR' and found this to be positive for all scenarios. It is approximately 2.4 for the Policy Freeze and 3.9 for the Green Future, which is encouraging.
- There is a cost to government due to the reduced indirect tax revenues with ecoDriver systems in place – i.e. European drivers pay less in tax and duty on fuel and energy and this impacts on government receipts. However from the government's perspective this financial cost is worth taking: the benefit:cost ratios calculated show that the BCR to government is around 2 for most scenarios. This is on the borderline between 'medium' and 'high' value for money, a positive result.
- The industry/OEM participants are assumed to offer ecoDriver systems on a commercial basis, i.e. the revenues must exceed the costs of production - we allowed for a 6% margin, and the results for road users and government take this into account.

In order to carry out the scenario development and the social and stakeholder CBA, it was necessary to build an estimate of the ecoDriver system cost. The primary sources of information were focus groups with industry participants, a background review of existing data sources including the US ITS Cost database, two willingness-to-pay exercises – both linked to questions about acceptance of ecoDriver systems, current market information, attempts to unpack the component cost of the system, and feedback from various sources on our initial estimates. The main finding of the system cost work was that there is a case for engineering the embedded ecoDriver system to a €250 price point. Embedded systems offer higher effectiveness than the mobile app ecoDriver system. Given that system effectiveness appears to be in the range of 2-5% in its immediate impact on the driver's energy costs, and given the CBA results above, there is genuine choice to be made in implementing the embedded system, the mobile app or both.

The great advantages of the mobile app are that it could be provided virtually free/at very low cost to users – we assumed a €15 lifetime cost including updates in our analysis – and that adoption does not require purchasing a new vehicle, therefore take-up can occur more-or-less immediately. This is reflected in the market penetration forecasts that are included in the CBA. The main requirement to use the ecoDriver app is a smartphone, and we found that smartphone market penetration is approaching 90% and likely to reach saturation at around 92% in the next 2 years or thereabouts. Not everyone wants a device that gives them driving advice (we found 38% of respondents would not want such a device at present), however for those that will accept ecoDriving advice, the mobile app allows for quick adoption into existing vehicles. For fleet and commercial vehicles, where controlling business costs is a priority, we expect high levels of take-up (and examples were given in the focus groups of fleets that had already adopted eco-driving systems using nomadic rather than embedded technology). The scenarios in the CBA include relatively large shares of drivers using the mobile app early on – within the period 2015-2020.

The main advantage of the embedded ecoDriver system is that it potentially offers greater energy savings and more impact across the wider set of benefits in this CBA. The question is then: does the incremental cost of an embedded system offer sufficient incremental benefits, and hence incremental value-for-money, over the mobile system? We found that it did, provided the price was set in an appropriate range, and assuming (based on the research to date) an incremental fuel saving of 3%. The share of car users who would potentially benefit from an ecoDriver system at different price points (including lifetime costs of the system), was found to be:

- 91% at €150
- 78% at €250
- 63% at €350.

The share of goods vehicle and bus operators that would benefit is greater, due to their higher annual mileage and their focus on the financial case.

Because the price of an embedded system is a one-off charge taken by the user on acquiring a new vehicle, they must make a judgement about the pro's and con's of purchasing an equipped vehicle, and a major factor in this decision is likely to be annual mileage. The case for adoption of an ecoDriver system by an individual driver varies across vehicle types and user types - given the relative fuel efficiency and annual mileage, and hence the magnitude of the potential savings. We expect most freight operators and bus operators to adopt an embedded ecoDriver system if available at this price point – and again assuming an additional 3% fuel saving over a mobile-based system. This is a clear choice, since the 'break-even' mileages for a bus or a truck are a factor of 10-100 times *below* the average annual distance driven by these vehicle types.

For fleet cars, the choice is slightly less clear-cut, and would depend not only on the individual vehicle's annual mileage, but also the economic scenario (e.g. fuel prices) and the precise fuel saving offered by the embedded system over the mobile app. Taking a 1.7% incremental fuel saving, a low fuel price scenario (Challenging Future) and a diesel-engined vehicle, the 'break-even' annual mileage would be about 15,000 km. For the average fleet car, whose annual mileage is around 30,000 km, there would be a clear fuel saving benefit from adopting the embedded system. However, this would need to be weighed carefully against any travel time effects – we can expect businesses to be sensitive to anything that slows down deliveries or business travel.

For privately-owned cars, the case for purchasing a vehicle with an embedded ecoDriver system is likely to be very dependent on the same key factors: expected annual mileage, expected fuel prices, and the incremental fuel saving. If a 5% incremental fuel saving is achievable, then we estimate for averagely-sized petrol-engined cars that around 87% would benefit from an embedded ecoDriver system over and above a mobile app. However, if the incremental fuel saving is lower – and the effect sizes emerging from WP43 suggest that something lower is more realistic – then it may be that in the ballpark of 50% of private car drivers may stand to benefit from an embedded ecoDriver system.

6.6 Lessons learned

Among the main lessons learned from this analysis are potentially that:

- The best target markets for the embedded system in its '€250/3%' form would be, in descending order of priority, buses and goods vehicles, and then fleet cars – focusing on the higher-mileage users first. In these markets, no subsidy or financial incentive should be needed to make adoption worthwhile.
- For many private car purchasers, the case for adoption is finely balanced / not clear-cut. There is therefore something to gain for suppliers – in terms of market share and revenue – from focusing on increasing the incremental effectiveness of the embedded over the mobile system. A '5% better than mobile app' system would potentially be attractive to 85% of private drivers, but a '0.8% better' system would probably be very hard to sell.
- The Challenging Future scenario creates some headwinds for the ecoDriver system, notably from lower fuel prices undermining the fuel cost savings on which the system relies.
- Nevertheless, the stakeholder CBA gives some insight that there are other benefits which governments might want to tap into in making the case for eco-driving. In particular, the ecoDriver system appears to have significant safety benefits – some of which may be apparent as 'internal' benefits to road users, but a large part of which are external and may form the basis for a case for financial incentives in support of eco-driving. In similar policy space, there may be

a case for incentivisation of eco-driving based on the NO_x reduction and public health benefits following from that – this would require gaining confidence in the ability of the system to control NO_x emissions at the aggregate level, particularly in the Challenging Future scenario where some of the numbers appear to be pointing the opposite way. With CO_2, in the longer term the external benefits of eco-driving should be internalised through the ETS (emissions trading system) and fuel prices, however in the short term this may provide a further basis for support – the CO_2 benefits in the CBA results are substantial.

- Finally, the analysis indicates that there is some uncertainty around the travel time effects of the ecoDriver system. These are large enough to have a major impact on the CBA – at the moment they are included (out of caution) but we wonder whether further analysis would reveal their true importance is different from that assumed. One way of investigating this would be through specific, targeted consumer testing of products that provide different levels of fuel saving and travel time change. It could also be tackled as part of a wider value of travel time study incorporating behavioural responses above/in the vicinity of official speed limits. Several value of time research programmes are ongoing within the EU28.

7. Implications for the ecoDriver project

7.1 Conclusions regarding the project goals

The scaling up and CBA results are directly relevant to the following ecoDriver project goals (see Section 1):

6. Look at the impacts of eco-driving support on driver attention and safety – *this relates to the scaling up of safety results*.
7. Look at a variety of impacts: CO_2 (carbon dioxide), NO_x (nitrogen oxide), particulates etc. and the balance between impacts – *this relates to the scaling up of environmental results on emissions*.
8. Consider how the observed effects on driving style would affect network-wide energy use and a variety of aspects of network performance including network efficiency – *this relates to the scaling up of environmental results on fuel and energy consumption and to the scaling up of throughput results*.
9. Consider scenarios for future powertrain adoption, and how eco-driving might affect the road networks of the future – *this relates to the scaling up in general*.
10. Perform a cost benefit analysis considering a range of scenarios of powertrain adoption – *this relates to the CBA*.

The scaling up based on the simulation results showed that the effect of the ecoDriver system on the target indicators is as intended, but the environmental effects (on CO_2 and NO_x emissions, fuel/energy consumption) are small. For CO_2 emissions and fuel/energy consumption the effects are in most scenario-future years combinations less than -1%. In the most positive case (Green Future 2035) the effect is about -1.7%.

The ecoDriver system results in lower speeds, which is beneficial for safety, but detrimental to travel times. This results in a slight disbenefit regarding travel times in the CBA.

The field trials and simulations showed higher effects. However, these results were not representative for the entire EU, as the scaling up showed. The main reason for this is that ecoDriver has little or no effect in situations where driving behaviour is to a large extent dictated by the surrounding traffic (i.e. congested traffic). Also, in the simulations we assumed less than 100% penetration rates and compliance with advice in all combinations of scenarios and future years.

The effects of the ecoDriver system vary between road types. The largest effects are found on rural roads. These roads also have the highest share in EU-28 mileage and the lowest share of congestion.

The overall benefit:cost ratio is considered to be good for the Policy Freeze and Green Future scenarios at around 2 or higher. For the Challenging Future scenario the costs are greater than the benefits: the BCR falls below 1. The stakeholder CBA shows that we can be reasonably confident the system is worth purchasing for drivers. This depends not only on their own fuel saving but also on whether other benefits are big enough, because there are substantial time losses which weigh on the driver and because there are some substantial benefits which accrue, in part, to ‘others’ on the road, i.e. the safety benefits. For buses and trucks, the case for the ecoDriver system is very positive. Also for a representative European diesel car with the typical mileage, the fuel savings would easily justify purchasing the ecoDriver system.

The results from the field trials (determined in SP4) show that the effectiveness of the ecoDriver system could be twice as high as the effects found in the simulations in SP5. Assuming that a version of the ecoDriver system can be developed that enables drivers on the road to achieve that increased level of fuel/energy and CO_2 savings, we have carried out a sensitivity analysis of the CBA results to determine what that would mean for the benefit:cost ratio and other CBA results. The impact on the NPV is strongly positive, whilst the BCR to government remains just ‘good’ – this is because the cost to government increases due to loss of indirect tax revenue.

It is unclear if these extra savings would be achieved by driving at lower speeds (lower than found with the version of ecoDriver that we evaluated in this deliverable), which would mean that there are also other effects, such as on travel times and safety, that need to be quantified. It is also not clear whether a more effective version of the ecoDriver system would need additional hard- or software (such as a haptic gas pedal) and what this would mean for the costs of the system. However, if the ecoDriver system can be engineered to achieve higher benefits at a cost of €250 per unit, then the case for several stakeholders looks stronger.

7.2 Considerations for future projects

We have shown in this project that it is possible to scale up results to the European level and that this delivers useful results for decision making. The scaling up was part of a larger framework, so assumptions and decisions that were made in each step are coherent and consistent throughout the entire scaling up and future casting process. For instance, the ecoDriver system functionalities determined which sample networks and traffic conditions should be simulated, and early in the project the data sources needed for scaling up and CBA were researched. In this way, we made sure that scaling up data could be found or derived for these sample networks and traffic conditions.

However, there were several challenges. These challenges were dealt with in the ecoDriver project; choices made were reported. For future projects, some of the solutions used can be used again, and improved upon. We used open source data, which proved very useful, but data from proprietary sources could be a useful addition if budgets allow the acquisition of such data.

Specifically, the following difficulties were encountered:

- Data availability, data processing and forecasting were the key difficulties during the scenario development.
- Modelling the ecoDriver systems and drivers’ interactions with the system were not trivial. On top of this there was the enormous number of cases that we considered and that caused difficulties in terms of data collection, processing and analysis.

- Data availability and processing to the right aggregation level for scaling up was another non-trivial issue. It is hard to retrieve data on what happens on the European roads in reality. For example, data on congestion and/or demand levels are hard to find and for the data that were found there are many inconsistencies. This is true for many projects, and as a consequence scaling up is often not done, or in a much simpler form, or using outdated data such as data from older projects of which the source is often unclear. For scaling up the impacts of C-ITS applications the type of data as discussed above is also very useful.
- Event-based scaling up data is even harder to find. Possibly, the UDRIVE project (a large scale European naturalistic driving study) will provide datasets that could be used for event-based scaling up.
- For the CBA, the increases in travel time and whether to count travel time gains from speeding as a benefit or not was a challenge. Further research on this would be worthwhile, as this is relevant for all projects dealing with measures that influence speeds. Also, differences between how countries treat this topic in their national guidelines for CBAs need to be considered.

For future projects on systems that affect driver (or vehicle) behaviour, it would be interesting to acquire more data about variations in driving behaviour across Europe, and also about conditions that could affect how the systems function, such as the weather. In the ecoDriver simulations, generic European circumstances and distributions of driver behaviours (such as desired speed distributions) were used. In theory, different drivers and weather conditions as can be found across Europe are represented in this way. Data per country to verify how representative this modelled behaviour is are not available yet (and to derive these data would be a project in and of itself). If these variations would be taken into account in the simulations, this also has consequences for the scaling up (especially if this leads to more simulations, for instance for several weather conditions).

There was a discussion within the project about the extent to which ecoDriver systems might increase journey time reliability. The conclusion of this discussion was that reliability impacts would be limited by the presence of other, non-ecoDriving traffic. However, in future studies where widespread adoption of (perhaps) co-operative systems across the network is envisaged, it may be more realistic to investigate improvements to traffic flow as a whole and hence to journey time reliability. In that case, the scaling-up and the CBA would need to be extended to models and methods incorporating reliability: traffic simulation models would again be useful in generating journey time distributions; whilst the reliability ratio approach could be used in the CBA.

Overcoming the challenges regarding the scaling up and the CBA was worthwhile, since the work resulted in a full picture with costs and benefits (for stakeholders) on the EU level, and this helps accelerate deployment. The scaled up results put the field test results in a wider context giving insights into how the penetration rates influence the traffic system for different road and traffic conditions and how this adds up to an overall estimation of the impacts. Furthermore it gives the possibility to estimate the effects for future situations. The approach and a large part of the data are general and can be reused for scaling up effects of other driver support systems.

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Annex

Annex A. Absolute numbers for the EU-28

Table 29: Absolute numbers for all scenarios, environmental and throughput indicators (EU-28)

Scenario	Vehicle kilometres (x 1,000,000)	CO_2 (x 1,000 tonnes)	NO_x (x 1,000 tonnes)	Energy consumption (x 1,000,000 kJ)	Travel times & travel times corrected for speeding (x 1,000,000 hours)
2015	3842886	813,942	2,910	$1.17*10^{10}$	69,383
2020 GF	4210947	877,560	2,141	$1.26*10^{10}$	76,335
2025 GF	4559419	934,012	1,997	$1.34*10^{10}$	83,134
2030 GF	4895544	978,385	1,818	$1.40*10^{10}$	89,963
2035 GF	5182292	992,266	1,635	$1.45*10^{10}$	96,339
2020 PF	4311647	900,342	2,195	$1.29*10^{10}$	78,421
2025 PF	4741990	978,057	2,092	$1.40*10^{10}$	87,002
2030 PF	5149606	1,050,234	1,953	$1.51*10^{10}$	95,372
2035 PF	5546170	1,085,314	1,799	$1.58*10^{10}$	103,732
2020 CF	4600040	960,691	2,347	$1.38*10^{10}$	84,509
2025 CF	5309337	1,095,765	2,353	$1.57*10^{10}$	99,338
2030 CF	6105629	1,247,293	2,335	$1.79*10^{10}$	116,319
2035 CF	6687024	1,313,851	2,190	$1.92*10^{10}$	129,857

Table 30: Absolute numbers for the EU-28 for all scenarios, safety indicators

Scenario	Fatalities	Serious casualties	Slight casualties
2015	21,954	122,044	914,942
2020 GF	18,657	106,929	796,538
2025 GF	13,994	95,172	710,426
2030 GF	10,533	74,293	553,426
2035 GF	7,669	68,916	498,083
2020 PF	19,103	109,486	815,586
2025 PF	14,555	97,448	727,415
2030 PF	11,080	78,148	582,147

Scenario	Fatalities	Serious casualties	Slight casualties
2035 PF	8,207	72,493	523,932
2020 CF	20,381	116,809	870,139
2025 CF	16,296	103,966	776,070
2030 CF	13,137	92,657	690,222
2035 CF	9,896	85,951	621,200

Annex B. Conversion OpenStreetMap data to ecoDriver road types

The following ‘rules’ have been applied to translate OpenStreetMap (OSM) data on road kilometres to the ecoDriver road types.

Motorways

All streets in OpenStreetMap that have as type of highway ‘motorway’, are considered motorways. To distinguish between urban and interurban motorways, the following translation was used:

Table 31: Translation of OSM data to ecoDriver road type 2 for motorways

OSM no. of lanes	**OSM speed limit**					
	N.a.	**Numerical <= 110**	**Numerical > 110**	**None**	**Signals**	**Other**
N.a.	Interurban	Urban	Interurban	Interurban	Urban	Interurban
1	Interurban	Urban	Interurban	Interurban	Urban	Interurban
2	Interurban	Urban	Interurban	Interurban	Urban	Interurban
3	Interurban	Urban	Interurban	Interurban	Urban	Interurban
4	Interurban	Urban	Interurban	Interurban	Urban	Interurban
> 4	Urban	Urban	Urban	Urban	Urban	Urban

Some adjustments were made for countries that have different speed limits than most other countries for motorways. Settings per country are:

- Sweden: highest SL appears to be 110 km/h. Urban SL seems to be 90 or 70 → interurban: >=110 km/h
- Cyprus: interurban: >= 100 km/h
- UK: interurban: >=70mph

Rural roads and urban roads

All streets in OpenStreetMap that do not have as type of highway ‘motorway’, are considered rural roads and urban roads. Rural roads are outside built up areas, and urban roads are inside built up areas. However, OpenStreetMap does not provide that information. Usually, rural roads have speed limits from 60 to 100 km/h, and urban roads have speed limits of 50 km/h and lower, with a few exceptions (e.g. in The Netherlands there are urban roads with a 70 km/h speed limit) for which we have made adjustments.

For rural roads, we made the distinction between high intersection density roads and low intersection density roads. We interpreted this for this purpose as main vs. local roads and selected by speed limit: a rural road with a speed limit of 80 km/h or above is considered a main road (high intersection density) and a rural road with a speed limit below 80 km/h is considered a local road (low intersection density, or if there are intersections the main flow always has priority and does not need to slow down).

When it comes to urban roads, we view cities as compact when they are older towns, with an unplanned town / road network lay-out, with narrower streets (in terms of perception, not necessarily lane width) and more intersections per kilometre (e.g. Amsterdam in The Netherlands). We view cities as spacious when they are newer towns, with a planned town / road network lay-out, with wider streets (again in terms of perception) and fewer intersections per kilometre (e.g. Rotterdam in The Netherlands). We did not find a good measure in OpenStreetMap for this so we did not make this distinction but divided the roads 50-50 between compact and spacious.
In the end, the following translation was used:

Table 32: Translation of OSM data to ecoDriver road type 2 for rural roads and urban roads

OSM speed limit	**OSM type of highway**							
	Trunk	**Primary**	**Secondary**	**Tertiary**	**Unclassified**	**Residential**	**Service**	**N.a.**
<= 50 km/h	Urban	Urban	Urban	Urban	Urban	Urban	Urban	Urban
60 km/h	Urban	Urban	Rural local	Rural local	Rural local	Urban	Urban	Rural local
70 km/h	Urban	Urban	Rural local	Rural local	Rural local	Urban	Urban	Rural local
>= 80 km/h	Rural main	Rural main	Rural main	Rural main	Rural main	Rural main	Rural main	Rural main
N.a.	Urban	Urban	Mix 50-50 urban / rural local*	Urban	Urban	Urban	Urban	Rural local

* This was chosen based on a check of roads in the UK and France.

Annex C. Mileage per inhabitant per day

After the vehicle kilometres were split into kilometres on motorways (urban and interurban), rural roads (high and low intersection density) and urban roads (compact and spacious) for all NUTS 3 regions in EU-28, a check on the number of vehicle kilometres per inhabitant per day per type of region was done, because this division was based on the number of road kms in a NUTS 3 region, and some regions have relatively long road networks, and other regions relatively short road networks.

First, the initial number of vehicle kilometres per inhabitant per day was calculated for each NUTS 3 region. Some of these numbers turned out to be very high or very low. Therefore, a scaling factor was applied to these numbers and where necessary they were cut off at certain boundaries. This resulted in a corrected number of vehicle kilometres for each NUTS 3 region. Below a description of how this was done.

Scaling
Available was the number of vehicle kilometres for motorways, rural roads and urban roads at NUTS 0 (country) level. This needed to be disaggregated to NUTS 3 level (regions) and more detailed road types (urban/interurban motorways, etc.). This was done based on the number of road kms found in OpenStreetMap (with some corrections based on other sources). The assumption was that in a region with a lot of road kms, a lot vehicle kms would be made. Therefore, initially, we divided the vehicle kms over regions simply based on their share of road kms. This resulted, for some regions, in very high or very low number of vehicle kms per inhabitant per day. To obtain more realistic numbers of vehicle kms, a scaling factor was derived that decreased the number of vehicle kms in regions that had numbers that were too high, and increased the number of vehicle kms in regions that had numbers that were too low. We calculated the ratio between the number of road kms per inhabitant per country (NUTS 0) and the number of road kms per inhabitant per NUTS 3 region. For each NUTS 3 region, this ratio was, with a formula, brought closer to 1 in order to remove extremes. The formula for the scaling factor is:

$$factor = \frac{1 - \frac{\left(roadkm/_{inh}\right)_{NUTS0}}{\left(roadkm/_{inh}\right)_{NUTS3}}}{2} + \frac{\left(roadkm/_{inh}\right)_{NUTS0}}{\left(roadkm/_{inh}\right)_{NUTS3}} = \frac{1}{2} \times \left(1 + \frac{\left(roadkm/_{inh}\right)_{NUTS0}}{\left(roadkm/_{inh}\right)_{NUTS3}}\right)$$

The scaling factor is arbitrary and could also be chosen differently. The number 2 by which is divided could have been a 3, for example. However, since no better information was available we worked with this formula. The scaling factor usually turns out to be close to 1, more than 75% is between 0.7 and 1.3, so in most cases only small adjustments needed to be made.

Cutting off at boundaries
After applying the scaling factor, some regions still showed unrealistic numbers of vehicle kms per inhabitant per day. These needed to be corrected. We determined lower and upper bounds on the number of vehicle kilometres per inhabitant per day, numbers that we thought realistic. This is based

on the precondition that even with a lot of or very little transit traffic the number of vehicle kilometres stays within certain boundaries (although this differs per type of area). We determined these bounds based on country data on vehicle kilometres per inhabitant per day for Flanders (Belgium), England, the Netherlands and Sweden; for these countries that type of data could be found. The data showed that (as expected) that in urban areas people drive less kms than in rural areas. Furthermore, we assumed that there is a link between number of road kms and number of vehicle kilometres in a region (the more road kms, the more vehicle kilometres). The bounds we determined are given in Table 33.

Table 33: Bounds on the number of vehicle kilometres per inhabitant per day

Area type	Lower bound on vehicle kilometres per inhabitant per day	Upper bound on vehicle kilometres per inhabitant per day
Urban region	8	29
Intermediate region	8	55
Rural region	17	55

As in every step of the process, the resulting numbers were scaled so that the total number of vehicle kms per country was kept the same as the original number found in the statistics.

Annex D. Distribution of mileage over demand levels

There were several sources of information for categorizing countries according to how congested they are: (Inrix, 2015), (TomTom, 2015), (JRC, 2012) and (GoogleMaps, 2015). Countries were ranked in three categories with 'scores' attached to it: most congested countries (1), moderately congested countries (2) and least congested countries (3). Based on each source a classification was made. After this, for each country an average score was calculated. Then countries were divided into three final groups:

1. Most congested countries: Belgium, Germany, The Netherlands, United Kingdom
2. Moderately congested countries: Spain, France, Ireland, Italy, Luxembourg, Poland, Portugal
3. Least congested countries: Austria, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Greece, Finland, Croatia, Hungary, Lithuania, Latvia, Malta, Romania, Sweden, Slovenia, Slovakia

The base table that was used for the distribution of mileage over demand levels was as follows. This table was derived using numbers from the eIMPACT project, splitting the numbers for motorways and rural roads into two categories for these road types, and updating the numbers by incorporating information from the other sources which held more recent and in some cases more specific information about congestion on urban vs. rural/interurban roads and during what period of the day congestion occurred.

Table 34: Base table for distribution of mileage over demand types

Road type	Low demand	Moderate demand	Congested
Urban motorways	15%	71%	14%
Interurban motorways	70%	22%	8%
High intersection density rural roads	90%	7%	3%
Low intersection density rural roads	98%	2%	0%
Urban roads	30%	50%	20%

This base table was used as a starting point for all three country groups. From this table of 'averages' three tables were derived, increasing the shares of congested and moderate demand traffic in the more congested countries, and decreasing those shares in the less congested countries, reflecting the amounts of congestion found in the several sources for these countries. The resulting 2015 tables for each country group were as follows:

Table 35: Base table (2015) for distribution of mileage over demand types for most congested countries

Road type	Low demand	Moderate demand	Congested
Urban motorways	10%	70%	20%
Interurban motorways	30%	55%	15%
High intersection density rural roads	80%	13%	7%
Low intersection density rural roads	90%	8%	2%

Road type	Low demand	Moderate demand	Congested
Urban roads	15%	55%	30%

Table 36: Base table (2015) for distribution of mileage over demand types for moderately congested countries

Road type	Low demand	Moderate demand	Congested
Urban motorways	30%	60%	11%
Interurban motorways	55%	37%	8%
High intersection density rural roads	87%	10%	4%
Low intersection density rural roads	94%	5%	1%
Urban roads	32%	52%	17%

Table 37: Base table (2015) for distribution of mileage over demand types for least congested countries

Road type	Low demand	Moderate demand	Congested
Urban motorways	49%	49%	2%
Interurban motorways	80%	19%	1%
High intersection density rural roads	93%	6%	1%
Low intersection density rural roads	98%	2%	0%
Urban roads	48%	48%	4%

For future years, a growth in mileage is expected for each scenario (see Annex F). For future distributions of mileage over demand types, we developed some rules of thumb, for each scenario in the year 2035, distinguishing the three country groups. These rules were as follows:

- Green Future 2035
    - Most congested countries
        - Share of congested increases with 25%
        - Low demand stays the same, except for rural roads where it is lowered with 2%
        - Moderate demand = 100% - low demand – congested
    - Moderately congested countries
        - Share of congestion increases with 50%
        - Low demand minus 1% for all road types
        - Moderate demand = 100% - low demand – congested
    - Least congested countries
        - Share of congestion increases with 50%, except for rural low intersection density roads where it is going from 0% to 1%. For urban roads the share of congestion doubles.
        - Low demand minus 1% for all road types
        - Moderate demand = 100% - low demand – congested

- Challenging Future 2035
    - Most congested countries
        - Share of congested doubles
        - Low demand stays the same, except for rural roads where it is lowered with 10%
        - Moderate demand = 100% - low demand – congested
    - Moderately congested countries
        - Share of congestion doubles
        - Low demand minus 5% for all road types
        - Moderate demand = 100% - low demand – congested
    - Least congested countries
        - Share of congestion triples, except for rural low intersection density roads where it is going from 0% to 2%. For urban roads share of congestion is multiplied by 5.
        - Low demand minus 5% for all road types
        - Moderate demand = 100% - low demand – congested
- Policy Freeze 2035
    - Most congested countries
        - Share of congested increases with 35%
        - Low demand stays the same, except for rural roads where it is lowered with 4%
        - Moderate demand = 100% - low demand – congested
    - Moderately congested countries
        - Share of congestion increases with 75%
        - Low demand minus 2% for all road types
        - Moderate demand = 100% - low demand – congested
    - Least congested countries
        - Share of congestion doubles, except for rural low intersection density roads where it is going from 0% to 1%. For urban roads share of congestion is multiplied by 3.5.
        - Low demand minus 2% for all road types
        - Moderate demand = 100% - low demand – congested

For the years between 2015 and 2035, linear interpolation was used. We are aware that that is a very rough estimation and that congestion does not develop linearly, but for this analysis we considered it detailed enough. Anyone interested in all tables that we used can contact the authors of this deliverable that are from TNO.

Annex E. Hilliness

Based on information about region types, we made a translation from these categories to share of vehicle kilometres driven on hilly roads. See the table below.

Table 38: Share of mileage on hilly roads for different types of regions

Hilliness of region	Predominantly urban regions	Intermediate regions, close to a city	Intermediate, remote regions	Predominantly rural regions, close to a city	Predominantly rural, remote regions
> 50 % of surface	10%	20%	35%	35%	35%
> 50 % of population*	15%	30%	50%	50%	50%
> 50 % of population and 50 % of surface	15%	30%	50%	50%	50%
other regions	0%	0%	0%	0%	0%
#N/A	0%	0%	0%	0%	0%

* This concerns only three (German) regions, so we assume the same percentages for this category as for the '> 50 % of population and 50 % of surface' category

Note that slopes are not usually very steep in cities, especially on the main roads. But a slope of about 3% is not unusual.

The hilliness information (first column of the table) was based on the previous NUTS classification. We used a conversion table for the newest classification.

Annex F. Mileage growth

For mileage growth a base table was defined for each scenario-future year combination (Jopson et al., 2015). This table we used for the group of moderately congested countries (see Annex D) and part of the least congested countries. For the most congested countries we assumed a mileage growth that was 50% lower, and for part of the least congested countries (the countries where we expect a low of growth is possible) we assumed a mileage growth that was 50% higher. The tables that we used are as follows.

Table 39: Indexed mileage (2015 = 100) for most congested countries

Road type	**Scenario**	**2015**	**2020**	**2025**	**2030**	**2035**
Urban roads	Policy Freeze	100	106.81	113.112	119.1053	124.9745
	Green Future	100	105.3214	110.5789	116.0304	121.5788
	Challenging Future	100	111.1656	121.6005	133.3399	141.8963
Rural roads	Policy Freeze	100	107.0899	113.5996	119.7644	125.7554
	Green Future	100	105.5161	110.7036	115.5973	119.473
	Challenging Future	100	111.4578	122.2168	134.3058	143.1344
Motorways	Policy Freeze	100	107.8223	114.9141	121.5942	128.0512
	Green Future	100	106.3705	112.1525	117.4747	121.5592
	Challenging Future	100	112.3276	123.8262	136.6551	146.0401

Table 40: Indexed mileage (2015 = 100) for moderately congested countries and part of the least congested countries*

Road type	**Scenario**	**2015**	**2020**	**2025**	**2030**	**2035**
Urban roads	Policy Freeze	100	113.62	126.224	138.2106	149.949
	Green Future	100	110.6428	121.1577	132.0608	143.1576
	Challenging Future	100	122.3312	143.2009	166.6797	183.7925
Rural roads	Policy Freeze	100	114.1798	127.1992	139.5287	151.5107
	Green Future	100	111.0323	121.4071	131.1946	138.9459
	Challenging Future	100	122.9155	144.4337	168.6117	186.2687
Motorways	Policy Freeze	100	115.6446	129.8283	143.1884	156.1024
	Green Future	100	112.741	124.3049	134.9494	143.1183
	Challenging Future	100	124.6552	147.6524	173.3102	192.0802

* The least congested countries included in this group are Austria, Cyprus, Denmark, Finland, Malta, Sweden.

Table 41: Indexed mileage (2015 = 100) for part of the least congested countries*

Road type	Scenario	2015	2020	2025	2030	2035
Urban roads	Policy Freeze	100	120.43	139.336	157.3159	174.9236
	Green Future	100	115.9642	131.7366	148.0912	164.7363
	Challenging Future	100	133.4968	164.8014	200.0196	225.6888
Rural roads	Policy Freeze	100	121.2697	140.7989	159.2931	177.2661
	Green Future	100	116.5484	132.1107	146.792	158.4189
	Challenging Future	100	134.3733	166.6505	202.9175	229.4031
Motorways	Policy Freeze	100	123.4669	144.7424	164.7826	184.1536
	Green Future	100	119.1115	136.4574	152.4242	164.6775
	Challenging Future	100	136.9828	171.4787	209.9653	238.1203

* The least congested countries included in this group are Bulgaria, Czech Republic, Estonia, Greece, Croatia, Hungary, Lithuania, Latvia, Romania, Slovenia, Slovakia.

Annex G. Assumptions about travel times

We could not find statistics for travel times at the EU-28 level. We therefore estimated this from the vehicle kilometres per road type, demand level and vehicle class by assuming an average speed of the speed limit or below.

See the table below for our assumptions for the travel speed. These were used for all scenario-future year combinations. Indirectly it is taken into account that in future years travel times will be higher because of increased congestion.

Table 42: Travel speeds for all combinations of categories

Vehicle class	Demand level	Terrain type	Road type 1	Road type 2	Average speed (km/h)
Cars & vans	Low & moderate	All	Motorway	Interurban	120
Cars & vans	Low & moderate	All	Motorway	Urban	100
Trucks	Low & moderate	All	Motorway	All	80
Buses	Low & moderate	All	Motorway	All	100
All	Congested	All	Motorway	All	40
All	Low & moderate	All	Rural roads	High intersection density	75
All	Congested	All	Rural roads	High intersection density	40
Cars, vans & buses	Low & moderate	All	Rural roads	Low intersection density	85
Trucks	Low & moderate	All	Rural roads	Low intersection density	80
All	Congested	All	Rural roads	Low intersection density	40
Cars, vans & trucks	Low & moderate	All	Urban roads	All	35
Buses	Low & moderate	All	Urban roads	All	20
Cars, vans & trucks	Congested	All	Urban roads	All	20
Buses	Congested	All	Urban roads	All	15

Annex H. Detailed scaling up results

Table 43: Scaling up results in % change (ecoDriver compared to no ecoDriver) for environment and traffic efficiency

Scenario	CO_2 emissions	NO_x emissions	Fuel consumption	Energy consumption	Travel times	Travel times corrected for speeding
2020 GF	-0.28%	-0.76%	-0.28%	-0.27%	0.70%	0.03%
2025 GF	-1.00%	-1.98%	-1.07%	-0.97%	1.97%	0.14%
2030 GF	-1.72%	-2.15%	-1.69%	-1.68%	3.24%	0.30%
2035 GF	-1.71%	-1.86%	-1.69%	-1.68%	3.44%	0.35%
2020 PF	-0.03%	-0.08%	0.00%	-0.03%	0.05%	0.01%
2025 PF	-0.37%	0.05%	-0.36%	-0.35%	0.86%	0.03%
2030 PF	-0.60%	0.00%	-0.59%	-0.60%	1.39%	0.11%
2035 PF	-0.79%	-0.46%	-0.78%	-0.76%	1.63%	0.16%
2020 CF	-0.06%	0.21%	-0.06%	-0.06%	0.03%	0.00%
2025 CF	-0.20%	0.12%	-0.19%	-0.09%	0.49%	0.07%
2030 CF	-0.31%	0.28%	-0.30%	-0.29%	0.74%	0.09%
2035 CF	-0.06%	0.24%	-0.04%	-0.06%	0.60%	0.10%

Table 44: Scaling up results in % change (ecoDriver compared to no ecoDriver) for safety

Scenario	Fatal accidents	Serious casualty accidents	Slight casualty accidents	Fatalities	Serious casualties	Slight casualties
2020 GF	-3.26%	-1.89%	-0.95%	-3.99%	-2.81%	-1.23%
2025 GF	-7.48%	-4.38%	-2.24%	-9.08%	-6.47%	-2.88%
2030 GF	-11.20%	-6.65%	-3.41%	-13.48%	-9.72%	-4.40%
2035 GF	-11.97%	-7.12%	-3.66%	-14.39%	-10.40%	-4.72%
2020 PF	-1.78%	-1.02%	-0.52%	-2.17%	-1.53%	-0.67%
2025 PF	-3.87%	-2.24%	-1.13%	-4.72%	-3.33%	-1.46%
2030 PF	-5.46%	-3.18%	-1.61%	-6.65%	-4.71%	-2.08%
2035 PF	-6.22%	-3.63%	-1.84%	-7.56%	-5.37%	-2.38%
2020 CF	-1.43%	-0.82%	-0.41%	-1.75%	-1.23%	-0.54%
2025 CF	-2.51%	-1.44%	-0.73%	-3.06%	-2.15%	-0.94%
2030 CF	-3.30%	-1.91%	-0.96%	-4.03%	-2.84%	-1.25%
2035 CF	-2.71%	-1.57%	-0.79%	-3.32%	-2.33%	-1.02%

Table 45: Scaling up sensitivity analyses results in % change (ecoDriver compared to no ecoDriver) for environment and throughput

Scenario	CO_2 emissions	NO_x emissions	Fuel consumption	Energy consumption	Travel times	Travel times corrected for speeding
SA1	-1.26%	-0.54%	-1.23%	-1.22%	2.50%	0.41%
SA2	-1.74%	-0.99%	-1.72%	-1.71%	3.50%	0.43%
SA3	-1.75%	-2.26%	-1.73%	-1.72%	3.44%	0.36%
SA4a	-1.75%	-2.06%	-1.73%	-1.72%	3.53%	0.39%
SA4b	-1.45%	-1.69%	-1.44%	-1.43%	2.89%	0.33%

Table 46: Scaling up sensitivity analyses results in % change (ecoDriver compared to no ecoDriver) for safety

Scenario	Fatal accidents	Serious casualty accidents	Slight casualty accidents	Fatalities	Serious casualties	Slight casualties
SA1	-8.99%	-5.33%	-2.73%	-10.83%	-7.80%	-3.53%
SA2	-12.02%	-7.16%	-3.68%	-14.45%	-10.44%	-4.74%
SA3	-12.37%	-7.36%	-3.79%	-14.87%	-10.75%	-4.88%
SA4a	-12.66%	-7.53%	-3.87%	-15.23%	-11.00%	-4.99%
SA4b	-9.93%	-5.91%	-3.04%	-11.94%	-8.63%	-3.92%

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