
# Service Request 12

"Consideration of the impacts of Light-Duty Vehicles scrappage schemes"

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Note: From 1 September 2015, we rebranded as Ricardo Energy & Environment, a trading name of Ricardo-AEA Ltd. The legal entity of Ricardo-AEA Ltd remains unchanged and all formal company information presented in this proposal, including previous years' financial accounts, are all in the name of Ricardo-AEA Ltd.

In November 2012, Ricardo plc acquired the assets and goodwill of AEA Technology plc and formed a new company, Ricardo-AEA Ltd. The entire capability and resources previously represented by AEA Technology plc were transferred to Ricardo-AEA, as were all employees. Consequently, where specific projects or track record referenced in this proposal were undertaken and completed prior to the acquisition, for contractual reasons, these continue to be identified as AEA Technology plc.

# Executive summary

**Objective of the project**

Ricardo Energy & Environment has been commissioned by DG Climate Action to provide technical support to the European Commission on 'Consideration of the impacts of Light-Duty Vehicles scrappage schemes'.

The main purpose of this work was to:

1. Gather information on the impact of scrappage schemes on the climate impacts of the car and LCV (light commercial vehicle) fleet.
2. Explore the coherence of the impacts of scrappage schemes with other policy objectives, such as reducing pollutant emissions.
3. Assess the cost-effectiveness of scrappage schemes, and compare the results to alternative policy options for reducing transport's GHG emissions.

This report provides an overview of the project methodology and main findings. In part, these findings have been informed by the modelling framework that was developed during this project.

**Findings from the literature**

An initial literature review showed that assessments of scrappage schemes in terms of their effectiveness in reducing GHG emissions were rarely positive. Even when tailpipe GHG emissions alone are considered, the assessments conclude that scrappage schemes are not the best option to reduce the climate impact of transport. When lifecycle GHG emissions are taken into account, the reviewed studies generally concluded that the effectiveness of scrappage schemes is even more uncertain. Scrappage schemes may have the potential to deliver other, non-environmental, benefits, such as safety, economic or industrial benefits. However, also the economic and industrial benefits appear to be contested in the available literature.

The literature review also showed that results of scrappage scheme assessments are in general very difficult to compare. This is, for example, due to different assessment timeframes (i.e. they range from 3 to 20 years in the reviewed studies) and different ways of presenting the results (i.e. as a % in/decrease to a business as usual scenario or as total emission reductions) across the different studies. Furthermore, all assessments depend on a wide range of assessment parameters and assumptions, such as concerning the vehicle kilometres travelled of trade-in and replacement vehicles or the type of $CO_2$ emissions that are considered (e.g. real-world or test-cycle emission estimates for tank-to-wheel emissions).

**Findings from this project's modelling framework – Sensitivity analyses and case studies**

The model framework developed for this study is also based on various input assumptions, many of which were designed as flexible inputs that can be adjusted by the model user. As such, the model framework allowed to test a wide range of different scenarios and hence the sensitivity of $CO_2$ emissions results to different assessment parameter and scrappage scheme design factor settings.

The nature of the response of the results to the change in inputs was understandable and mostly as expected. For example, embedded $CO_2$ emissions (emissions due to the manufacturing of the new vehicle), are high in comparison to the savings in annual $CO_2$ emissions that the new vehicle brings. It is therefore important to be aware of the contribution of these embedded emissions when assessing the results of the scrappage model. The same applies to assumptions concerning the vehicle mileage that are key to assessment results and can change the overall assessment of a scrappage scheme's $CO_2$ impacts from positive to negative.

In terms of scrappage scheme design, longer schemes with a high financial incentive and stringent selection criteria for both the trade-in vehicle and replacement vehicle in terms of the $CO_2$ performance yield the best performance in terms of the schemes' $CO_2$ reduction. However, a stringent age-criterion for the trade-in vehicle appears counter-productive. This is because of a reduction of the eligible trade-in vehicle stock that results in overall fewer vehicles that take part in the scheme. Also annual vehicle mileages that decrease with the vehicles' age (as observed in practice and reflected in the model framework) contribute to this counter-intuitive effect of the vehicle age criterion (which would incite the scrapping of comparatively older vehicles that are closer to their natural retirement and, on average, less used than newer vehicles).

Three case studies have been assessed for notional scrappage schemes, i.e. a 'short lax' scheme, a 'long stringent' scheme and a 'short stringent' scheme. The results show that the short lax scheme may result in insufficient improvements in annual $CO_2$ emissions to offset the increased emissions in the implementation year (due to the embedded $CO_2$ in the additional new vehicles) and so may give an overall increase in $CO_2$ emitted. The long stringent scheme (five times the duration of the short stringent scheme) was able to provide significant reductions in annual $CO_2$ emissions for a number of years after the closure of the scheme; however, these reductions then decayed over a number of years leading to a cumulative saving in $CO_2$ emissions at the end of a 14-year assessment timeframe (i.e. in the year 2030 in this project's model framework) of 0.17% of the BAU (business as usual) value.

**Economic implications of scrappage schemes**

The analysis has shown that it is a complex task to assess the economic implications of scrappage schemes. This is mainly due to i) the many assessment variables and scheme design factor settings on the basis of which estimates are established, ii) the multitude and complexity of the impacts of scrappage schemes (whether this concerns only their environmental performance or broader market impacts), and iii) the various different cost items that may be taken into account in a cost-effectiveness assessment.

The cost-effectiveness of scrappage schemes was assessed in terms of reductions in vehicles' life-cycle $CO_2$ emissions (with and without the co-benefits of reductions in air pollutant emissions) and considering only governmental expenditures for the financial incentives for the scrappage schemes as costs. For a baseline scenario and an assessment timeframe of 14 years, a cost of 610 EUR/t $CO_2$ abated was identified. This value is similar in magnitude to other estimates found in the literature. Considering also air-pollutant co-benefits, this value reduces to 585 EUR/t $CO_2$. However, this value varies significantly depending on the underlying assessment assumptions and also on the design of the scrappage scheme. For example, an assessment timeframe of 20 years yields a cost of 409 EUR/t $CO_2$; if the assessment timeframe is further reduced to only three years, the cost increases to 5,000 EUR/t $CO_2$ (reflecting that in the very first years of the scheme the total emissions increase compared to the BaU scenario due to the increased use of the renewed fleet).

The cost-effectiveness values that were identified on the basis of this project's modelling framework are difficult to compare with cost-effectiveness estimates of other policy measures. This is mostly because the estimates found in literature either consider different cost impacts or a different set of co-benefits. Identified values suggest that scrappage schemes are relatively less cost-effective than a set of other measures, however, this cannot be concluded with certainty. A more detailed analysis of the magnitude of the co-benefits that were considered in other studies and their impact on the cost-effectiveness calculation would be required.

**Wider considerations for the design of scrappage schemes**

There are wider potential economic and environmental considerations of scrappage schemes that are worth mentioning, although they are not straightforward to prove conclusively in practice. The first consideration is that if more money is being spent on car purchases, less is being spent on something else, whether this is in other sectors, for investment purposes or for savings. In the literature, losses in the retail sector in Germany in early 2009 were blamed on the national scrappage incentive, while it had been demonstrated in the US that a scrappage scheme had diverted money to car purchases that would otherwise have been invested. The assessment of the impacts of a pan-European scrappage scheme concluded that while a scrappage scheme would lead to increased employment in the automotive sector, most of this benefit would be offset by employment losses in other sectors. The fact that more old cars are scrapped also has the potential to affect related sectors, as there might be fewer cars to repair, but more scrap to process.

Also, scrappage schemes could result in price increases of older cars as the accelerated scrappage reduces their supply. Prices of younger cars could increase if they could be used as a replacement car (depending on the design of the scheme). It is also possible that such price impacts occur in related sectors, e.g. scrap metal prices could decline as a result of the increased supply. Such knock-on vehicle price effects could result in even older being longer on the market (e.g. in countries that mainly rely on the import of second-hand vehicles). This would have adverse effects on the $CO_2$ performance of a scrappage scheme as older, more polluting vehicles could be kept on the road for longer than they would otherwise have been.

**Conclusions**

Modelling the environmental impact of scrappage schemes requires a range of assumptions on the development of vehicle fleets and vehicle usage behaviour with and without a scheme in place. Sensitivity analyses showed that variations in these assumptions have the potential to turn scrappage schemes from a relatively low impact and relatively costly policy measure (from a cost-effectiveness perspective in terms of costs per $tCO_2$ abated) to a relative effective policy measure. However, a number of potential negative secondary environmental effects (such as effects on the vehicle use in export markets) could not be quantitatively assessed in this project, and studies that have done so could not be identified in the literature. This leads to some uncertainty in this area. Scrappage schemes also have effects on the automotive industry, and therefore on the economy of a country and its import/export countries as a whole. In addition to other potential safety benefits, such effects could not be assessed in the context of this project either, but could potentially significantly influence the overall outcome.

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# 1 Introduction and overview

## 1.1 Introduction

Ricardo Energy & Environment has been commissioned by DG Climate Action to provide technical support to the European Commission on “Consideration of the impacts of Light-Duty Vehicles scrappage schemes” (hereafter, the ‘project’) under a framework contract (reference CLIMA.C.2/FRA/2012/0006).

This report provides an overview of the project methodology and main findings. In part, these findings have been informed by the modelling framework that was developed during this project; this framework is further described in Section 4 of this report.

## 1.1 Project context

Existing $CO_2$ Regulations for light duty vehicles (LDVs) are delivering emissions reductions from these vehicles. However, one obvious drawback of the EU LDV $CO_2$ Regulations is that they only apply to new vehicles. LDVs can have average lifetimes of around 15 years (depending on the Member State) and many are on the road for much longer. Hence, in any particular year less than 10% of the vehicle fleet is likely to be replaced by new, efficient vehicles. Consequently, the average $CO_2$ emissions of the LDV parc will be higher than the average $CO_2$ emissions of new vehicles.

It might be concluded that scrappage incentives, under which owners of older vehicles would be given a financial incentive to scrap their vehicles, could be a potentially useful policy tool. First, as such schemes take older, more polluting and less efficient vehicles off the road, they could reduce the average tailpipe $CO_2$ emissions of the vehicle parc. Second, there could be a further improvement in the average tailpipe $CO_2$ emissions of the vehicle parc if the financial incentive was re-invested into a new, more efficient vehicle. In addition to the beneficial impact on in-use $CO_2$ emissions, there are other potentially beneficial environmental, social and economic impacts of scrappage incentives like reduced pollutant emissions and improved safety. Increased purchases of new vehicles could also help manufacturers to increase turnover and profits at least in the short-term. Additionally, measures to improve fuel efficiency will have social benefits, as users’ fuel costs decline as a result of driving more efficient vehicles, which in turn would have knock-on economic effects, as the money saved is spent elsewhere in the economy.

Hence, scrappage incentives have many *potential* benefits, but it is far from clear whether these are significant enough to make such schemes cost-effective compared to alternative policy instruments and whether there are indeed net environmental benefits once full lifecycle considerations have been taken into account over the medium-long term, or that they strike the right balance from a social perspective.

## 1.2 Project objectives

The purpose of this work was to:

4. Gather information on the impact of scrappage schemes on the climate impacts of the car and LCV (light commercial vehicle) fleet.
5. Explore the coherence of the impacts of scrappage schemes with other policy objectives, such as reducing pollutant emissions.
6. Assess the cost-effectiveness of scrappage schemes, and compare the results to alternative policy options for reducing transport’s GHG emissions.

## 1.3 Structure of this report

This report is structured as follows, with the following seven sections provided after this introduction:

- **Section 2** of this report provides the results of a high-level literature review that allowed to gain first insights into the functioning and design of scrappage schemes as well as into their environmental, safety, industrial or other impacts.

- **Section 3** then explores five shortlisted studies in more detail. This more detailed review of the studies allowed to understand more explicitly how assessment frameworks have been built in practice, what parameters can and/or should be used, and what scrappage scheme design options should be accommodated in the modelling framework.
- **Section 4** then describes the set up of the scrappage scheme modelling framework that was set up in the context of this study. A baseline scenario on the basis of which sensitivity analysis and further scenario analysis is carried out is introduced.
- **Section 5** then provides these latter analysis with a focus on providing scrappage scheme results in terms of their $CO_2$ impacts compared to a BaU (Business as Usual) scenario (the scenario without any scrappage scheme in place). This assessment allows to understand the main determents of the environmental 'successes' of scrappage schemes and the key assessment parameters that are most relevant for adequately reflecting a scrappage scheme's impact.
- **Section 6** explored the cost-effectiveness of scrappage schemes in terms of their $CO_2$ reduction capacity in more detail.
- Based on the findings, **Section 7** then derives conclusions on the design of scrappage schemes and takes wider considerations and impacts into account that could not be assessed in the context of this project. Overall conclusions are also provided in this section.
- **Section 8** provides a list of all the references included in the report/project analysis.

# 2 Review of literature assessing the impacts of scrappage schemes

## 2.1 Aim and approach

The aim of the literature review was to collate and review reports that assessed the impacts of scrappage schemes for light duty vehicles (LDVs), i.e. cars and light commercial vehicles (LCVs). The focus was on those studies that included an assessment of the impact of scrappage incentives on greenhouse gas (GHG) emissions. For those studies that did consider GHG impacts, the relevant reports were reviewed, as far as possible, to identify the approach taken to the assessment, particularly in relation to the estimation of the GHG impacts, and to identify the other environmental, economic and social impacts that were assessed. The ultimate aim of the review was to identify up to five reports that were considered to be particularly relevant for the project, which would be critically examined in more detail (see Section 3).

In identifying relevant reports, the objective was to collate reports that had a broad geographical scope. In particular, as agreed with the Commission at the project inception stage, the project team tried to identify studies that had looked at scrappage schemes in Eastern European countries: the idea being that where the LDV fleets are older, the impact of a scrappage scheme would potentially be greater. Another particular focus was to try to identify studies that covered LCVs in addition to, or even instead of, cars. Most of the studies of which the project team were aware of at the start of the project tended to focus on cars rather than LCVs. Even when LCVs were eligible, schemes were not always successful at persuading LCV owners to scrap their old vehicles (e.g. (Cooke, 2010)). The project team also aimed at uncovering studies that assess impacts other than environmental ones – such as safety or social impacts. Assessing such impacts of scrappage schemes is not the focus of this project, but literature might provide important lessons learnt in such respect, which can be valuable for the broader discussion of the effect of scrappage schemes in this project.

Relevant reports were identified from the existing collections of the project partners, an internet search and a search of relevant databases. A spreadsheet was developed that contained nearly 30 different columns in which information on the various issues of interest – from the approach taken by the project and the relevant aspects of the design of the respective scheme(s) to the type and estimation of the various impacts – were recorded in order to enable a comparative assessment. The basic information – title, year and internet link – were recorded for all of the reports identified, but the more detailed information was only recorded for the reports that assessed the impacts of scrappage schemes on GHG emissions and/or on fuel economy.

The following sections present the results of the literature review with respect to, respectively, the coverage of and information presented in the various studies, the methodologies used in the studies and the impacts covered. The section concludes by explaining the rationale behind the identification of the five most relevant reports, which were the subject of a more detailed, critical examination.

## 2.2 Coverage of the reports and the presentation of information

The coverage of the reports and the way in which the information was presented was not consistent. Eight of the studies reviewed in detail focused on only one country, which were either a western EU Member State, the US or Japan. In the remaining 10 studies that focused on multiple countries, the focus was similarly on western European countries, as well as various sub-national schemes, particularly in the US. There were few mentions of schemes in Central and Eastern Europe, although a couple of reports did provide information on schemes in some eastern EU Member States, i.e. Hungary, Romania and Slovakia, as well as in Serbia and the Russian Federation (ECMT, 1999) (IHS, 2010) . These two reports were selected to be critically examined, so further details of relevance will be discussed in Section 3. Most of the studies appear to focus on cars rather than LCVs, although this was rarely stated explicitly. Some reports implied that they covered LCVs, but then did not present any further information of relevance (ITF, 2011) (Schweinfurth, 2009). While the analysis undertaken in (IHS, 2010) focused on cars, the report did note that where a scheme did cover LCVs, there was usually a low take-up rate.

Most of the reports reviewed contained information on various elements of the design of the respective schemes assessed. The reports that covered more than one scheme often, but not always, summarised the main elements of the design of the various schemes covered in a table (or tables). The presentation of the design elements was not consistent between reports or even, in some cases, within the same report. Typical information on the design of a scheme that was presented included the eligibility conditions relating the scrapped and new vehicles, the level of subsidy, its timing and/or duration and, in some cases, the stated governmental objective. Further information on the information included in the reports that were critically examined can be found in Section 0.

## 2.3 Methodologies used in the various studies

One of the main findings with respect to the methodologies used in the various studies reviewed is that there is no one common approach to assessing the impacts of scrappage schemes. Some studies focused on one scheme, which was sometimes real (Jimenez, 2011), but sometimes constructed theoretically (Brand, 2013); others covered many different schemes, some of which simply reviewed results (Wee, 2011), while others attempted their own assessments (ITF, 2011).

Most of the studies assessed scrappage schemes that were put in place in the last decade, although some studies went back to the 1990s. The analysis was typically based on available data about scrapped cars (such as their number, characteristics, etc.) and/or new car purchases. In some studies (CCC, 2009) (TUG, 2009), however, such statistics were not available, so assumptions had to be made about fleet turnover, for example. GHG emissions and fuel efficiency variations were then either observed from datasets (Leheyda, 2013) (Schweinfurth, 2009) (Pleifer, 2015) or estimated (ITF, 2011) (IHS, 2010) (CCC, 2009) (Jimenez, 2011) (Li, 2011) (TUG, 2009). Some studies also carried out a counterfactual analysis in order to isolate the effects of scrappage programs. To do this, the studies took either a difference-in-difference approach (Leheyda, 2013) (Pleifer, 2015) (Li, 2011), which compares countries with and without a scrappage scheme in place, or a modular-stepped approach where scrappage scheme costs and benefits within a single country are incrementally added to get to an overall impact assessment (IHS, 2010). (ECMT, 1999) assessed costs and benefits against the non-intervention option and isolated the effects of the scrappage scheme from those of other existing policies. (Pleifer, 2015) also assessed what impacts would have been brought by scrappage schemes in those European countries that did not implement a scheme.

Another approach that was taken was to design a theoretical scrappage scheme, by defining its scheme design factors, and to evaluate the corresponding impacts. In these cases, models were used to analyse the response of the transport market to the new policy and to determine the consequences in terms of GHG emissions. The main models used in the studies reviewed were the UK Transport Carbon Model (Brand, 2013), MIT and JRC analyses (Lelli, 2010), TREMOVE and the EU27 Input-Output tables (JRC, 2009).

Other reports did not directly assess the impacts of a scrappage scheme. Some of these studies focused on evaluating the optimal age for vehicles to be scrapped based on their environmental performance (Wee, 2010) (Kim, 2003), or analysed the effects of increasing or decreasing a vehicle's life (Kagawa, 2011). (Allen, 2009) evaluated the fuel efficiency improvements that were required if replacing an old car with a new one was to at least offset the increase in non-use phase emissions. Finally, one report (Wee, 2011) presented a literature review of studies concerning scrappage schemes, drawing some conclusion on their effectiveness.

## 2.4 Impacts identified and assessed

Of the 18 reports that were reviewed (i.e. that included some sort of assessment of the impact on GHG emissions), around half focused only on tailpipe emissions, with the remainder covering at least some aspect of lifecycle and/or embedded emissions. The assessment of the scrappage scheme(s) in terms of their cost-effectiveness in reducing GHG emissions were rarely positive.

Even when tailpipe GHG emissions alone are considered, the assessments conclude that scrappage schemes are not the best option to reduce the climate impact of transport. Most studies reviewed either concluded that there would be an increase in the use-phase GHG emissions (Pleifer, 2015) (TUG, 2009) or highlight the poor cost-effectiveness of such policies (IHS, 2010) (ITF, 2011) (Jimenez, 2011) (Li, 2011). Among the reasons for an increase in GHG emissions or the poor cost-effectiveness of the measure was the rebound effect (ITF, 2011) – i.e. longer mileage driven by owners of more efficient vehicles – and the use of the subsidy to upgrade a vehicle (if the scheme is not properly targeted) (Pleifer, 2015). It was also pointed out that the reductions in GHG emissions are short-lived, since scrappage schemes are temporary, leading to an increase in emissions in the years after the scheme has finished (CCC, 2009) (Pleifer, 2015).

When lifecycle GHG emissions are taken into account, the studies generally concluded that the effectiveness of scrappage schemes is even more uncertain. For example, (ECMT, 1999) stated that the effect on carbon emissions is not clear and is strongly dependent on the specific design of the scheme. Several reports found that scrappage schemes do not produce a significant effect on overall $CO_2$ emissions, since the increased production-phase emissions offsets the emission reductions in the use-phase (Lelli, 2010) (JRC, 2009) (Schweinfurth, 2009). Lifecycle emissions were also found to increase in some studies (Brand, 2013), unless dramatic increases in fuel efficiency in future technologies were to occur, coupled with either a reduction in the embedded energy (Wee, 2011) (Wee, 2010) or a major uptake of hybrid vehicles (Kagawa, 2011). (Allen, 2009) identified the required fuel economy improvement of the newly purchased vehicle compared to the scrapped one that was necessary to have at least a neutral effect on lifecycle GHG emissions. On the other hand, (Kim, 2003) concluded that the optimal lifetime of a vehicle (in terms of minimising its lifecycle GHG emissions) is in some cases lower than the actual average lifetime. Hence, generally studies do not conclude that scrappage schemes are beneficial from the perspective of GHG emissions, although the dependency on the design of the scheme is stressed in many cases, which suggests that there might be scope to design a scheme that would deliver reductions in GHG emissions.

The review of the other impacts covered suggests that scrappage schemes have the potential to deliver other benefits, including environmental ones. Over half of the reports that were reviewed estimated another environmental impact; all of these focused either on amount of air pollutants emitted, or on the impacts of these pollutants more generally (e.g. impact on exposure to pollutants). A couple of the reports that took account of lifecycle and/or embedded GHG emissions, took a similar approach for air pollutant emissions (Kim, 2003) (JRC, 2009). Few other environmental impacts were considered with only (Wee, 2011) making a qualitative reference to noise (stating that the noise characteristics of the scrapped and new vehicle might be different), while (Lelli, 2010) also covered waste. With respect to air pollutant emissions, reports mainly considered emissions of $NO_x$, CO, VOCs and PM (see more details on the results of these assessment in Section 3.2). Several studies concluded that scrappage schemes can significantly reduce the emissions of air pollutants from vehicles (ITF, 2011) (Lelli, 2010) (ECMT, 1999) (Kagawa, 2011) (TUG, 2009). Again, some papers suggested that such reductions were not obtained cost-effectively (IHS, 2010) (Wee, 2010) (Li, 2011), or that these effects were just pulled forward in time as a result of the schemes (JRC, 2009).

Only three of the reports considered any relevant social impact and in each case it was safety, as newer cars were likely to be safer, both to occupants and others, than scrapped cars. While (Wee, 2011) covered safety in only in qualitative theoretical terms, (ITF, 2011) monetised the associated benefits, while (IHS, 2010) estimated the increase in the number of cars on the road that were fitted with selected safety equipment as a result of the scrappage schemes. Around half of the reports considered, or took account of, the impact of scrappage schemes on purchasing behaviour. A number of reports used evidence from various national statistics to estimate the impacts of scrappage schemes (IHS, 2010) (ITF, 2011) (Leheyda, 2013) (Pleifer, 2015) (Li, 2011). Other reports had to make assumptions in order to estimate the impact of a theoretical scheme (Brand, 2013) or focused on theoretically outlining potential behavioural responses, many of which were considered to be minor including a redistribution of use between different family cars and potential impacts on the use of other modes (Wee, 2011).

The majority of the reports addressed the economic impacts of scrappage schemes to some extent. As already noted, several of the reports concluded that scrappage schemes were not a cost-effective way of reducing emissions of either GHGs or air pollutants. The primary objective of most of the scrappage schemes implemented in the last years was to help support the automotive industry. Many studies found that the scrappage incentives had been successful in achieving this goal by increasing the demand for cars (JRC, 2009) (ECMT, 1999) (Leheyda, 2013) (Pleifer, 2015) (IHS, 2010). (IHS, 2010) also estimated the number of jobs that scrappage schemes had saved. Some reports argued that these effects were short-term, due to the temporary nature of the scheme (ECMT, 1999) (Schweinfurth, 2009), or found that a scheme benefitted domestic manufacturers rather than foreign ones (Leheyda, 2013). It was also argued that scrappage schemes distorted the market, as they promoted the automotive industry at the expense of other sectors (JRC, 2009) (Schweinfurth, 2009). Contrary to the findings of many of the reports, one study found that there was only a very limited increase in the demand for new cars (Jimenez, 2011), as a result of variations in prices that were applied by manufacturers, so that the subsidy only partially benefitted car owners. In the theoretical assessment, (Brand, 2013) estimated the loss in fuel tax revenue as a result of the increase in efficiency of the car fleet. As with other impacts, (Wee, 2011) provides a theoretical overview of possible economic impacts, which also included potential price increases, e.g. as a result of a decrease in supply of older cars.

## 2.5 Conclusions

The five reports that were chosen to be the subject of a more detailed criterial review were: (ECMT, 1999); (IHS, 2010); (ITF, 2011); (Lelli, 2010); and (Li, 2011). The rationale for their selection is summarised below.

1. (ECMT, 1999) tries to identify the conditions under which schemes would be beneficial, even though it was one of the older reports reviewed. The report sets out lessons for the eligibility criteria that should be used, relating to both the vehicles to be scrapped and the replacement vehicle as well as the incentive to be provided.
2. (IHS, 2010) is one of the more comprehensive of the recent reports that draws on existing evidence, rather than adopting a more theoretical approach such as (JRC, 2009). In particular, (IHS, 2010) contains a lot of detailed information about the many schemes covered and the methodology used for estimating the impacts on $CO_2$ emissions, etc.
3. Although it only covers three schemes, i.e. those in France, Germany and the US, the methodology used in (ITF, 2011) is clearly set out and is based on the original data from three schemes covered. The assumptions underlying the cost effectiveness calculation are explicitly set out, while the report also estimates the monetised value of various impacts, including of reduced $NO_x$ emissions and improvements to safety, which could provide insights for this project.
4. (Lelli, 2010) undertook a long-term lifecycle assessment and clearly set out the estimated impacts in relation to GHG emissions, although some of the assumptions could have been clearer.
5. Finally, (Li, 2011) undertakes its own assessment of the US scrappage scheme using a difference-in-difference approach taking Canada as the control market, i.e. the market without a scrappage scheme. All the assumptions are clearly stated and the analysis uses existing datasets, as this project plans to do.

Additionally, all of these reports estimated the impact of scrappage schemes on air pollutant emissions, while all but (Lelli, 2010) considered economic impacts; the short-list also includes two of three reports that considered safety and the main report that mentioned scrappage schemes in Eastern Europe.

# 3 Detailed examination of selected studies

This Section provides a more detailed review of the literature that was shortlisted in the high-level literature review as described in Section 1. The specific focus of this more detailed review was to identify:

i. Whether specific scheme design factors (such as the eligibility criteria of the vehicle etc.) have been identified to have specific impact on the environmental impact of the scheme, and

ii. How environmental impacts of scrappage schemes, and $CO_2$ impacts in particular, have been assessed.

In the following section the results of the review are split into these two elements. Table 3-1 lists the five studies that were reviewed in detail under this task and shows the scrappage schemes that were reviewed in the respective studies as well as the number of vehicles that were scrapped under the analysed schemes.

**Table 3-1: Real-word scrappage schemes considered by literature source reviewed**

| Study | Scrappage schemes considered | Number of scrapped vehicles (in 1000) |
|---|---|---|
| (Lelli, 2010) | n/a – fictional model scheme | n/a |
| (ITF, 2011) | DE (2009), FR (2009), US (2009) | DE: 1380; FR: 470; US: 678<br>*In % of LDV fleet*:<br>DE: 3.6%; FR: 1.5%; US: 0.3% |
| (IHS, 2010) | All 2009 schemes in Europe<br>(DE, IT, UK, FR, ES, NL, AT, RO, GR, SK, PT) | Max of ~ 32% of new LDV sales or around 4.4 million vehicles (given budget constraints) |
| (Li, 2011) | US (2009) | 678 |
| (ECMT, 1999) | Various European | n/a |

## 3.1 Scheme design factors defining environmental impacts

None of the reviewed studies provides a quantitative assessment (e.g. in terms of elasticities or sensitivity analyses) of the effect of scheme design factors on the environmental impact of the scheme. However, some of the studies provide qualitative assessments or considerations.

Table 3-2 provides an overview of these qualitative assessments by scheme design factor. It shows that there is no 'silver-bullet' solution to the design of scrappage schemes. None of the studies provides a clear view on how a specific design factor should look, the main issue being that it appears to remain unclear which vehicles should be targeted by such schemes. In theory, the following three criteria have to be met to ensure a successful scrappage scheme in terms of its environmental impact:

a) Scrap only 'biggest emitters' in terms of their actual emissions, defined by their fuel-efficiency *and* their actual use (e.g. $tCO_2$ over a certain timeframe);

b) Scrap only vehicles that would not have been 'naturally' scrapped in the foreseeable future while remaining 'biggest emitters' over that timeframe;

c) Replace scrapped vehicles only with most environmental vehicles while ensuring that these new vehicles are used similarly (or less) than the vehicles that were replaced.

However, in practice these criteria cannot be controlled/verified. For example, it is typically unknown what would have happened to vehicles if they had not been scrapped or how much they would have been used. Similarly, it is typically not known how much the replacement vehicles will be used.

Financial incentives and eligibility criteria for concerned vehicles that are based on the environmental performance or age of vehicles can provide a certain remedy - however, only to a certain extent. For example, older vehicles are typically less fuel-efficient, which would make them an ‘obvious’ target; however, these vehicles are also typically used less than newer cars (likely influenced by higher running costs and lower reliability). Therefore these vehicles are more likely to replaced ‘naturally’, resulting in a reduced environmental impact if these vehicles were to be replaced compared to others that would still be longer in use[1].

Targeting newer cars, on the other hand, would result in higher costs to society (high-value cars are being scrapped) at which other environmental policies would become more cost-efficient. Similar uncertainty revolves around other scheme design factors – the “right” setting does not seem to have been identified and a right balance between environmental performance of the scheme and its cost-effectiveness is difficult to strike.

**Table 3-2: Effects of scheme design factors on the environmental performance of schemes – considerations identified in reviewed literature**

| Scheme design factor (study) | Consideration concerning environmental impact |
|---|---|
| **Level of incentive** | |
| (ECMT, 1999) | **Low incentive**<br>• Will attract only older, badly maintained vehicles with a lower market value and high expected repair costs<br>  ○ This will attract vehicles with higher average emission rates;<br>  ○ However, the vehicles are likely to be close to their ‘natural’ retirement with a short remaining life (the vehicles would have soon been retired anyway and greater emissions reductions could have been achieved elsewhere);<br>• Will hardly persuade low-income owners of ‘gross emitters’ to replace vehicles (as this involves considerable expenditure).<br>**High incentive**<br>• Will increase the total amount of emission reduction, but attract vehicles with relatively better environmental performances → it will lower the cost-effectiveness of the scheme.<br>*Study concludes that incentive should be matched with other eligibility requirements that select the ‘dirtier’ vehicles.* |
| (IHS, 2010) | **Incentive based on the price of the new car**<br>• The study suggests that this can help to reduce bias towards cheaper cars and possibly increase bias towards vehicles with better environmental performance.<br>*[However, it would seem equally likely to result in replacement with larger or higher performance/less efficient vehicles.]* |
| (ECMT, 1999) | **Alternative incentives (Public transport pass)**<br>• Can decrease the size of the fleet and therefore significantly reduce emissions<br>• However, could only be a temporary effect and more due to the delaying of replacement purchases<br>*[In both countries mentioned (Norway and Denmark), the fleet started increasing a few months after the end of the scheme, without any permanent effect from the short-term fleet reduction.]* |
| **Eligibility criterion of vehicles to be replaced (age-related i.e. only older vehicles are eligible)** | |
| (ITF, 2011) | • Reduces the expected VKM by the retired vehicles (older vehicles travel less), limiting the $CO_2$ benefit of the scheme |

[1] For example, (Li, 2011) found that around 45% of program expenditure on the US (2009) scrappage scheme was spent on consumers who would have purchased a new vehicle even in the absence of the program

| Scheme design factor (study) | Consideration concerning environmental impact |
|---|---|
| (ECMT, 1999) | • Targeting older vehicles could result in supply shortages of such vehicles, resulting in even older vehicles being longer on the market and increased $CO_2$ emissions<br>*[The study suggest therefore that the schemes should retire only a limited number of old vehicles.]* |
| (IHS, 2010) | • The use of an older age threshold does not necessarily translate into a proportional reduction in vehicle emissions |
| **Eligibility criterion of replacement vehicles** | |
| (ITF, 2011) | • Restricting replacement vehicles to *new* vehicles may result in ignoring the highest-emitting vehicles (many owners of particularly old vehicles may not be able to purchase new cars) |
| (IHS, 2010) | • Allowing for *second-hand* vehicles caps the one time transaction emission benefit |
| (Li, 2011) | • Better environmental outcomes of schemes 'should be possible' by increasing the fuel economy requirements for new vehicles |
| **Type of scheme (incentive-to-scrap vs. incentive-to-replace)** | |
| (ECMT, 1999) | • Incentive-to-replace schemes need higher incentive to attract owners. They are therefore likely less cost-effective unless higher emissions reductions can be achieved. |
| **Size of the scheme** | |
| (ECMT, 1999) | • Larger schemes may avoid a greater amount of total emissions, but at a progressively increasing cost. |
| **Timing of schemes** | |
| (IHS, 2010) | • It is to be ensured that schemes are not implemented immediately ahead of significant improvements in emissions standards; as was the case with the 2009 schemes (ahead of the introduction of the Euro-5 standard) |

The analysis carried out by (ITF, 2011) highlights that the objective of cost-effective $CO_2$ emissions reduction is inherently difficult to achieve – the setting of scheme design parameters would need to be different for enhancing cost-effectiveness and for maximising $CO_2$ reductions (see Table 3-3). Undoubtedly, the design of schemes becomes even more complex where other, non-environmental targets are also to be achieved (such as increased industrial activity, increased GDP etc.).

**Table 3-3: Insights into scheme design parameters**

| Design parameter | Choice for desired target impact/objective | |
|---|---|---|
| | $CO_2$ | Cost-effectiveness |
| Age of targeted vehicles | Newer | Older |
| Class of targeted vehicles | Heavier/ medium | Heavier/ medium |
| Transaction conditions | New car: lower fuel consumption | Retired car: should still be in active use |

*Source:* (ITF, 2011)

In practice, many more different approaches to scheme design have been taken than those that have been qualitatively discussed in the reviewed literature (see Table 3-2). Table 3-4 provides examples of approaches that were identified in the reviewed literature concerning the most relevant scheme design factors. It can be seen that partly quite complex approaches were taken, where multiple criteria for the eligibility of trade-in or replacement vehicles were defined. A good example here is the US (2009) scrappage scheme that combined many different criteria to define which vehicles could be traded in, for which type of new vehicle. The level of financial incentive (which varied between USD 3500 and 4500) was dependent on the difference in the fuel-efficiency of the trade-in and the replacement vehicle.

**Table 3-4: Examples of scheme design approaches in practice**

| Identified approaches per design factor | Example schemes |
|---|---|
| **Type of incentive** | |
| Financial, dependent on… | |
| Characteristics of new vehicle (age and/or $CO_2$ and/or air pollutant emission levels) | DE (2009), FR (2009) etc. |
| Performance *difference* between new and trade-in vehicle | USA (2009) |
| Public transport pass | HU ('93), DK ('94), CAN ('96) |
| | |
| **Eligibility of replacement vehicles** | |
| age-, technology-related | US (1999) |
| age- (new car), emissions-related | DE (2009), FR (2009), AT(2009 |
| age- (new car), emissions-, powertrain-related | IT (2009) |
| age- (new or used <5y), emission-, technology-related | ES (2009) |
| age- (new), emission-, price-, segment-related | US (2009) |
| | |
| **Eligibility of trade-in vehicles** | |
| age-related | DE (2009), FR (2009), PT (2009), RO (2009), LU (2009) |
| age-, ownership-, condition-related (driveable) | US (2009) |
| | |
| **Type of scheme** | |
| No replacement required | DK (1994), GR (2009) |
| Required replacement | Most European 2009 schemes, US (2009) |
| **Duration of the scheme** | |
| Limitation of funds | US (2009) [set to 1 billion – a threshold which was not adhered to; close to 3 billion USD were spent] |
| Temporary restriction | Most European 2009 schemes |

As mentioned before, the specific impact of the different design factor settings was not further explored in the examined literature (with exception to the qualitative assessment that are provided in Table 3-2). The extent to which it was possible to account for the different scheme design approaches within this project is further discussed in Section 4.

## 3.2 Assessment parameters used in studies for defining environmental impacts

The tables present in this section give insight in the information that has been presented in the studies and that was useful for the further tasks of this project with regards to the assessment of environmental impacts of scrappage schemes. As such, these tables are focused on providing insight in the main approaches that have been taken rather than stating explicit values. The main approaches that are analysed refer to i) vehicle use assumptions, ii) assumptions directly related to $CO_2$ emission assessments, and iii) assumptions directly related to air pollution assessments.

It is important to note that the reviewed studies varied in their level of detail when providing the assumptions underlying their assessments. Furthermore, studies had a varying focus and did not coherently treat all types of impacts (or not in similar detail). A coherent presentation of information and/or results provided is therefore not always possible.

Table 3-5 shows the main assumptions that were taken in terms of **vehicle use** (in VKM – vehicle kilometres travelled). Since vehicle emissions are directly related to vehicle use, this parameter is considered to be one of the key parameters for the environmental assessment of the schemes.

The table highlights three main assumptions that were (or were not) taken by the respective studies. These refer to whether the VKM are dependent on:

i. *The vehicles' type / size* – this is important when considering that vehicle scrappage schemes might result in shifts between different size classes, powertrains or specific models. In case such shifts are observed they might point to increased/decreased vehicle use of the respective vehicle user.

ii. *The vehicles' age* – this is important since distances travelled can vary with vehicle age; typically the assumption is that VKM decrease with vehicle age (which is in agreement with all the - studies reviewed here where VKM is assumed to be age-dependent). Replacing a vehicle with a newer car could therefore result in increased VKM of the person replacing their vehicle.

iii. *The rebound effect* – the effect that the typically more fuel-efficient vehicles that replace older vehicles in scrappage schemes are driven comparatively more due to a decrease in fuel costs (an increased in 'miles per gallon' , or 'kilometres per litre').

**Table 3-5: Vehicle use assumptions found in reviewed literature (VKM – vehicle kilometres travelled)**

| Study | Main VKM assumption (VKM depend on…) | | | Details / Data source |
|---|---|---|---|---|
| | Vehicle type/ size | Vehicle age | Rebound effect | |
| (Lelli, 2010) | ✓ | | | The study assumes that the annual mileage for the BAU fleet and the replacing fleet is the same; values reflect the average EU-25 fleet in 2005 and are constant over time<br>**Vehicle types considered**: diesel/ petrol |
| (ITF, 2011) | ✓ | ✓ | | Study does not specify specific assumptions;<br>VKM assumptions are considered to be a '*key parameter*' to the assessment;<br>Approach is seen to be "*conservative*" as replacement fleet is estimated to travel more than the old fleet<br>**Vehicle sizes considered**: light/ medium/ heavy |
| (IHS, 2010) | ? | ✓ | ✓ | **Vehicle types considered**: unclear whether a distinction has been made<br>**Age effect**: data from TREMOVE 2008<br>**Rebound effect**: "typically used cost elasticities reported in literature", being VKM increases by 250-450km per new car per year (unclear whether/ how this is varied across different fuel-efficiencies) |
| (Li, 2011) | (✓) | ✓ | ✓ | **Vehicle types considered**: averages used for cars and light trucks respectively (no further distinction).<br>**Age effect**: (Remaining) lifetime VKM for different vehicle types are based on another study that investigated the US travel survey.<br>**Rebound effect**: varied between a 0-0.5 "rebound elasticity" (unclear |

| Study | Main VKM assumption (VKM depend on…) | | | Details / Data source |
|---|---|---|---|---|
| | | | | whether/ how this is varied across different fuel-efficiencies) |
| (ECMT, 1999)* | | (✓) | (✓) | *Observations* of assessed schemes suggest that there ‘might’ have been changes on average VKM<br>Study acknowledges age and rebound effect on VKM |

*Notes*: * The study does not model impacts but is ‘observation based’; the stated items ‘should be’ considered in schemes’ impact-assessments

Table 3-5 shows that most studies take such vehicle usage considerations in their impact assessments into account. (Lelli, 2010) is the most simplistic in this respect, accounting only for VKM differences between diesel and petrol vehicles. Most other studies account for the fact that VKM typically correlate to vehicle age and that more fuel-efficient vehicles are frequently used more. (ITF, 2011) highlights that VKM assumptions are a ‘key parameter’ to the assessment of scrappage schemes. At the same time, the approach of age-based VKM - resulting in (ITF, 2011) in overall increases of the total fleet VKM - is seen to result in a “conservative” estimate of the environmental impacts of scrappage schemes. Clearly, accounting also for rebound effects can then be seen to be even more conservative – an approach that was taken by (IHS, 2010) and (Li, 2011) and that is suggested by (ECMT, 1999). Depending on the data sources that are used to account for age-based VKM and a rebound effect separately, there is also the risk of “double-counting” increases in vehicle VKM of new, more fuel-efficient vehicles (see Section 3.3).

Table 3-6 provides information on the **emissions assumptions** that have direct effect on the $CO_2$ impact assessment of scrappage schemes. It shows that (Lelli, 2010) provides the most comprehensive approach by accounting for life-cycle $CO_2$ emissions. These comprise of TTW (tank-to-wheel) emissions, WTT (well-to-tank) emissions, emissions stemming from vehicle production and those also from the vehicles’ end-of-life; however, the specific assumptions and the ‘depth’ of these is not always entirely clear. All other studies account ‘only’ for tank-to-wheel (TTW) emissions; (ITF, 2011) justifies this approach by highlighting that 85% of the lifecycle emissions of a vehicle stem from vehicle use. (Lelli, 2010) and (ITF, 2011) us real-world emission estimates in their analysis, while (IHS, 2010) (and probably also (Li, 2011)) base their analysis on test-cycle emissions.

**Table 3-6: $CO_2$ emissions assumptions found in reviewed literature**

| Study | GHG emissions considered | | | | Details / Data source |
|---|---|---|---|---|---|
| | **TTW** | **WTT** | **Prod.** | **End-of-life** | |
| (Lelli, 2010) | ✓ | ✓ | ✓ | ✓ | Specific values used are mostly provided (how these were derived from partly combined sources unclear); values are averages for diesel/petrol and different technology scenarios over time<br>**TTW**: based on **real-world** driving (use of ARTEMIS database and ‘other’) and technology forecasts (and their $CO_2$ impacts) for future sales (3 different technology scenarios are assessed)<br>**WTT**: use of JRC studies and ‘other’<br>**Production**: use of “Ecoinvent” database and other<br>**End-of-life**: Method/ values used unclear and not provided |
| (ITF, 2011) | ✓ | ✗ | ✗ | ✗ | **TTW**: based on **real-world** driving (use of TREMOVE data up to 2030)<br>Only TTW considered “since research has shown that […] TTW account for approximately 85% of total life-cycle emissions”. |

| Study | GHG emissions considered | | | | Details / Data source |
|---|---|---|---|---|---|
| (IHS, 2010) | ✓ | ✗ | ✗ | ✗ | **TTW**: based on **test-cycle** emissions; average emission values of the respective country's fleet are considered (based on Commission's monitoring of new sales and IHS database) – estimates for future sales are based on expected regulatory requirements |
| (Li, 2011) | ✓ | ✗ | ✗ | ✗ | **TTW**: Study appears to apply type-specific **test-cycle** fuel efficiency (based on EPA fuel database; average values for trade-in and scrappaged vehicles are provided); $CO_2$ conversion factors not stated |
| (ECMT, 1999)* | ✓ | ✗ | ✗ | ✗ | Study does not provide detailed analysis of impact of schemes on $CO_2$ emission; refers to test-cycle emissions only. *"More detailed analysis of fuel-consumption characteristics of the scrapped and replacement cars"* would be required. |

*Notes*: *The study does not model impacts but is 'observation based'; the stated items should (at least) be considered in schemes' impact-assessments according to ECMT.

Table 3-7 shows the estimated $CO_2$ impacts of these studies. It becomes apparent that defining a link between the specific $CO_2$ assessment approach and the outcomes is difficult to make. Results are in general very difficult to compare, due to the following reasons (among others):

- *Assessment timeframes are different*- they range from 3 to 20 years, or, in the case of (Li, 2011), they cannot be easily identified since $CO_2$ comparisons between the BAU scenario and the scrappage scenario are made on the basis of the vehicle lifetimes (measured in VKM) of concerned vehicles;
- *Emissions reductions are presented differently*- not all studies provide emissions reductions as a % in/decrease to the BAU scenario; total emission reductions are however not comparable due to the different scopes and uptakes of the schemes. Also a derivation of per-vehicle estimates is not possible as the number of vehicle transactions is not always reported. A per-vehicle estimate could furthermore be misleading.

Furthermore, all emission assessments depend on various other input parameters (such as vehicle use, as described above).

Nevertheless, Table 3-7 provides some general interesting insights that are worth highlighting:

- Annual emission impacts reduce and can even inverse over time- as a result, studies applying longer assessment timeframes will find comparatively less significant annual emission impacts of the analysed schemes than studies that assess the impacts only over a limited period of time. This is, for example, due to the effect of vehicle transactions that take place in the BAU scenario: if the assessment timeframe is too short, then such transactions are not considered, as they typically happen in a later point in time compared to when a scrappage scheme is in place (i.e. the so-called '*pull-forward'* effect of scrappage schemes would not be accordingly reflected in the assessment).
- The cost-efficiency of scrappage schemes in terms of $CO_2$ reduction is seen to be poor; (Lelli, 2010) even estimates a GHG emission increase (a more detailed analysis of the studies' estimated cost-effectiveness of schemes is provided in Section 6 of this report).

**Table 3-7: GHG emissions impacts of scrappage schemes as identified in literature**

| Study | Scrappage scheme impacts on $CO_2$ emissions | Assessment timeframe |
|---|---|---|
| (Lelli, 2010) | **~1% GHG emission increase** compared to BAU (non-scrappage) scenario for all case studies (petrol cars and diesel cars, for all different technology uptake scenarios – GHG increase for advanced technology scenarios is less) | 20 years |

| Study | Scrappage scheme impacts on $CO_2$ emissions | Assessment timeframe |
|---|---|---|
| (ITF, 2011) | <u>German 2009 scheme:</u><br>**~0.05% $CO_2$ decrease** compared to BAU in first year (equal to ~65 kt $CO_2$ saved); effect significantly decreases over time (even reverses for certain years), resulting in cumulative $CO_2$ decreases of ~200 kt up to 2030<br><u>French 2009 scheme:</u><br>**~0.06% $CO_2$ decrease** compared to BAU in first year (equal to ~65kt $CO_2$ saved); effect significantly decreases over time, resulting in cumulative $CO_2$ decreases of ~265kt $CO_2$ up to 2030<br>*"overall results suggest $CO_2$ abatement should not be the main rationale for putting a fleet renewal scheme in place" – the value of the found impact is <10 MEuro in Germany and France* | 1 year / 20 years<br>(2010; 2010-2030) |
| (IHS, 2010) | **$CO_2$ decrease of 2.3 million tonnes over 3 years** by all 2009 EU scrappage schemes assessed (average gCO2/km of new vehicles in 2009 reduced by 5g compared to BAU) **–** annual impact decreases over assessment timeframe | 3 years (2009-2011) |
| (Li, 2011) | **$CO_2$ decrease by ~10-30 million tonnes** (depending on scenario – 12 different scenarios are developed)<br>*"If the program were to be judged as an environmental program, the implied costs of reducing $CO_2$ emissions are quite high"* | n/a (comparison based on vehicles' lifetime measured in VKM) |
| (ECMT, 1999) * | n/a<br>(analysis not carried out; "*No conclusions on the effect of the French, Greek, Irish, Italian and Spanish schemes can be drawn*") | n/a |

Table 3-8 provides an overview of the approaches that were applied to estimate the impacts of scrappage schemes on **air pollution** in the reviewed studies. (Li, 2011) provides the most comprehensive assessment by considering NOx, PM, CO and VOCs emissions. The estimates are furthermore based on real-world emission estimates and depend on the age of the vehicle. More details are, however, not provided; values are obtained from 'MOBILE6', a program maintained by EPA. The studies assessing European scrappage schemes ((ITF, 2011) and (IHS, 2010)) concentrate on NOx and PM impacts only. (ITF, 2011) appears to take the more advanced approach, considering real-world as well as vehicle age-based emission factors.

**Table 3-8: Air pollutants considered in reviewed literature**

| Study | Pollutants considered | | | | | Details / Data source |
|---|---|---|---|---|---|---|
| | NOx | PM | SOx | CO | VOCs | |
| (Lelli, 2010) | | | | | | No air pollutant effects considered |
| (ITF, 2011) | ✓ | ✓ | | | | NOx: **real-word** emission factors by **vehicle age** class (from TREMOVE)<br>PM: exhaust-related; order-of-magnitude assessment using regulatory emission limits |
| (IHS, 2010) | ✓ | ✓ | | | | Effects assessed on the basis of Euro standards, therefore based on **test-cycle** emissions |
| (Li, 2011) | ✓ | ✓ | | ✓ | ✓ | Emissions of pollutants are from MOBILE6, a program maintained by EPA; **test-cycle** emission values accounting for **vehicle age** |
| (ECMT, | (✓) | (✓) | (✓) | (✓) | (✓) | Impacts are not analysed but study suggests to account for these in impact assessments |

| Study | Pollutants considered | | | | | Details / Data source |
|---|---|---|---|---|---|---|
| 1999)* | | | | | | |

*Notes*: * The study does not model impacts but is ‘observation based’; the stated items should (at least) be considered in schemes’ impact-assessments according to ECMT.

Table 3-9 provides the impact assessment results in terms of air pollutants. Again it can be seen that the outcomes cannot be easily compared. General findings can however be summarised to be the following:

- Scrappage schemes have had a positive impact on air pollutant emissions, although better effects could have been achieved if the objective of the schemes would have been to reduce air pollutants (and according eligibility criteria of vehicles would have been introduced);
- Annual air pollutant benefits decrease over time (as is the case with $CO_2$ emissions).

**Table 3-9: Air pollutant emission impacts of scrappage schemes as identified in literature**

| Study | Scrappage scheme impacts on air pollutant emissions | Assessment timeframe |
|---|---|---|
| (ITF, 2011) | DE:<br>**2010: -7kt NOx compared to BAU**; impact decreases over time - till **2025: total -32kt NOx compared to BAU** (*“scheme was not designed to reduce NOx emissions; there were shifts from small- to medium-sized vehicles”*)<br>FR:<br>**2010: -3kt NOx compared to BAU**; impact decreases over time - till **2025: total -12kt NOx compared to BAU** (*“shift away from medium-sized vehicles but NOx emissions increased on per vehicle basis resulting from large share of Diesel vehicles”*) | 1 year / 15 years<br>(2010; 2010-2025) |
| (IHS, 2010) | Without the scheme there would have been more Euro-5 vehicles on the road in 2011 (schemes retired vehicles that would have been replaced later anyway → later replacement would have resulted in more Euro-5 compliant vehicles);<br>**The impact on NOx and PM emission reduction is positive** for the assessment timeframe but the annual abatement falls over time.<br>*(exact NOx and PM emission reductions unclear – no units provided)* | 3 years (2009-2011) |
| (Li, 2011) | n/a [Reductions are observed that are accounted for in C/B calculations as **‘co-benefits’**, but estimates for pollutants are not provided separately] | n/a (comparison based on vehicles’ lifetime measured in VKM) |

# 3.3 Qualitative assessment of studies’ approaches

This section provides an assessment of the approaches that were used in the reviewed literature to identify the environmental impacts of scrappage schemes. As in the previous section, the approaches that were taken to identify VKM of trade-in and replacement vehicles are first discussed and then the approaches that were taken to assess $CO_2$ emission impacts. All qualitative assessments are provided in Table 3-10. These have also guided the building of the modelling framework developed under this project (see Section 4).

**Table 3-10: Qualitative assessment of evaluation approaches used in the reviewed literature and potential implications on the studies’ outcomes**

| Category / Approach | Assessment | Impact on study outcomes / Further considerations |
|---|---|---|
| **Vehicle use – VKM (vehicle kilometres travelled)** | | |
| **Age-based** | Approach appears | It is to be considered that the recent evidence on age- |

| Category / Approach | Assessment | Impact on study outcomes / Further considerations |
|---|---|---|
| **VKM** | reasonable given latest insights in vehicle usage behaviour of the EU vehicle fleet (see "Understanding vehicle lifetime mileage […]" by Ricardo-AEA (2014)). | based VKM does not provide evidence for the *household* travel behaviour. A household that decides to purchase a new car could indeed use this new car relatively more compared to the car that was replaced. However, the mileage of a second-vehicle could decrease at the same time, which would keep the overall household VKM in balance.<br><br>It is also to consider that the cited study finds decreasing VKM with the vehicles' age for the average vehicle fleet. Such age-based decreases could happen step-wise, when vehicles get sold (as second-/ third-hand vehicles) to a household that drives less than the household who was the previous owner. Again, the age-based VKM assumption does therefore not necessarily hold for a household's vehicle usage behaviour.<br><br>The modelling of households' vehicle usage dynamics is outside the scope of this project. Most relevant in the context of this project is that VKM assumption are coherent between the scrappage scenario and BAU (business as usual) scenario (the scenario without a scrappage scheme in place).<br><br>Given the above, it is suggested that the age-based mileage assumption (which results in the replacement fleet (= the younger fleet) to travel more than the base fleet over the total assessment timeframe) be taken as a conservative estimate of the overall environmental impact of a scrappage scheme (as this is also done in (ITF, 2011). An approach with constant VKM over time (as in (Lelli, 2010)) could be taken as a more incautious estimate for the environmental impact of scrappage schemes and was therefore also accommodated in the modelling framework. |
| **Rebound effect** | Approach appears reasonable assuming that cheaper transport results in an increased level of transport demand according to supply and demand principles that may also apply to an individual household level | In the literature, households/persons are typically identified to have constant travel time budgets: as soon as trips get quicker, persons tend to travel relatively more so to spend the same amount of time/money as they did previously. This is a frequently observed phenomenon described in literature (e.g. (Banister, 2011)) and is also one of the causes of urban sprawl. It is typical for this concept to be explicitly put in context with travel time, rather than travel cost. However, it appears to be a reasonable assumption that households also have a fixed travel *cost* budget that they are willing to spend. A reduction in travel costs per km can then result in increased travel activity (longer distances travelled).<br><br>The higher the assumed rebound effect, the more conservative the estimate of the environmental benefit of the scheme will be. This is, as above, because the replacement fleet (= the newer and on average more fuel-efficient fleet) is therefore assumed to travel more than the base fleet over the assessment timeframe. |
| **Type/model** | Approach appears | Statistics on vehicle mileage show that VKM typically |

| Category / Approach | Assessment | Impact on study outcomes / Further considerations |
|---|---|---|
| **based** | reasonable given that vehicle type/model decisions are typically influenced by the expected VKM. | correlate with the size of the vehicle. Vehicle users that expect to travel more are more willing to buy comparatively more expensive, larger cars that are seen to provide more driving comfort and/or more safety benefits. Also the choice of the powertrain is typically correlated with the VKM (i.e. powertrains that result in lower energy costs per km typically show higher VKM). |
| **$CO_2$ emissions assumptions** | | |
| **TTW emissions based on real-world driving** | Real-word driving emission estimates are seen to be the more reasonable approach compared to test-cycle emission estimates | Studies have shown that there is an increasing gap between test-cycle and real-world emissions. As a result, using test-cycle emissions could lead to inflated emissions reduction estimates. It is therefore relevant to assess the impact of both test-cycle and real-world driving emissions in the model framework developed for this study. |
| **Other (WTT and embedded/end-of-life emissions)** | Accounting for embedded and WTT emissions is relevant given the reduced lifetime of vehicles to be scrapped. | Accounting for embedded emissions will result in more realistic $CO_2$ emission estimates that are likely to have a negative effect on the environmental effect of scrappage schemes: (ITF, 2011) argues that 'only' 15% of the life-cycle emissions of vehicles are due to non-driving related emission estimates. However, shortening the lifetime of a vehicle due to a scrappage scheme will increase the share of non-driving related emissions. Accounting for such emissions is therefore relevant in the context of this project. |

## 3.4 Other findings in the reviewed literature

This section provides an overview of further findings of the reviewed literature that are of particular interest (as agreed in the Kick off meeting of this project).

### 3.4.1 Other effects of scrappage schemes

The reviewed studies partly also assess non-environmental impacts of the schemes. The assessment of such non-environmental impacts are not possible within the scope of this project. However, keeping such other effects in mind is relevant for deriving overall conclusions on the broader usefulness and potential co-benefits of scrappage schemes. Table 3-11 provides an overview of the impacts that have been assessed in the reviewed studies (in addition to the environmental impacts that were discussed in Section 3.2)

**Table 3-11: Non-environmental impacts of scrappage schemes assessed by reviewed studies**

| Study | Other impacts | | | Description |
|---|---|---|---|---|
| | **Safety** | **Industrial effects** | **Market effects** | |
| (Lelli, 2010) | | | | No non-environmental effects considered |

| Study | Other impacts | | | Description |
|---|---|---|---|---|
| (ITF, 2011) | ✓ | | | **Safety**: based on change in age distribution of vehicle fleet and penetration of safety technologies (Airbags and ESC) – calculation of reduction in seriously injured and deaths |
| (IHS, 2010) | ✓ | ✓ | ✓ | **Safety**: based on change in age distribution of vehicle fleet and penetration of safety technologies (Airbag, ABS, seat belt indicators and ESC) by a safety simulation model – calculation of reduction in (serious) accidents (pedestrians + drivers)<br>**Industrial** effects: vehicle sales, vehicle production, capacity utilisation, jobs<br>**Market** effects: impact on GDP |
| (Li, 2011) | | ✓ | | **Industrial** effects: vehicle sales |
| (ECMT, 1999)* | | ✓ | ✓ | **Industrial** effects: vehicle sales, vehicle prices, industry profits |

In the following paragraphs a high-level overview is provided of the main findings of these studies in terms of the non-environmental impacts.

**Safety impacts** are generally seen to have been positive:

- (ITF, 2011) found that, in the long run, the **US** scheme would avoid ~2800 serious injuries, of which ~40 fatalities. In **Germany**, it was estimated that ~6100 injuries and ~60 fatalities would be avoided. The **French** scheme is estimated to have had a much more limited impact: only ~330 serious injuries avoided, of which ~20 fatalities. This limited impact is due to the smaller scale of the scheme, the lower expected remaining VKM of the scrapped fleet (higher share of very old cars) and the lower penetration rate of the safety features in the new cars in comparison with the other countries. The overall conclusion of (ITF, 2011) was that preference should be given to older cars for trade-in vehicles in order to enhance the safety impacts of scrappage schemes.
- (IHS, 2010) states that *"scrapping schemes have unambiguously improved the normalised 'safety quality' of the European vehicle fleet"* due to the 2009 scrappage schemes. They have increased the number of cars on European roads fitted with safety technologies. However, as with emissions, the net impact of this improved technology penetration decays over time. Nevertheless, it was estimated that at the end of 2011 there were 700,000 more cars fitted with airbags; 930,000 more cars with ABS; and 890,000 more cars with ESC.

**Industrial effects:**

- (IHS, 2010) estimates for the 3-year assessment timeframe that 2.16 million incremental new car sales were generated thanks to the 2009 European scrappage schemes. This has
  - supported activity in the retail dealer network;
  - provided a cash flow injection for a large number of vehicle manufacturers;
  - prevented the loss of up to 120,000 direct jobs;
  - prevented a decline in LDV production by an additional two million units;
  - avoided a higher number of bankruptcies of component and parts manufacturers;

  Longer term industrial effects were however not explored in (IHS, 2010), which, according to (Li, 2011) are relevant to see the 'big picture' (see below).
- (Li, 2011) found that a large portion of vehicles sold under the US (2009) scrappage scheme was 'only' a result of demand switching from months surrounding the program: The program increased vehicle sales by 0.37 million during July and August, but the estimated net effect on sales became practically zero by the end of 2009.
- (ECMT, 1999) analysed mainly the difference between cash-for-replacement and cash-for-scrappage schemes. The conclusion was that in the very short-term, cash-for-replacement schemes increase the demand for new models more than cash-for-scrappage schemes. However, the increase seems to be due mainly to bringing forward replacement decisions and may lead to severe subsequent falls in new car sales - particularly in countries where the size

of the fleet is stable or increasing only very slowly. When making longer-term comparisons, the difference between the two types of schemes is seen to be smaller. Furthermore, (ECMT, 1999) also found that cash-for-scrappage schemes are likely to have positive (though limited) effects on industry profits, both in the short- and mid-term. The effects of cash-for-replacement schemes are seen to be beneficial in the very short-term but costs in the mid- to long-run may offset the short-term advantages. The study does not clarify what timeframes are referred to by "(very)short/mid/long" term. However, it does suggest that the "very" short term refers to a period of less than a few months, and the short term refers to a few months.

**Economic effects:**

- (IHS, 2010) concluded that the EU scrappage schemes in 2009 added a net 0.16–0.2% to EU-wide GDP. The study also highlighted that there are *"unconfirmed estimations"* that this growth may have reached as 0.26% in the third quarter of 2009, *"implying that the stimulus for the scrapping schemes was one of the key drivers behind the Eurozone emerging from recession"*.

The above shows that studies seem to be generally aligned concerning the positive impacts that scrappage schemes have on road safety. This is due to the "pull-forward" effect of scrappage schemes, resulting in higher/quicker penetration rates of safety technologies.

Concerning industrial effects, the studies appear to come to somewhat different conclusions. While (IHS, 2010) sees vast beneficial effects of scrappage schemes on EU industry (and economy), (Li, 2011) and (ECMT, 1999) rather argue that any such effects are only temporary (due to the 'pull-forward' of vehicle sales). Such effects are seen to even out when taking a more holistic (longer-term) assessment approach.

Once again, as was the case with environmental effects, it becomes evident that effects of scrappage schemes should be analysed over a sufficiently long time period to ensure a balanced assessment.

### 3.4.2 Cause-effect relationships

It was also agreed in the Kick-off meeting to review whether studies provided a critical discussion concerning cause-effect relationships, i.e. an analysis whether the observed effects can really be related to the introduction of a scrappage scheme or whether (also) other parameters might have contributed to the observed effect that can therefore not solely be retraced to the scheme.

It was found that only (IHS, 2010) provided a more critical discussion in this context, however, not in the context of environmental effects of the scrappage schemes:

The analysis provided by (IHS, 2010) shows that scrapping schemes typically have a disproportionate effect on the uptake of smaller and cheaper new cars. This is because replacement vehicles are usually required to be (at least on average) smaller and more fuel-efficient than the vehicles that are traded in. The study therefore argues that, in Europe, scrappage schemes target vehicles with stronger domestic regional linkages, given that Europe has a strong competitive position in the small car segments[2]. The expected effect of the scrappage scheme is therefore to lower the import rate of foreign vehicles.

However, the study estimated that the actual import propensity of all cars sold under scrapping schemes was 16.3% in Europe, compared with the 13% for the total 'usual' automotive market, therefore representing an additional leakage. It is argued that this increase is due to the down-pricing and downsizing effect of scrapping schemes in combination with Asian-sourced micro-car additions to the Toyota and Nissan European line-ups that were likely to have increased import penetration of these segments (however also without scrapping schemes).

This discussion shows that:

- The expected effects of scrappage schemes do not necessarily hold true once the scrappage schemes have been put in place

[2] According to information in the EEA's $CO_2$ monitoring database, the top selling models accounting for the majority of sales in the smaller segments are from European vehicle manufacturers.

- The root-causes of developments in the automotive market might not (exclusively) be related to the introduction of scrappage schemes; however, disentangling different causes and identifying the impact of each on the observed outcome is difficult in practice. (I.e. in the above example, it is unclear whether the increased penetration of imports is a result from either the scrappage scheme, the availability of new vehicle models from abroad, or some wider economic development).

### 3.4.3 Considerations concerning older fleets (i.e. in Eastern Europe)

Out of the reviewed studies, (ECMT, 1999) was the only one that discussed the usefulness of scrappage schemes in Eastern European countries. For this purpose, (ECMT, 1999) looked at fleet characteristics of respective countries and the Hungarian scrappage scheme (that was in place in 1993). It concluded that the economic conditions that prevailed at the time of the study suggested that cash-for-replacement schemes that require a switch to a new vehicle would not be successful. New cars were then still very expensive with respect to the average purchasing power of Eastern European households. As a result, those families who can afford to buy a new model did not own an old, poorly maintained car, or if they did, they would soon replace it anyway, even without the scheme.

On the contrary, the owners of the ‘gross emitters’ cannot generally afford to purchase new models. The incentives they would need in order to buy these would be too high to make the scheme feasible and efficient. Cash-for-scrappage schemes were therefore seen to be more useful. The low-income owners of the ‘gross emitters’ would probably use the incentive to buy old, second-hand, Western vehicles of which the emissions might still be considerably lower than those of the old, Eastern models eligible for the incentive. To reduce the likelihood of imports of poorer-quality models, it would be particularly important to check carefully the environmental and safety characteristics of the second-hand imported cars.

However, when the study was carried out, most of the Eastern European countries were experiencing very rapid fleet growth, with a relatively higher number of new registrations every year. Therefore (ECMT, 1999) came to the overall conclusion that policy-makers should steer their attention more towards measures that boost the purchase of cleaner cars, independently of scrappage decisions.

# 4 Design of a scrappage scheme modelling framework

## 4.1 Modelling considerations

This section describes the approach adopted for the development of a quantitative assessment framework that allows enough flexibility to assess the impact of specific assessment parameters and scheme design factors on the environmental impact of the scrappage schemes.

To understand the options for the model design, a list of scheme design factors and potential scheme parameters was generated from the literature reviewed in the earlier tasks. This produced a long list with a diverse range of parameters and options that could be included. It was identified hat it would not be possible to include every possible design factor in a model that could be generated within the limited scope of this project. Therefore, a subset of the most relevant options was identified as priority options to investigate for inclusion in the model.

A key aspect of identifying the design options to include in the model was the determination of whether the right data were available to allow the required flexibility of calculation. For example, to model the effects of removing older vehicles from the fleet (as a result of them being scrapped) requires data for the fuel efficiency of vehicles registered in previous years, not just fleet average fuel efficiencies.

From the review of the different design parameters that were to be included in the model and the required modelling flexibility that would be needed to address the options, it was decided to build a bespoke model for this project rather than attempting to the structure of an existing tool such as the SULTAN model developed previously for DG CLIMA (AEA, 2010) (AEA, 2012).

Table 4-1 shows the design factors that were selected for inclusion in the tool.

**Table 4-1: Design factors selected for inclusion in the model**

| Design Factor | Directly affects | Rationale |
|---|---|---|
| Scheme timeframe | Total uptake | An 'end criterion' is necessary to limit the duration of the scheme - different options are possible/were identified. They appear feasible to be modelled. |
| Scheme cost | Total uptake | |
| Target number of vehicles | Total uptake | |
| Scheme start date | Existing stock characteristics | Although this parameter is included in the model, it is important that the start date is selected so that the scrappage scheme does not interact with other measures such as (unknown) future emissions standards. |
| Scheme type (incentive for scrappage vs. replacement) | Incentive | According to the literature, uptake rates are affected by the type of scheme. Especially for assessing environmental impacts therefore it seems essential to allow for non-replacement decisions in the model. |
| Vehicle age | New stock characteristics | If scrapped vehicles can be replaced with second hand vehicles, the emissions-saved profile changes dramatically. Additionally, it will affect the uptake rate, especially where consumers with a lower income cannot afford to replace the scrapped vehicle with a new car, even after the subsidy. Several real-life examples of such schemes could be identified. |
| Vehicle emissions | New stock characteristics | The replacement vehicle emission performance is likely to be an essential metric affecting the $CO_2$ benefits of a scheme; numerous real-life examples of such schemes could be identified. |
| Vehicle age | Eligible stock | Age-based eligibility criteria for trade-in vehicles are the main criteria in most scrappage schemes identified. It directly affects the eligible stock and is related to the emissions performance of trade-in vehicles. |
| Vehicle emissions | Eligible stock | It is expected that overall emissions benefits are directly affected by $CO_2$-based eligibility criteria so it would be beneficial to include. |
| Vehicle powertrain | Eligible stock | Understanding the share of each powertrain type in the vehicles before and after the scheme is a simple proxy to emission performance in certain pollutants, such as PM. As mentioned above for replacement vehicles, adding the vehicle powertrain to the eligibility criteria is not expected to add much complexity to the model. |
| Vehicle segment | Eligible stock | As for eligibility criteria of new vehicles, this criterion may not provide significant functionality beyond the emissions-related criteria for selecting vehicles for eligibility. However, it is feasible to include this criterion without significant extra complexity. |
| Financial incentive type | Uptake rate | (IHS, 2010) identified that a government rebate attracts a greater response from consumers than a private discount of equal amount. No data has been found to suggest the magnitude of this effect, however, and thus it is assumed for now that all schemes utilise the 'government rebate' approach. |
| Financial incentive (set values) | Uptake rate | The incentive directly affects the uptake rate and as such is essential in determining the cost effectiveness or environmental benefits of a scheme. Data is limited, however, so it may be necessary to introduce generalised assumptions. |

## 4.2 Scrappage scheme model description

The purpose of the developed modelling framework is to evaluate the effects of different options and assumptions for an EU-wide LDV scrappage scheme. The developed model is implemented in Microsoft Excel and contains a *User Input* sheet, various output sheets (both data and charts), fixed input data sheets, and a number of calculation sheets (which are normally hidden).

### 4.2.1 Basic principle of operation

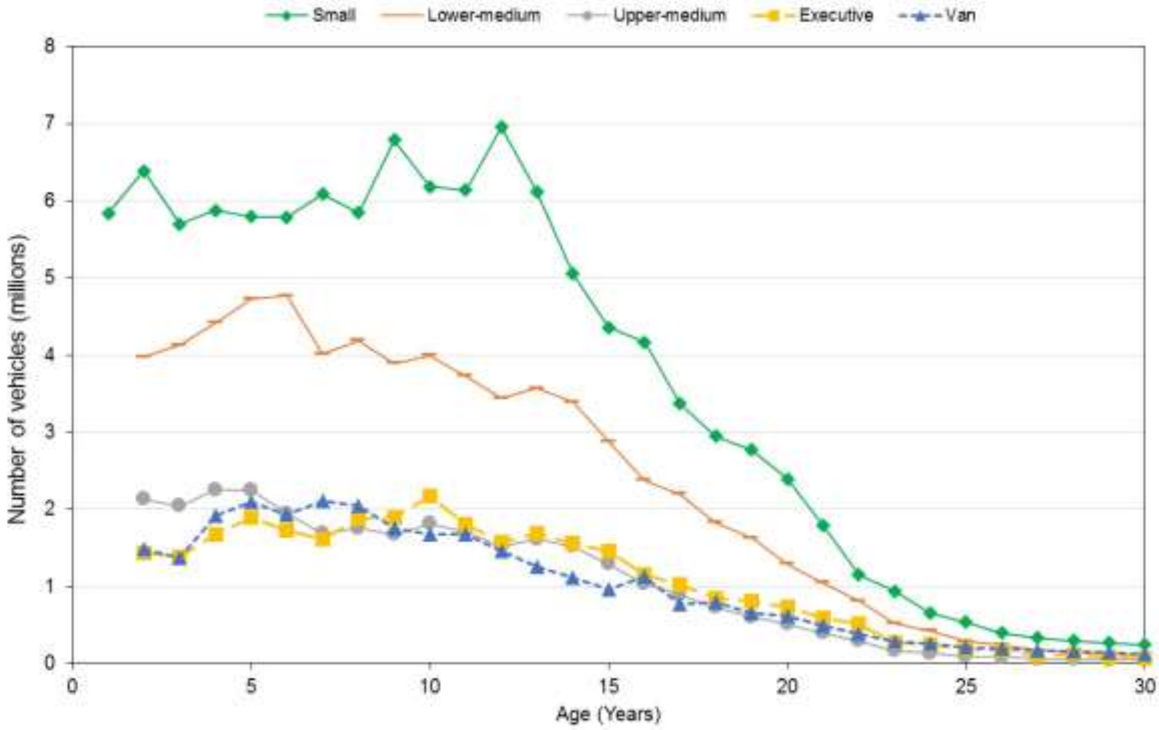
The model is set up so it can evaluate a Business as Usual (BaU) scenario plus a scrappage scheme scenario (referred to as the “Scenario” in the model).

The BaU scenario consists of vehicle age distributions that are in line with TRACCS[3] data, together with a “fleet rollover” model (also referred to as a fleet turnover model). For each year following the base year, the rollover model applies a survivor curve to identify how many vehicles survive into the following year from the existing fleet and a forecast of the growth of the total vehicle fleet over time. The difference between the total demand (the total vehicle fleet) and the surviving fleet from the previous year is then met by new vehicles.

This approach is applied separately for the different light duty vehicle segments included (i.e. Small Car, Lower Medium Car, Upper Medium Car, Executive Car, and Light Commercial Vehicle (LCV)), and the powertrain (or fuel type, i.e. Gasoline, Diesel, LPG, CNG, Flexi-Fuel and Other). The “Other” Powertrain category represents vehicles that do not directly emit $CO_2$ (or air pollutants), such as electric or hydrogen fuel cell vehicles[4].

The base year fleet distribution is taken from TRACCS data for EU28 in 2010 and is illustrated in Figure 4-1.

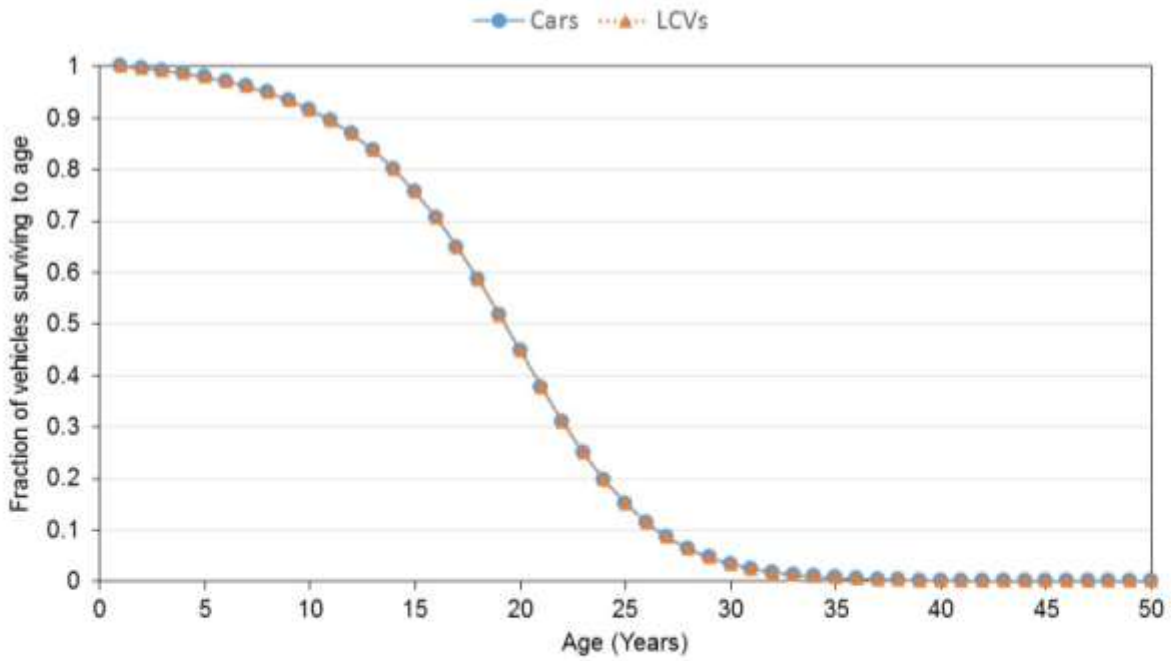
**Figure 4-1: Base year vehicle fleet age distributions from TRACCS by vehicle segment**




The survivor curves used in the model are taken from the latest SULTAN model (as being further developed under Service Request 13 of the framework contract) and are shown in Figure 4-2. In SULTAN, cars and LCVs currently utilise the same survivor curve.

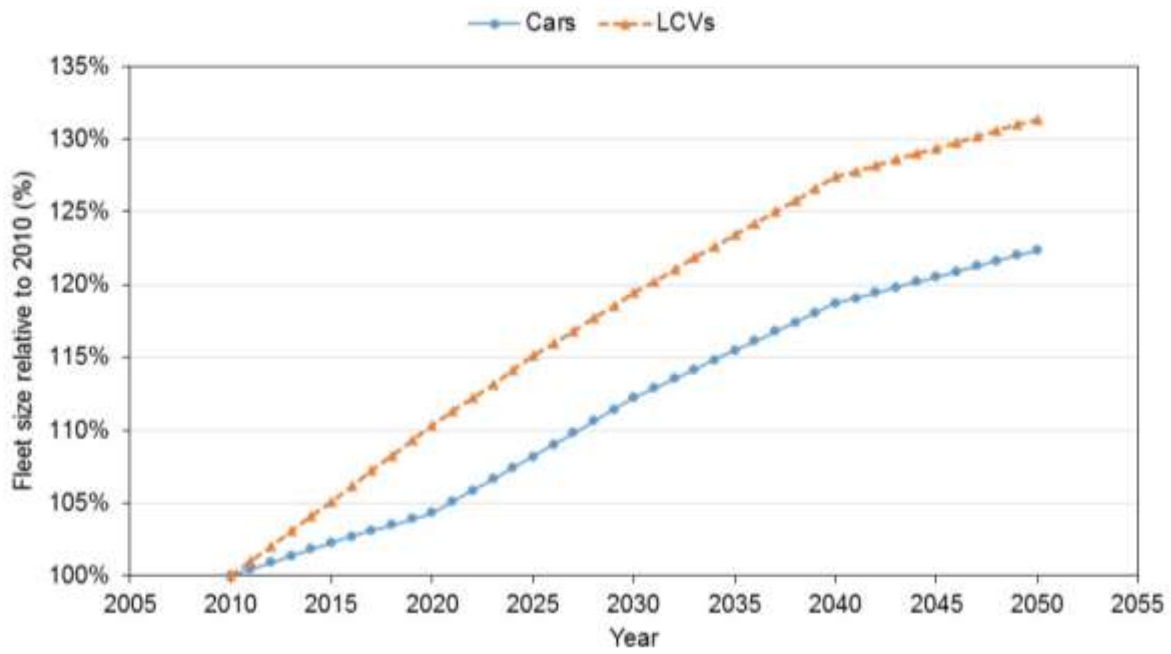
[3] http://traccs.emisia.com/
[4] Other powertrains with direct but significantly reduced emissions (such PHEV and REEV) are not accounted for in the model - there are currently no significant numbers of such vehicles in the fleet, and the effects of such powertrains can be approximated by other assumptions in forward-looking scenarios.

**Figure 4-2: Vehicle survivor curves taken from SULTAN**




The projected fleet growth is also taken from the SULTAN model. In this case, the vehicle stock numbers in the SULTAN model have been used to derive annual growth values (as percentages) which are then applied to the fleet numbers in the scrappage model:

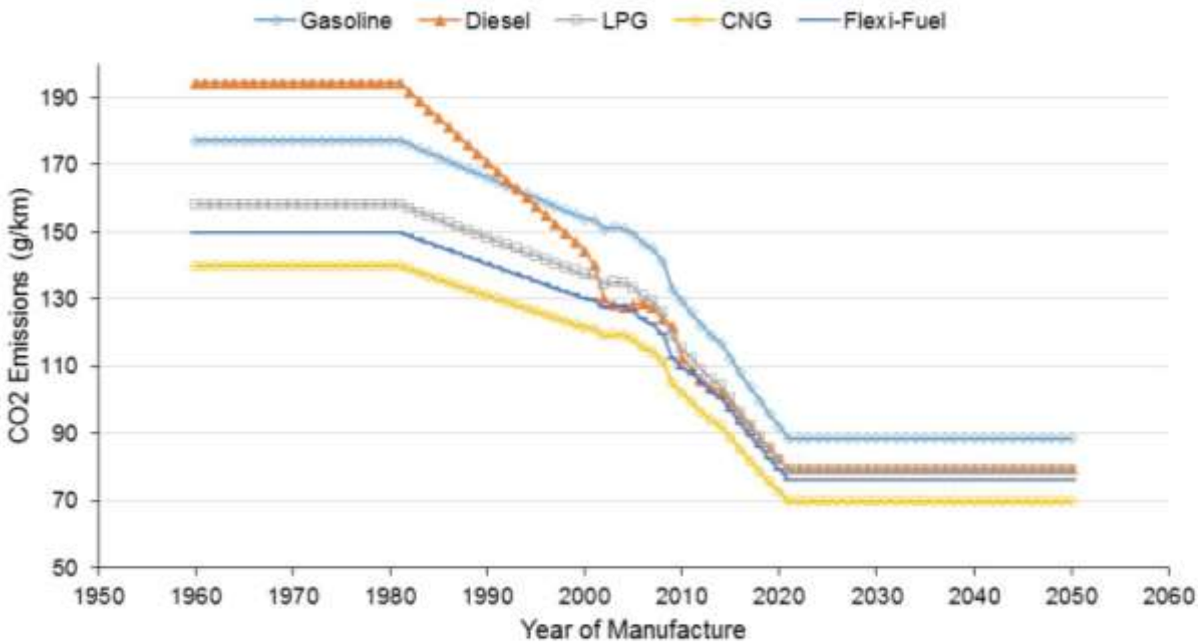
**Figure 4-3: Fleet growth derived from SULTAN**




Based on the vehicle fleet calculated in this manner, the model calculates vehicle mileages using distributions of annual mileage as a function of the age of the vehicle (and the vehicle segment and fuel type). These annual mileage distributions have been derived from analyses of the TRACCS data as used for the base year fleet. Alternatively, the user may input assumed annual mileages for each vehicle segment which are then applied uniformly (i.e. not varying by the age of the vehicle).

To calculate the fuel consumed in each year, the model applies fuel efficiency values derived from analyses of EEA datasets. The analyses considered vehicles delivered in each year from 2000 to 2014 and derived average fuel efficiency values for each vehicle type in each year. For application in the scrappage model, it was necessary to also provide data for fuel efficiencies in previous years from 1980 (i.e. for a vehicle which is 30 years old in 2010) and following years to 2050. For years before 2000, the fuel efficiencies have been extrapolated linearly back in time from 2000, using the average improvement rates from 2000 to 2005 (except that this rate should not be negative, i.e. a 1980 vehicle is not expected to be more efficient than an equivalent 2000 vehicle). For the years from 2014 to 2021, a rate of improvement has been calculated to achieve the EU target for an average car of 95 $gCO_2/km$ (and 147 $gCO_2/km$ by 2020 for LCVs). These improvement rates have been applied to the data for the 2014 vehicles to derive the fuel efficiencies for vehicles manufactured between 2014 and 2021 (2020 for LCVs). There are no EU regulations in place on LDV efficiency beyond this date, therefore the baseline assumption is for no further improvement in fuel efficiency between 2021 and 2050. As an example, the modelled fuel efficiency of small passenger cars is shown (in the form of $CO_2$ emissions per km) in Figure 4-4.

**Figure 4-4: Example set of fuel efficiency distributions for Small Passenger Cars**




By applying these fuel efficiency values (for the relevant manufacture year) to the mileage calculations, the model calculates the fuel consumption by vehicle type and fuel. Similarly, applying $CO_2$ emission indices (for the different fuels) and emission indices for NOx, PM and SOx, emissions are calculated for each vehicle category and fuel for each year to 2050.

In addition to the $CO_2$ emissions generated through the on-road fuel consumption, the model also includes contributions to $CO_2$ emissions from the manufacture (the “embedded” $CO_2$), maintenance and disposal of the vehicle. It further includes the $CO_2$ emissions related to the production of the fuel (the “Well-to-Tank”, or WTT, emissions). User input parameters are available to control whether these additional $CO_2$ emissions are included in the outputs.

The above description summarises the BaU calculation in the scrappage scheme calculation.

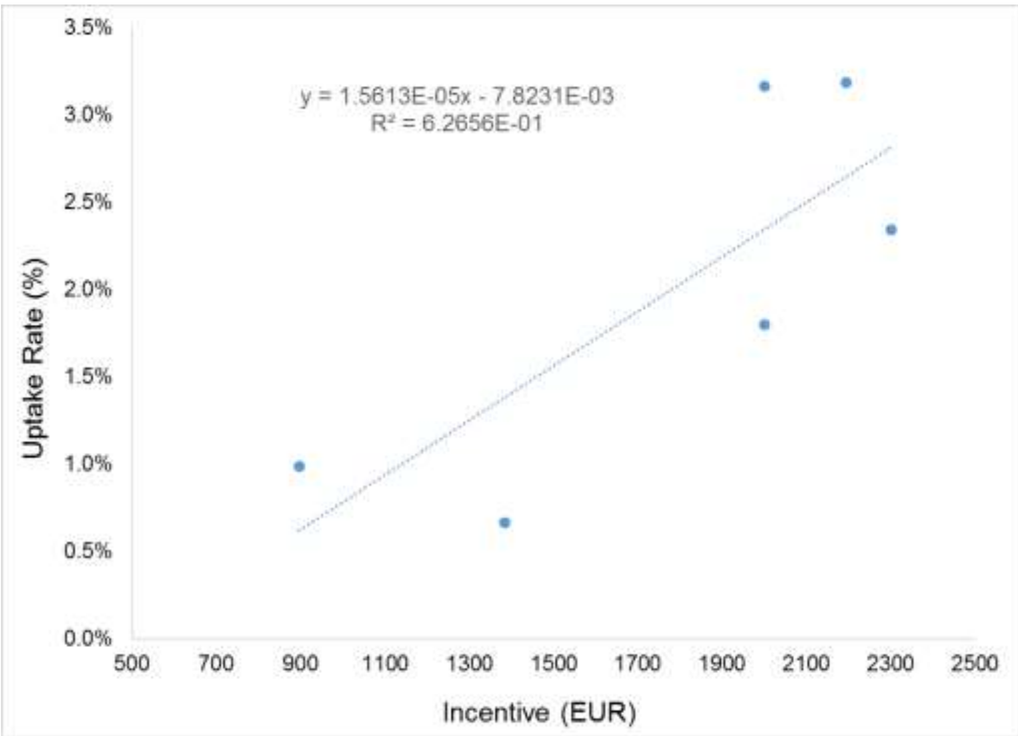
The Scenario calculation proceeds on the basis of a set of user inputs. The primary elements included are the estimation of the number of vehicles in the existing fleet that are eligible for scrappage under the scheme, and the percentage of those eligible vehicles that are actually scrapped (i.e. above the BaU rate, as part of the scheme).

The eligible vehicles are identified based on criteria such as their age (in the year(s) that the scrappage scheme operates), their fuel efficiency, the vehicle type and the fuel/powertrain type.

For the case of the fuel efficiency limit, the fuel efficiency data described above are used to define the efficiency of an “average” vehicle manufactured in a given year (separately for each vehicle type and fuel type). It is then assumed that the fuel efficiencies of actual vehicles are normally distributed around this mean (the standard deviation of this distribution is set by a user input, for example 10% of the mean). The eligibility limit set by the user as part of the scheme definition is then compared to this range (after converting to a fuel efficiency limit) to identify the percentage of vehicles of this manufacture year (and hence age in the year in which the scheme operates) that would be eligible.

The actual number of vehicles that would be scrapped under the scheme is then calculated by multiplying the number of eligible vehicles by a “percentage take-up”. The percentage take-up may be input as an assumption by the user, or may be calculated from a distribution obtained by fitting a linear trendline to some data identified for actual scrappage schemes (i.e. as presented Figure 4-5).

**Figure 4-5: Distribution of percentage take-up as a function of incentive derived from available data**




By using this approach, the number of vehicles scrapped under the scheme is derived. This is then added to the BaU “retirements” to derive a total retirement. An option has been included in the model to consider that the BaU retirements are contained within the scheme retirements (if the scheme retirements are larger than the BaU retirements). This allows for the situation where someone contemplating scrapping their car and replacing it is likely to do so within a scrappage scheme if one is in operation, which would reduce the number of additional vehicles scrapped. However, the actual situation is likely to be rather more complex (particularly with regards to whether this would reduce the total number of new vehicles sold back to the BaU level) and the results of the model have shown that the number of vehicles selected for the scrappage scheme may be smaller than the number of retirements in the BaU case; therefore, it is recommended that the option to consider the BaU retirements as being contained in the scheme retirements is not selected.

The rollover model for the Scenario case then operates in a similar manner to that for the BaU case, except that the number of retirements calculated as above is used to derive the number of vehicles which survive and the number of new vehicles which enter the fleet.

For a “Scrap-only” scheme, it is assumed that the total number of vehicles in the fleet will reduce by the number of vehicles scrapped in the years in which the scheme operates (i.e. those scrapped vehicles are not replaced immediately). It is assumed that the total number of vehicles in the fleet will recover over a period of time following the closure of the scheme to return to the BaU figure. The user may input the number of years over which this recovery is assumed to occur (e.g. 10 years). If the user inputs a very large number of years, the total number of vehicles will approach the BaU case only slowly and will effectively not replace those scrapped vehicles prior to 2050.

For a “Replacement” scheme, it is assumed that the total demand for vehicles remains as in the BaU case, which results in all the scrapped vehicles being replaced by new ones.

The total number of vehicles scrapped by the scheme, or the total cost, may also be limited by user input values. The limit on the scheme cost has an effect only if the user has input a value for the incentive.

This process then defines the vehicle fleet (numbers and age profile) for all years during and after the scheme operates. The mileage, fuel consumption and emissions calculations then follow the same approach as for the BaU case, except for a few exceptions:

It is possible to impose a criterion on the new vehicles purchased under the scheme representing a minimum fuel efficiency (maximum $CO_2$ emissions). A similar approach is then used to derive the average fuel efficiency of the new vehicles supplied under the scheme as is used for the eligibility of old vehicles, i.e. a normal distribution of efficiency around the average and only the portion of the spread below the user-input $CO_2$ emissions limit is used to calculate to average fuel consumption of vehicles supplied under the scheme.

The standard mileage distribution (as a function of age) gives an annual mileage of a new car to be significantly higher than that of an old car. Under a scrappage scheme this is recognised as a “rebound effect”, in that an increased use of the new car might be expected as it is more comfortable, reliable and fuel efficient than the old car that it replaces. However, there has also been a recognition that a family (or individual) which does not use their (old) car much, will not immediately increase their use of a car so significantly when they purchase a new one (even if it is purchased as part of a scrappage scheme). Therefore, the model includes an option to specify an equivalent age for the calculation of the mileage of the new cars purchased under the scheme. For example, if the minimum age of a car to be eligible to be scrapped is eight years, the average age of vehicles scrapped may be 12 years and the user may consider that the new vehicles would be used for an amount equivalent to that of a 10-year old vehicle. This equivalent vehicle age is a user input (setting it to 1 leaves the full rebound effect in operation). The equivalent age is only used for calculating the annual mileage; the fuel consumption and emissions are calculated using factors appropriate to a new vehicle.

In addition to the equivalent vehicle age, a further input parameter is included to provide an alternative approach to controlling the rebound effect; the user may input a factor (e.g. 50%) which is applied to any increase in annual mileage above the BaU value. A further limit on the effects of the rebound effect included in the model is that the annual mileage is restricted from falling below the BaU value (due to the changes in the age profile of the fleet caused by the introduction of the scrappage scheme, vehicle deliveries in subsequent years may be affected leading to a reduction in new cars which may lead to a lower mileage than the BaU case as the result of the age-based mileage profile used).

### 4.2.2 Input data

As described above, the model operates using a number of inputs provided by the user; some of these inputs define the parameters of the scrappage scheme being modelled, others control the assumptions in the calculations. Table 4-2 provides the list of input parameters together with brief descriptions of each.

**Table 4-2: Input parameters for scrappage model and its assessment**

| | Factor / Parameter | Description |
|---|---|---|
| Scheme design factors | **Basic scheme options** | |
| | Start Year | Initial year of scheme operation |
| | Duration of scheme | Number of years for which the scheme operates |
| | Scheme type | Select whether the scheme is Scrap-only or Replacement |
| | Scheme cost limit (€) | Limit on funding available - N.B. A non-zero cost limit takes precedence over a limit on the number of vehicles |
| | Number of vehicles limit | Maximum number of vehicles to be scrapped under the scheme |
| | **Incentive** | |
| | Incentive (€) | Value of incentive offered to scrap - leave blank if you wish to enter an assumed take-up rate (see below) |

| | Factor / Parameter | Description |
|---|---|---|
| | **Eligibility – Trade-In vehicle** | |
| | Minimum Age (years) | Minimum age of vehicle for it to be considered eligible |
| | Minimum $CO_2$ emissions (g/km) | Minimum $CO_2$ emissions of vehicle for it to be considered eligible (leave blank if no $CO_2$ requirement) |
| | Powertrain - Gasoline | Select whether the powertrain (fuel) would be eligible under the scrappage scheme (Yes/No) |
| | Powertrain - Diesel | |
| | Powertrain - LPG | |
| | Powertrain - CNG | |
| | Powertrain - Flexi-Fuel | |
| | Powertrain - Other | |
| | Size/segment - Small Passenger Car | Select whether the vehicle segment would be eligible under the scrappage scheme (Yes/No) |
| | Size/segment - Lower Medium | |
| | Size/segment - Upper Medium | |
| | Size/segment - Executive | |
| | Size/segment - Light Commercial Vehicle (LCV) | |
| | **Eligibility – Replacement vehicle** | |
| | Maximum $CO_2$ emissions (g/km) | Maximum value of $CO_2$ emissions for replacement vehicle for it to be eligible |
| **Assessment parameters** | **Scheme assumptions** | |
| | Percentage take-up (%) | Share of total vehicle fleet that is scrapped - only used if Incentive value is zero or blank (see above) |
| | **Modelling assumptions** | |
| | Fleet recover period | Number of years that it takes the fleet demand (total number of vehicles) to recover to BaU following the scheme closing in the case of the “Scrap-only” scheme (where the vehicles that are scrapped under the scheme are not replaced immediately, but the demand may recover to the BaU level over a period of time). |
| | **Input parameters concerning $CO_2$ emissions** | |
| | Standard deviation of TTW fuel efficiencies around average | To give a spread of fuel efficiencies around the average (vehicle age-based) value as input to the selection criteria. Input sets the standard deviation of the distribution to be a percentage of the mean. |
| | Include embedded $CO_2$ in output calculation? | Should the $CO_2$ embedded in the vehicle (during manufacture) be included in the output $CO_2$? (Y/N) |
| | Include end-of-life $CO_2$ in output calculation? | Should the $CO_2$ emitted during the end-of-life process be included in the output? (Y/N) |
| | Include well-to-tank (WTT) $CO_2$ in output calculation? | Should the $CO_2$ emitted during fuels production be included in the output? (Y/N) |
| | Include operation & maintenance $CO_2$ in output calculation? | Should the $CO_2$ emitted during operation and maintenance be included in the output (e.g. Operation Refrigerant Leakage)? (Y/N) |
| | Use test-cycle or real-world $CO_2$ emission factors? | For the calculation of vehicle efficiencies, use test-cycle or real-world measurements? |
| | **Input parameters concerning VKM** | |
| | Vehicle annual mileages uniform or age-based? | The model includes data for the variation of annual mileage with the age of the vehicle. Alternatively, select "Uniform" to use fixed values (by vehicle segment) below (“Age-based”, “Uniform”) |
| | *Small Car Annual Mileage* | *Input annual mileage for small car segment (only required if "Uniform" is selected above)* |

| | Factor / Parameter | Description |
|---|---|---|
| | *Lower Medium Car Annual Mileage* | *Input annual mileage for lower medium car segment (only required if "Uniform" is selected above)* |
| | *Upper Medium Car Annual Mileage* | *Input annual mileage for upper medium car segment (only required if "Uniform" is selected above)* |
| | *Executive Car Annual Mileage* | *Input annual mileage for executive car segment (only required if "Uniform" is selected above)* |
| | *Light Commercial Vehicle Annual Mileage* | *Input annual mileage for light commercial vehicle segment (only required if "Uniform" is selected above)* |
| | VKM rebound effect | Factor applied to restrict the increase in annual mileage which occurs due to the change in fleet mix and renewal of the fleet under the scrappage scheme, e.g. 50% (see the scenarios modelled in Section 5.1.2 for more insight in the effect and functioning of this input parameter) |
| | Factor on Year 1 Mileage (Age-based) | The data on which the age-based annual mileage model is based show a reduced mileage in year 1, reflecting the average purchase date being mid-year. For modelling, this mileage may be scaled to reflect a full year's use. Provide a factor to apply (2.0 is default; 1.0 would use the reduced Year 1 values in the TRACCS data unchanged). This parameter is not used if the Uniform annual mileage option is selected |

An example User Input sheet, including values for the parameters described above, is shown in Figure 4-6 for illustrative purposes only.

**Figure 4-6: Example User Input sheet for the scrappage model**

Scrappage scheme model: user input sheet

**Information**

***Model version 1.20***

*The values of the parameters defining the scrappage scheme are set on this tab.*

*Box 1 contains the settings of the scheme design. Other parameters, used to set assumptions necessary for the calculation of impacts, are set in Box 2.*

*Numerical results are provided in tab "Outputs-Data", while charts showing the time-history variations of key parameters, are provided in tab "Outputs-Charts".*

| Factor / Parameter | Options | Units | Comments |
|---|---|---|---|
| **1. Scheme design factors** | | | |
| **a. Basic scheme options** | *First, select the basic scheme parameters* | | |
| Start Year | 2016 | n/a | Enter a start year between 2010 and 2050 |
| Duration of scheme | 1 | Years | Enter a scheme duration. If left blank, the default is 1 year |
| Scheme type | Replace | n/a | Select whether the scheme is Scrap-only or Replacement |
| Scheme cost limit | | € | Enter a limit on funding available - N.B. A non-zero cost limit takes precedence over a limit on the number of vehicles |
| Number of vehicles limit | | Number of vehicles | Enter a maximum number of vehicles to be scrapped under the scheme |
| **b. Incentive** | | | |
| Incentive (€) | 1500 | € | Specify the value of incentive offered to scrap - leave blank if you wish to enter an assumed take-up rate (in Section 4a below) |
| **c. Eligibility old vehicle** | | | |
| Minimum Age | 12 | Age | Set the minimum age of old vehicles for eligibility under the scrappage scheme (leave blank if no age requirement) |
| Minimum CO2 emissions | 150 | gCO2/km | Set the minimum CO2 emissions (g/km) for eligibility under the scrappage scheme (leave blank if no CO2 requirement) |
| Powertrain - Gasoline | Yes | n/a | Select whether the powertrain (fuel) would be eligible under the scrappage scheme |
| Powertrain - Diesel | Yes | n/a | Select whether the powertrain (fuel) would be eligible under the scrappage scheme |
| Powertrain - LPG | Yes | n/a | Select whether the powertrain (fuel) would be eligible under the scrappage scheme |
| Powertrain - CNG | Yes | n/a | Select whether the powertrain (fuel) would be eligible under the scrappage scheme |
| Powertrain - Flexi-Fuel | Yes | n/a | Select whether the powertrain (fuel) would be eligible under the scrappage scheme. Flexi-fuel is assumed to be E85 fuelled vehicles |
| Powertrain - Other | Yes | n/a | Select whether the powertrain (fuel) would be eligible under the scrappage scheme. Other is assumed to be zero-emission vehicles |
| Size/segment - Small Passenger Car | Yes | n/a | Select whether the vehicle segment would be eligible under the scrappage scheme |
| Size/segment - Lower Medium Passenger Car | Yes | n/a | Select whether the vehicle segment would be eligible under the scrappage scheme |
| Size/segment - Upper Medium Passenger Car | Yes | n/a | Select whether the vehicle segment would be eligible under the scrappage scheme |
| Size/segment - Executive Passenger Car | Yes | n/a | Select whether the vehicle segment would be eligible under the scrappage scheme |
| Size/segment - Light Commercial Vehicle (LCV) | Yes | n/a | Select whether the vehicle segment would be eligible under the scrappage scheme |
| **d. Eligibility new vehicle** | | | |
| Maximum CO2 emissions | 100 | gCO2/km | Maximum value of CO2 emissions for vehicle supplied under the Replacement scheme |
| **2. Assessment parameters** | | | |
| **a. Scheme assumptions** | | | |
| Percentage take-up | | % | Percentage of eligible vehicles that are scrapped - this value is only used if the incentive value (set in Section 1) is zero or blank |
| **b. Modelling assumptions** | | | |
| Standard Deviation of fuel efficiencies around average | 10% | +/- % | To give a spread of fuel efficiencies around the average (age-based) value as input to the selection criteria. Input sets the standard deviation of the distribution to be a percentage of the mean. |
| Fleet recover period | 5 | Years | Number of years that it takes the fleet demand (total number of vehicles) to recover to BaU following the scheme closing |
| **c. CO2 settings** | | | |
| Include embedded CO2 in output calculation? | Yes | | Should the CO2 embedded in the vehicle (during manufacture) be included in the output CO2? |
| Include end-of-life CO2 in output calculation? | Yes | | Should the CO2 emitted during the end-of-life process be included in the output.<br>Note - this is not broken down by vehicle or fuel type - only the total vehicles column is affected |
| Include well-to-tank (WTT) CO2 in output calculation? | Yes | | Should the CO2 emitted during fuels production be included in the output? |
| Include operation & maintenance CO2 in output calculation? | Yes | | Should the CO2 emitted during operation and maintenance be included in the output (e.g. Operation Refrigerant Leakage)? |
| Use test-cycle or real-world CO2 emission factors? | Real-World | | For the calculation of vehicle efficiencies, use Test-Cycle or Real-World measurements? |
| **d. Mileage settings** | | | |
| Vehicle annual mileages uniform or age-based? | Age-Based | | The model includes data for the variation of annual mileage with the age of the vehicle.<br>Alternatively, select "Uniform" to use fixed values (by vehicle segment) below |
| *Small Car Annual Mileage* | | km | Input annual mileage for small car segment (only required if "Uniform" is selected above) |
| *Lower Medium Car Annual Mileage* | | km | Input annual mileage for lower medium car segment (only required if "Uniform" is selected above) |
| *Upper Medium Car Annual Mileage* | | km | Input annual mileage for upper medium car segment (only required if "Uniform" is selected above) |
| *Executive Car Annual Mileage* | | km | Input annual mileage for executive car segment (only required if "Uniform" is selected above) |
| *Light Commercial Vehicle Annual Mileage* | | km | Input annual mileage for light commercial vehicle segment (only required if "Uniform" is selected above) |
| Factor on Year 1 Mileage (Age-based) | 2 | | The data on which the age-based annual mileage model is based show reduced mileage in year 1, reflecting the average purchase date being mid-year. For modelling, this mileage may be scaled to reflect a full year's use. Provide factor to apply (2.0 is default; 1.0 would use the reduced Year 1 values in the TRACCS data) |
| Mileage rebound effect | 50% | % of max rebound | This parameter directly controls the degree of rebound vs BAU seen in the Scenario. Minimum mileage allowed is also the BAU level. All vehicle mileage is scaled down to maintain the level indicated vs BAU. |

### 4.2.3 Results for a baseline scrappage scheme scenario

This section shows example results from the calculation using the input values provided in Table 4-3 (and as shown in Figure 4-6 above). This scenario is in the following sections referred to as the baseline scrappage scheme scenario (compared to the BaU, which is the scenario in which no scrappage scheme is in place).

**Table 4-3: Input values for scrappage scheme baseline scenario**

| | Factor / Parameter | Setting |
|---|---|---|
| Scheme design factors | **Basic scheme options** | |
| | Start Year | 2016 |
| | Duration of scheme | 1 (Year) |
| | Scheme type | Replace |
| | Scheme cost limit | None |
| | Number of vehicles limit | None |
| | **Incentive level** | |
| | Incentive (€) | 1,500 |
| | **Eligibility – Trade-In vehicle** | |
| | Minimum Age | 12 |
| | Minimum $CO_2$ emissions | 150 ($gCO_2$/km) |
| | Powertrains considered | All |
| | Size/segment considered | All |
| | **Eligibility – Replacement vehicle** | |
| | Maximum $CO_2$ emissions | 100 ($gCO_2$/km) |
| Assessment parameters | **Modelling assumptions** | |
| | Standard Deviation of fuel efficiencies around average | 10% |
| | **$CO_2$ emission coverage / type** | |
| | Include embedded $CO_2$ in output calculation? | Yes |
| | Include end-of-life $CO_2$ in output calculation? | Yes |
| | Include well-to-tank (WTT) $CO_2$ in output calculation? | Yes |
| | Include operation & maintenance $CO_2$ in output calculation? | Yes |
| | Use test-cycle or real-world tank-to-wheel (TTW) $CO_2$ emission factors? | Real-world |
| | **Vehicle mileage assumptions** | |
| | Vehicle annual mileages uniform or age-based? | Age-based |
| | VKM rebound effect | 50% |
| | Factor on Year 1 Mileage (Age-based) | 2.0 |

The effects of the scrappage scheme defined in this manner are shown in Figure 4-7: to Figure 4-10.

**Figure 4-7: Annual new vehicles delivered under the baseline scrappage scheme (in % to BaU)**

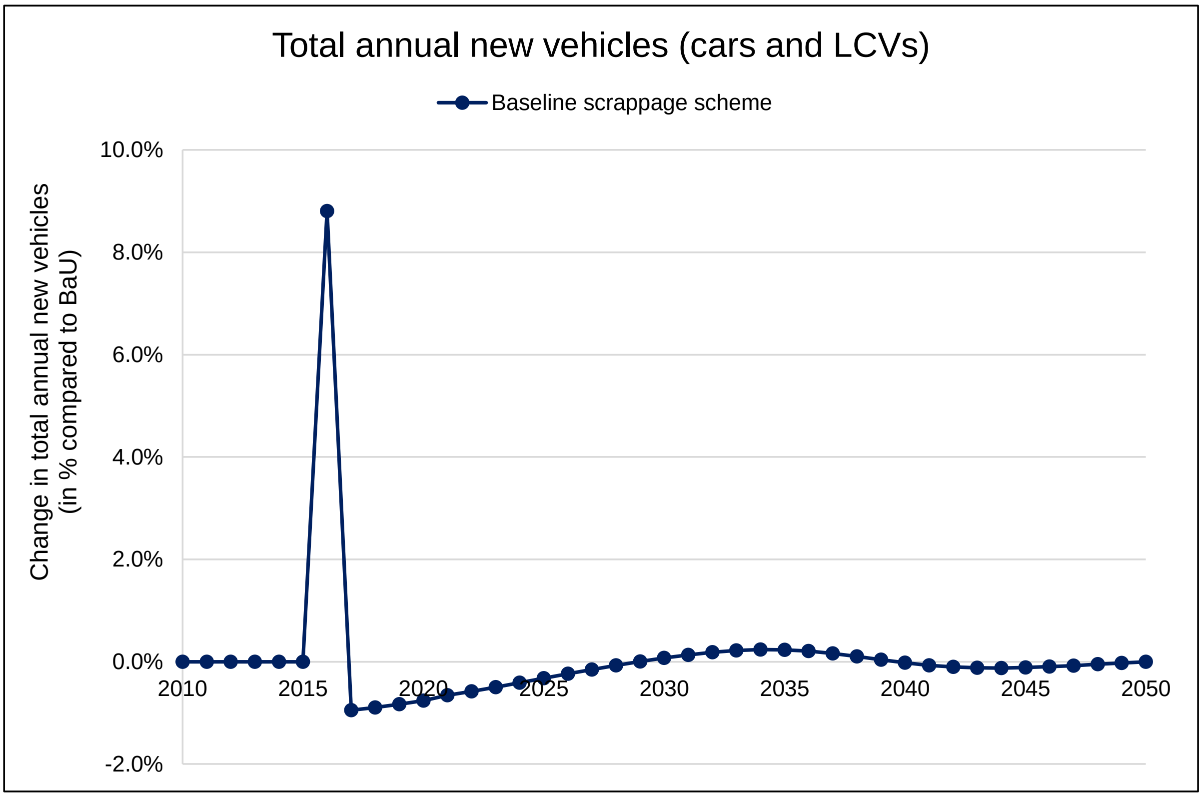



**Figure 4-8: Annual mileage for all vehicles under the baseline scrappage scheme (in % compared to BaU)**

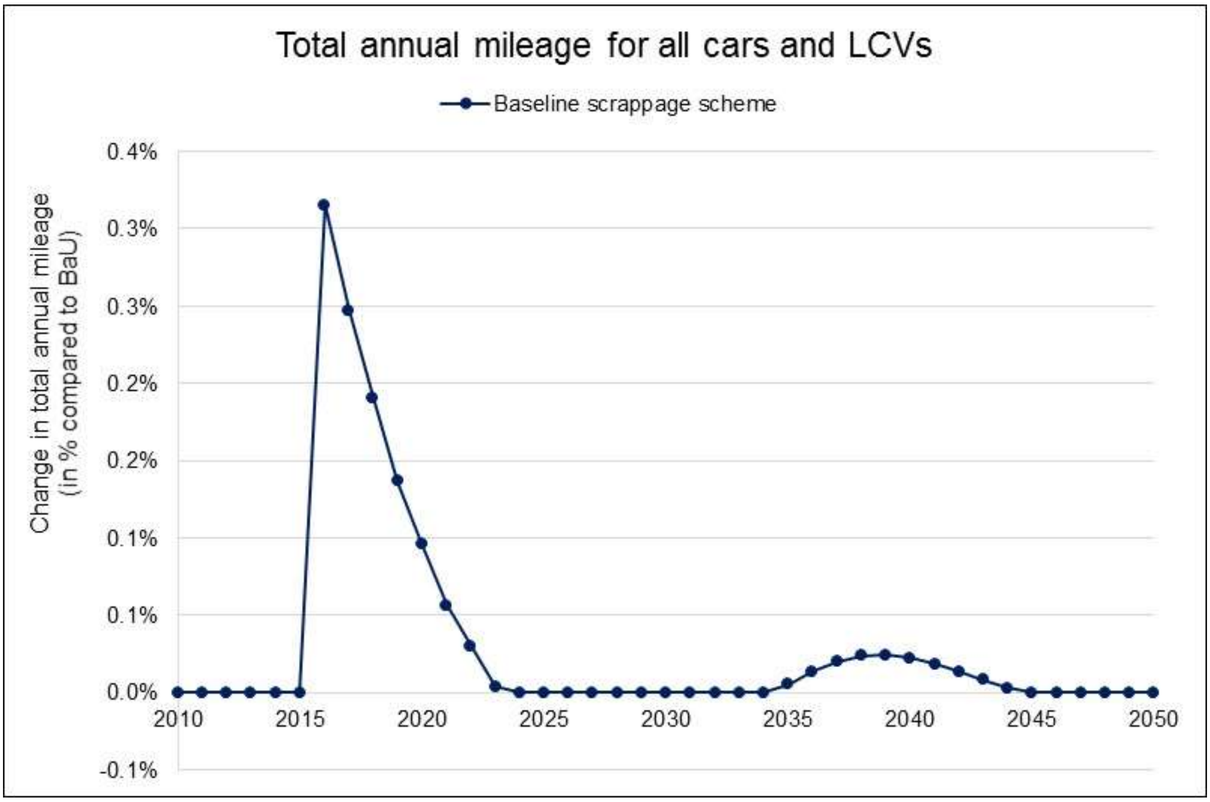


**Figure 4-9: Annual $CO_2$ emissions for all vehicles under the baseline scrappage scheme (in % compared to BaU)**

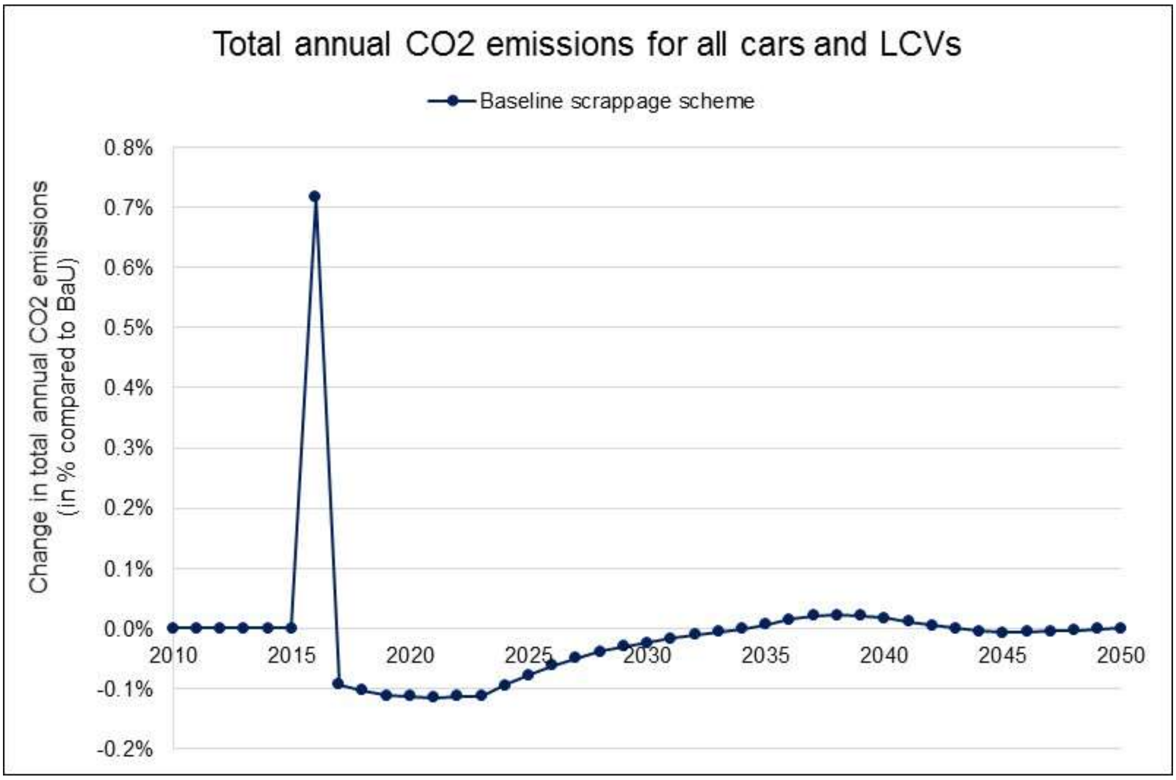
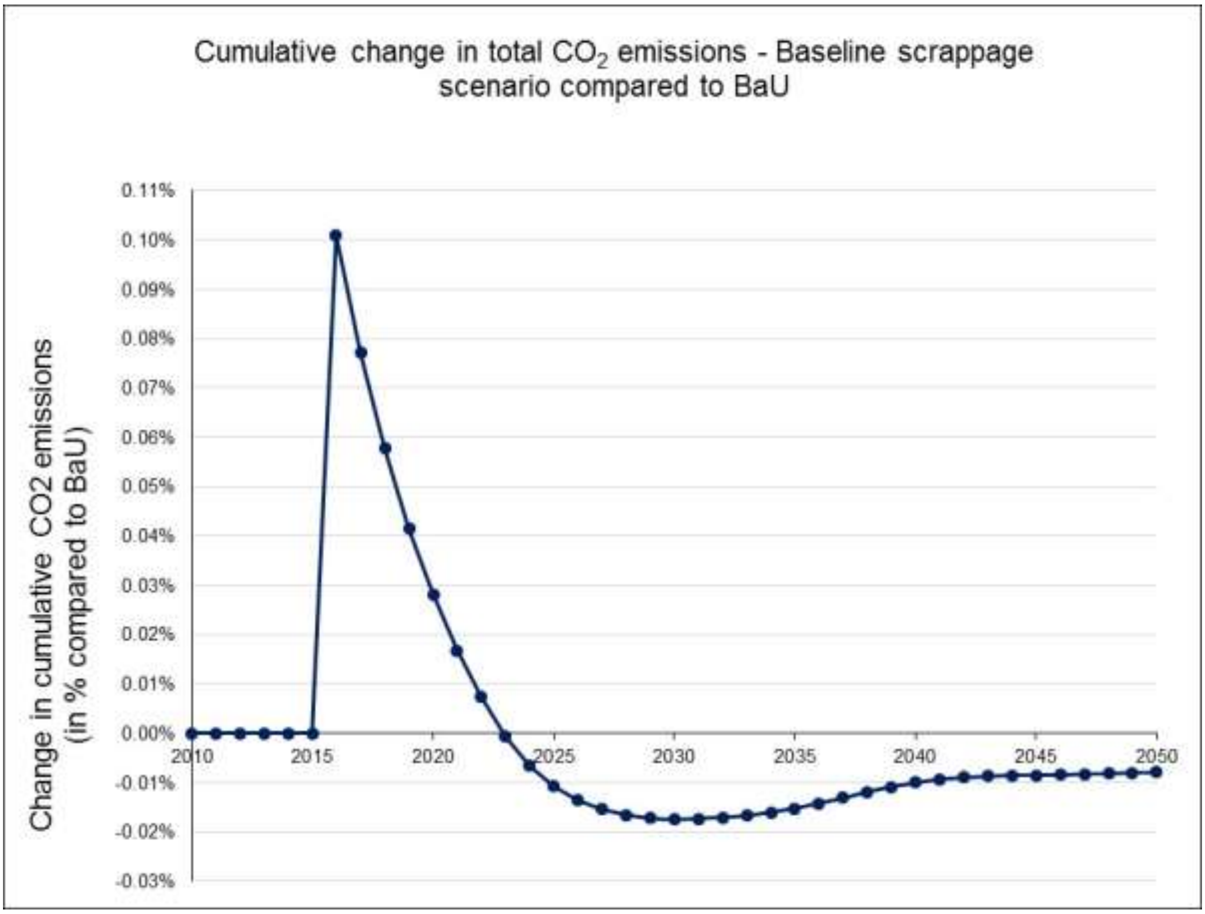



**Figure 4-10: Cumulative $CO_2$ emissions reductions for all cars and LCVs – Baseline scrappage scenario compared to BaU**



As shown in Figure 4-7:, there is a visible increase in the number of new vehicles delivered in the year in which the scheme operates (compared to the BaU case). In the following years, there is a small reduction in the number of new vehicles, as the number of vehicles being retired (and replaced) is lower because of the vehicles scrapped under the scrappage scheme.

The mileage and $CO_2$ emissions both show small increases during the year in which the scheme operates. In the years immediately following the scheme, the mileage remains slightly above the BaU value (due to the ongoing higher proportion of younger vehicles in the fleet). The $CO_2$ emissions reduce over time to be below the BaU case as the improved efficiency of the fleet begins to offset the increased mileage, and also there is a reduction in the number of new vehicles (and therefore reduced embedded emissions) in the initial few years following the scrappage scheme.

Figure 4-10 shows the difference in cumulative $CO_2$ emissions between the BaU case and the baseline scenario as percentage differences. The rise in emissions when the scrappage scheme operates is quite steep; investigations of the model have shown that this is largely related to the inclusion of the $CO_2$ emissions related to the manufacture of the vehicle (the embedded $CO_2$). The immediate increase in emissions is reduced considerably if this embedded $CO_2$ is not included in the outputs.

The changes in cumulative $CO_2$ emissions in Figure 4-10 shows that the effect of the one-year scrappage scheme in 2016 continues to give reductions in annual emissions (and hence giving a continuing increase in the magnitude of the cumulative reduction) to about 2031, by which time a %-reduction of cumulative emissions of around 0.02% is achieved. This emission reduction then fades out over time to around 0.01% by 2050.

# 5 Illustrations of the main factors influencing GHG emissions benefits

This section provides some results from sensitivity studies which have been performed to understand the influence of different input parameters (both scheme definition parameters and modelling assumptions) on the results. These sensitivity studies investigated variations in the values of individual parameters around the baseline scenario case described in Section 4.2.2. It also provides results from some case study calculations which have been performed to show the combined effects of different full scheme definitions.

## 5.1 Sensitivity analyses

The set of scheme design factors and assessment parameters that were varied, together with the specific settings investigated, is shown in Table 5-1. The last column provides the respective scenario ID that is partly referenced on the presented graphs in the following sub-sections. The following graphs present the results of the different scenarios in %-change to the baseline scrappage scheme scenario. The relevant settings for the single design factors and assessment parameters as used in the baseline scrappage scenario are therefore also provided in Table 5-1.

**Table 5-1: Design factor and parameter settings used in sensitivity analyses**

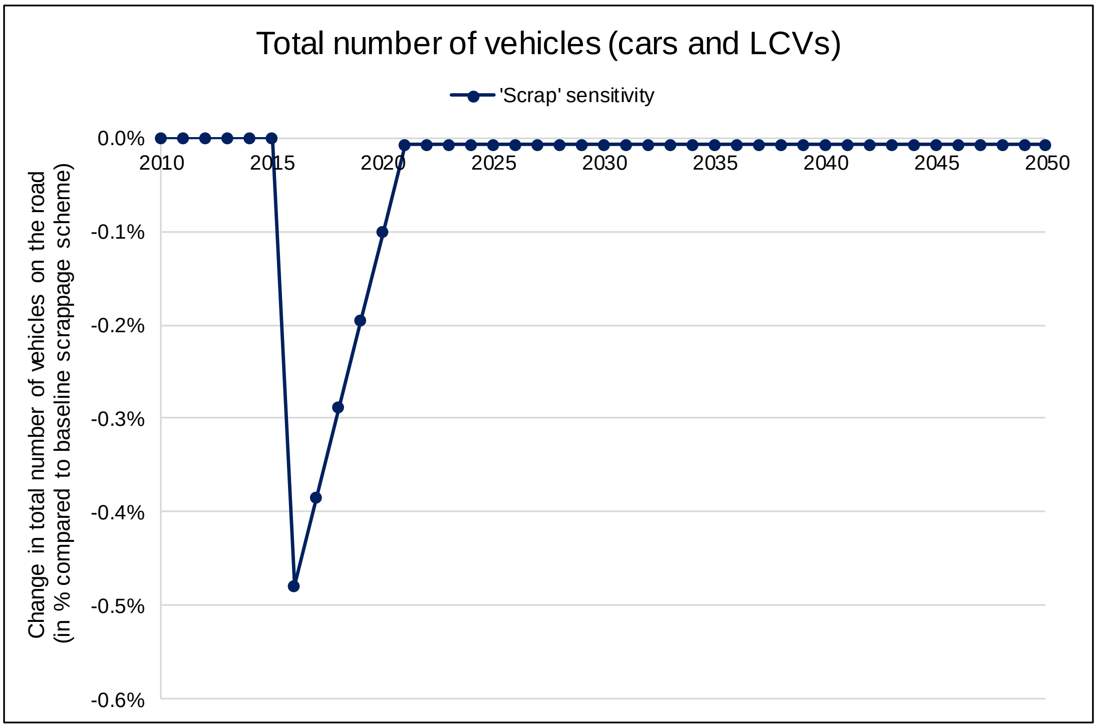
| | Variable | Setting considered | Scenario ID |
|---|---|---|---|
| **Scheme design factors (see Section 5.1.1)** | **Scheme type** | Replacement | Baseline |
| | | Scrap-only | 1 |
| | **Scheme duration** | 1 year | Baseline |
| | | 3 year | 2a |
| | | 5 years | 2b |
| | **Trade-in vehicle eligibility criterion I: Minimum $CO_2$ emissions** | 150 $gCO_2/km$ | Baseline |
| | | 120 $gCO_2/km$ | 3a |
| | | 135 $gCO_2/km$ | 3b |
| | | 165 $gCO_2/km$ | 3c |
| | | 180 $gCO_2/km$ | 3d |
| | **Trade-in vehicle eligibility criterion II: Minimum age limit** | 12 years | Baseline |
| | | 9 years | 4a |
| | | 15 years | 4b |
| | **New vehicle eligibility criterion: Maximum TTW $CO_2$ emissions** | 100 $gCO_2/km$ | Baseline |
| | | 80 $gCO_2/km$ | 5a |
| | | 120 $gCO_2/km$ | 5b |
| | **Financial incentive** | € 1,500 | Baseline |
| | | € 750 | 6a |
| | | € 3,000 | 6b |
| **Assessment parameters (see Section 5.1.2)** | **Mileage rebound effect** | 50% of maximum rebound | Baseline |
| | | 25% of maximum rebound | 7a |
| | | 75% of maximum rebound | 7b |
| | **Annual mileage** | Age-based | Baseline |
| | | Uniform - 10,000 km for all segments | 8a |
| | | Uniform - 20,000 km for all segments | 8b |
| | **Type of TTW vehicle efficiencies** | Real-world | Baseline |
| | | Test-cycle | 9 |
| | **Considered $CO_2$ emissions** | Life-cycle $CO_2$ emissions (including embedded, WTW, TTW, maintenance and end-of-life stages) | Baseline |
| | | TTW emissions only | 10 |

In the following the sensitivities of the results to changing scheme design factor settings is assessed first. Section 5.1.2 then explores the sensitivity of the scrappage scheme impact estimates to assessment parameters that underlie the analysis.

### 5.1.1 Sensitivity to scheme design factor settings

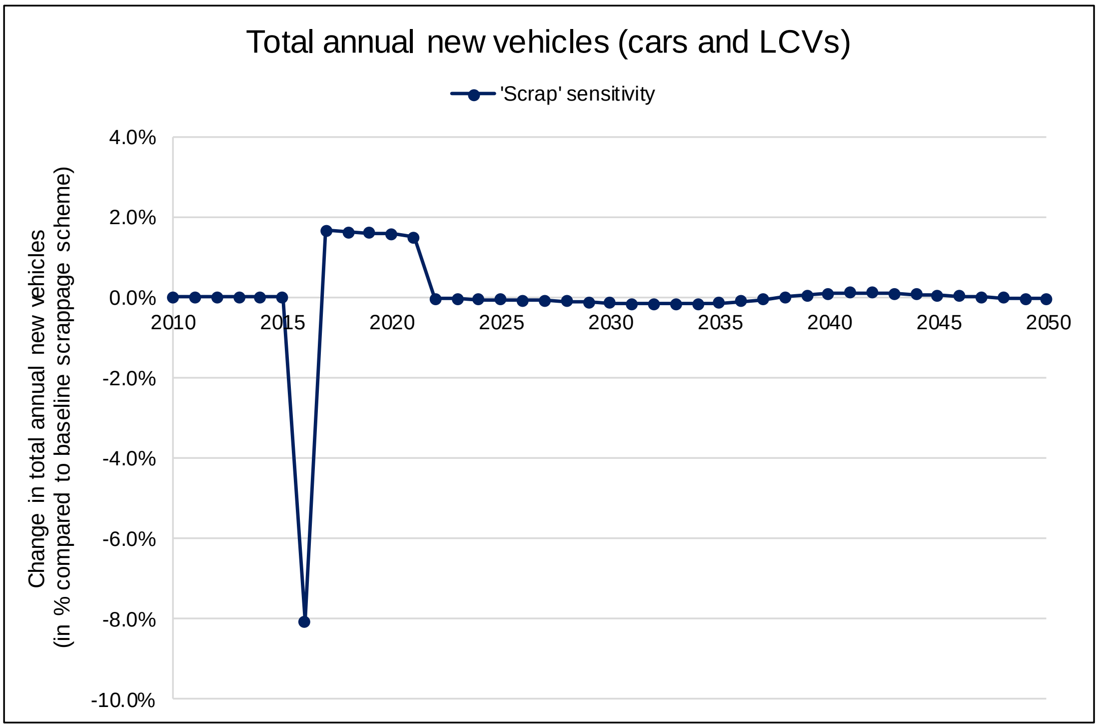
The selection of the **“Scrap-only” scheme type (Scenario 1)** reduces the total demand for vehicles in the years in which the scheme operates so that the vehicles which are scrapped under the scheme are not replaced. This reduction in the total number of vehicles decreases over a time (set to five years in the current calculations) so that the total demand returns to the level of the baseline (and BaU) scenario after that time period. This is shown in Figure 5-1:.

**Figure 5-1: Effect of selection of “Scrap-only” scheme type on the number of vehicles in the fleet compared to the baseline scrappage scenario (“replacement” scheme type)**



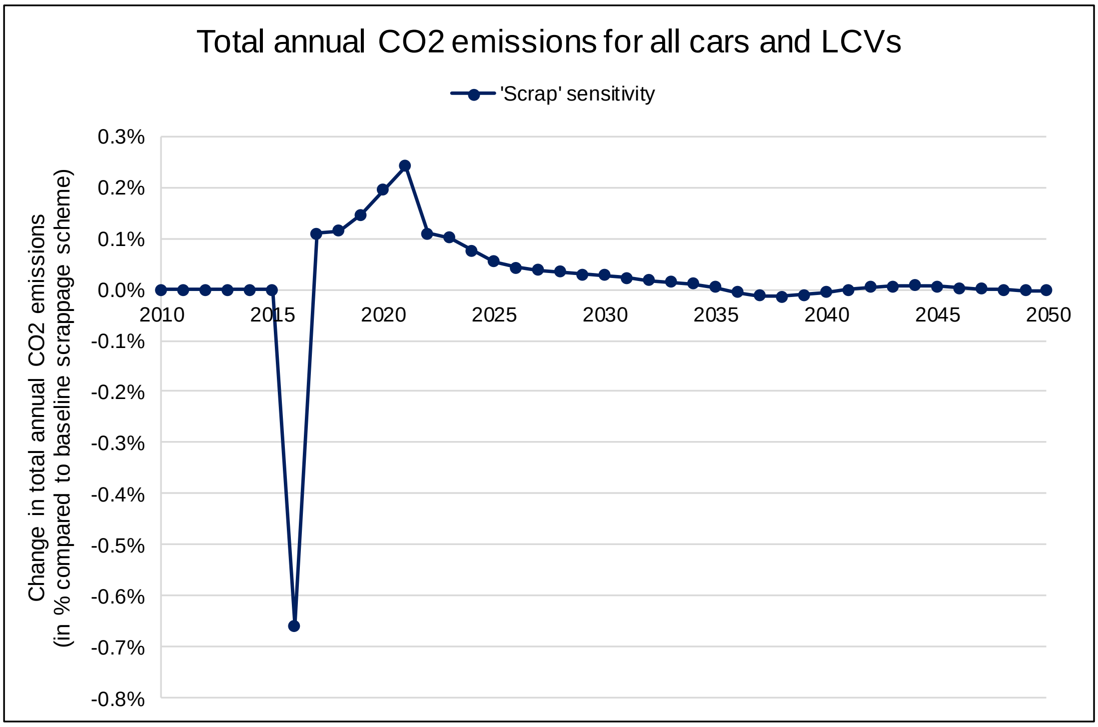

This leads to changes in the number of new vehicles supplied to the fleet as shown in Figure 5-2:.

**Figure 5-2: Effect of selection of "Scrap-only" scheme on the number of new vehicles supplied compared to the baseline scrappage scenario ("replacement" scheme type)**




The number of new vehicles supplied during the year in which the scrappage scheme operates is significantly reduced by the non-replacement of the scrapped vehicles. This is then followed by a period of five years in which the number of new vehicle supplied is higher than the baseline scrappage scheme scenario as the total fleet demand returns to the BaU level. Subsequently, the number of new vehicles returns to the baseline scenario level, with some small-amplitude oscillations due to the distortion to the age profile of the fleet. The effect of these changes on the annual $CO_2$ emissions of the fleet are shown in Figure 5-3:.

**Figure 5-3: Effect of selection of "Scrap-only" scheme type on annual $CO_2$ emissions compared to the baseline scrappage scenario ("replacement" scheme type)**



It can be seen that the reduction in demand in the year in which the scheme operates leads to an immediate reduction in $CO_2$ emissions (in line with the reduction in the total vehicle fleet). However, as the total fleet demand returns to the BaU level, there is an increase in demand for new vehicles (compared to the baseline case), with a corresponding increase in the annual mileage (because of the young age/rebound due to higher efficiency/lower running costs of those vehicles) and hence an increased level of $CO_2$ emissions.

The selection of different **periods of time over which the scheme operates (Scenarios 2a -b)** results in different numbers of vehicles being replaced and hence has an impact on the age profile of the fleet in subsequent years. These differences in the numbers of new vehicles supplied under the scheme lead to the changes in annual mileage and $CO_2$ emissions shown in Figure 5-4: and Figure 5-5:.

**Figure 5-4: Changes in annual mileage for scenarios 2a and 2b relative to baseline scenario (1-year scheme)**

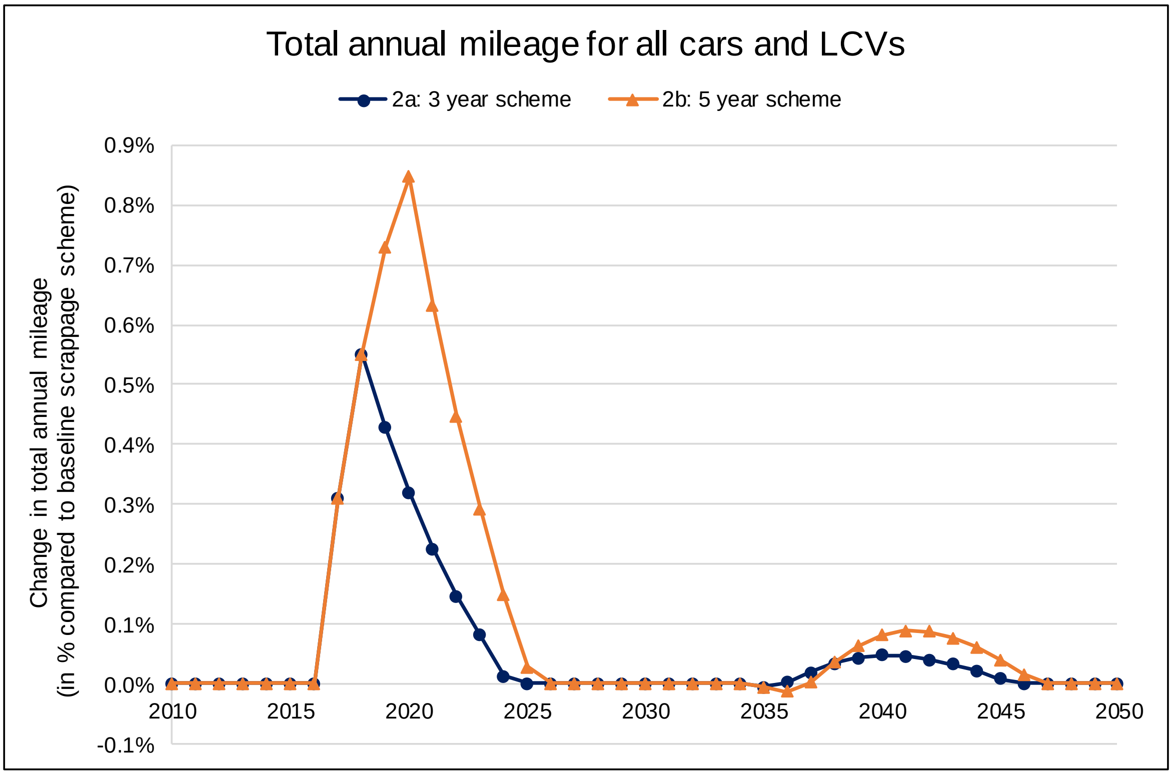
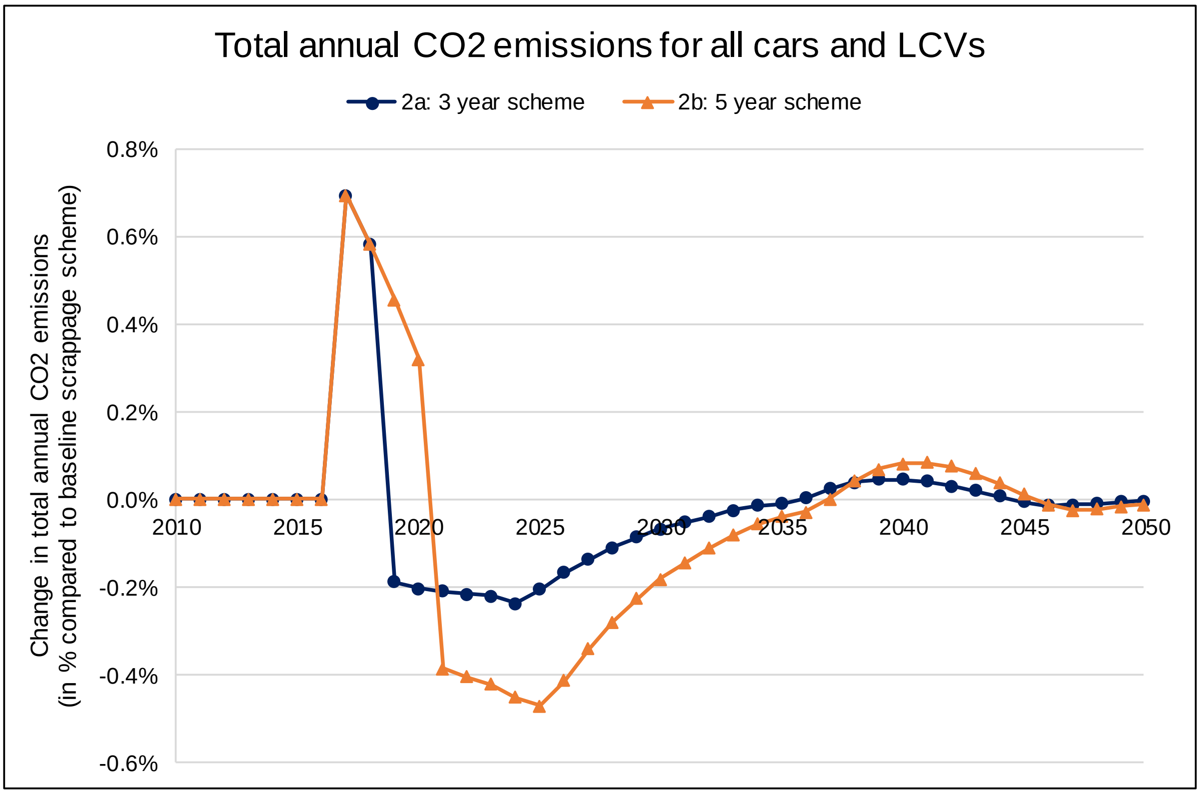


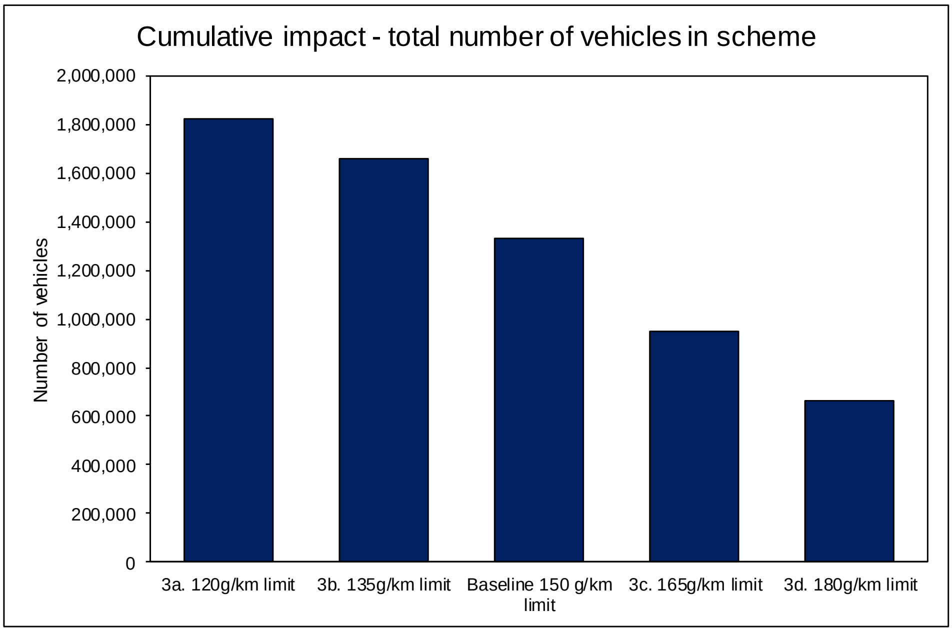
**Figure 5-5: Changes in annual $CO_2$ emissions for scenarios 2a and 2b relative to baseline scenario (1-year scheme)**




As expected, the increased duration of the schemes leads to a greater increase in the annual mileage, and hence emissions, as the proportion of new vehicles in the fleet increases further. The subsequent reductions in emissions, as the mileage reduces to the baseline scenario level and the effect of the improved efficiency of the new vehicles reduces the emissions, are also greater in magnitude.

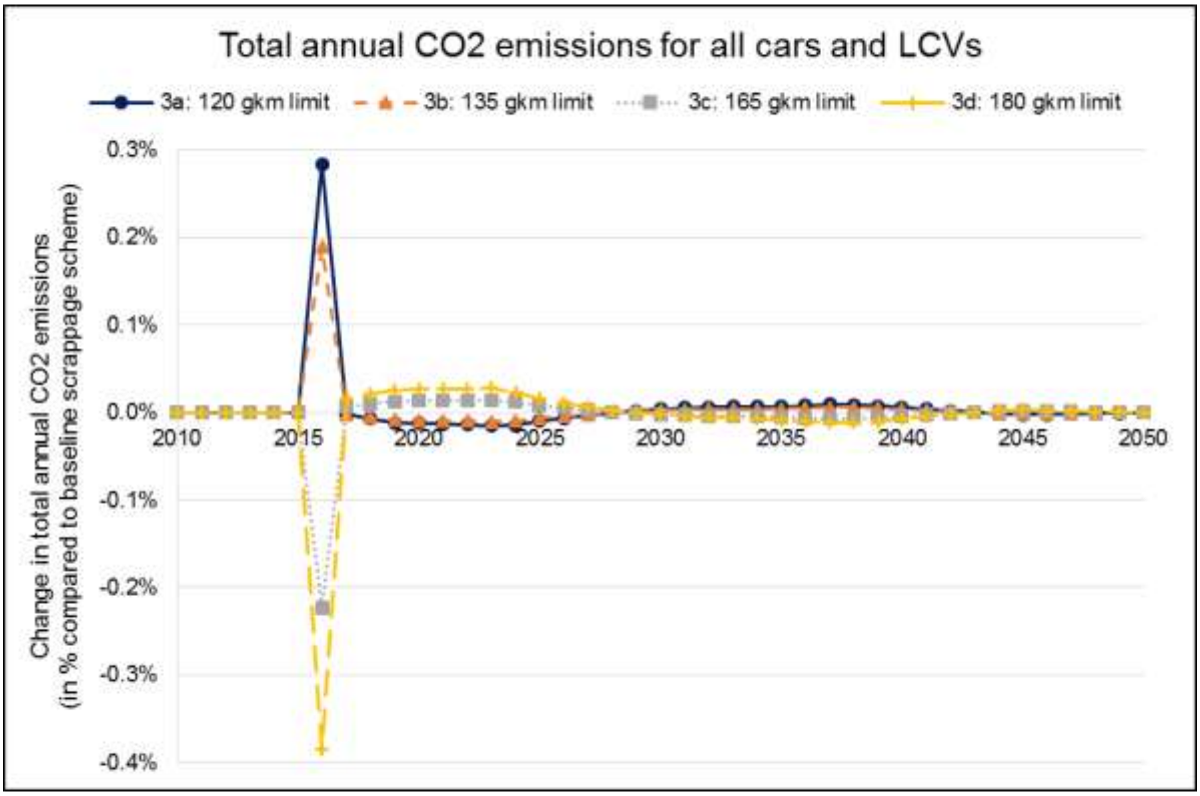
The selection of different **levels of $CO_2$ emissions for the trade-in vehicles (Scenarios 3a-d)** affects the number of vehicles eligible for the scheme. This is shown in Figure 5-6:.

**Figure 5-6: Variation in number of vehicles replaced under the scheme with limit on $CO_2$ emissions of trade-in vehicles**



It can be seen that the number of vehicles included in the scheme varies approximately linearly with the $CO_2$ emissions limit on the trade-in vehicles, though there is some indication of a flattening-off of the relationship at the lowest level (120g$CO_2$/km). This flattening-off is expected as there are fewer vehicles of the relevant vintage in the fleet below the limit which could be captured by any further reductions in the limit. The effects of the different number of vehicles in the scheme on the annual $CO_2$ emissions is shown in Figure 5-7:.

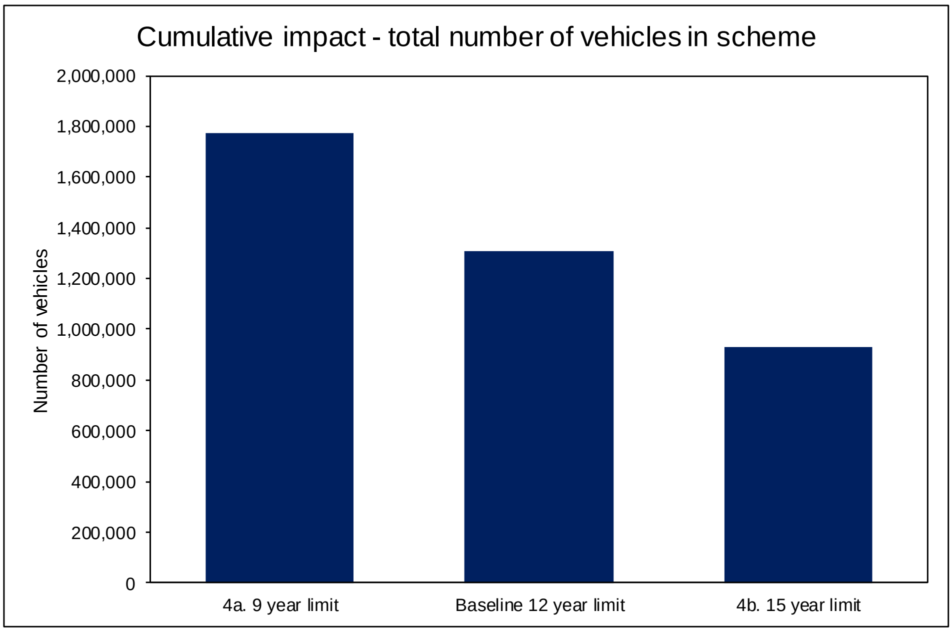
**Figure 5-7: Changes in annual $CO_2$ emissions for different limits on trade-in vehicle emissions, relative to baseline scrappage scheme (150 g/km limit)**




The lower limits on the emissions from the trade-in vehicles lead to an immediate increase in $CO_2$ emissions (relative to the baseline scenario), followed by a reduction to a lower level in subsequent years. The cases with higher limits (and lower numbers of vehicles in the scheme) show the opposite trends, as expected.

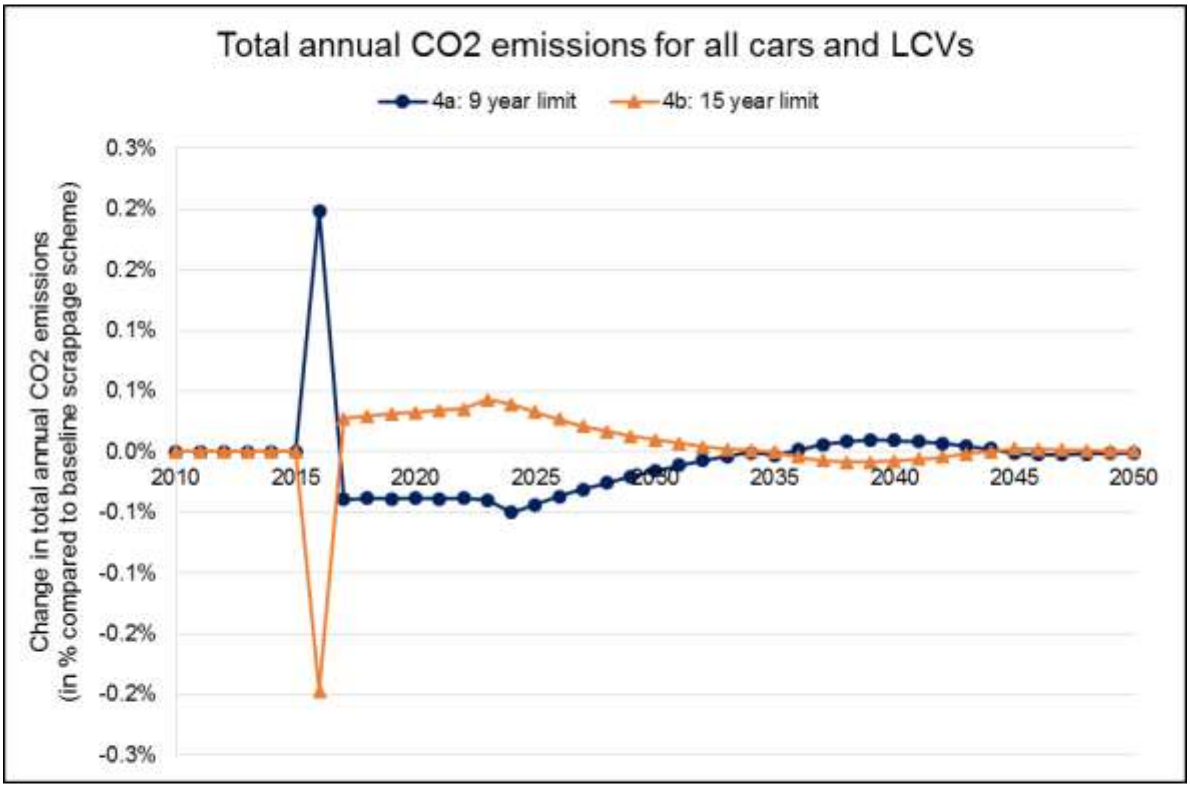
A similar variation is seen in the results of the sensitivity analysis of the **minimum age of the trade-in vehicle (Scenarios 4a-b)**. Figure 5-8: shows the effects on the number of vehicles in the scheme.

**Figure 5-8: Variation in number of vehicles scrapped under the scheme with limit on age of trade-in vehicles**



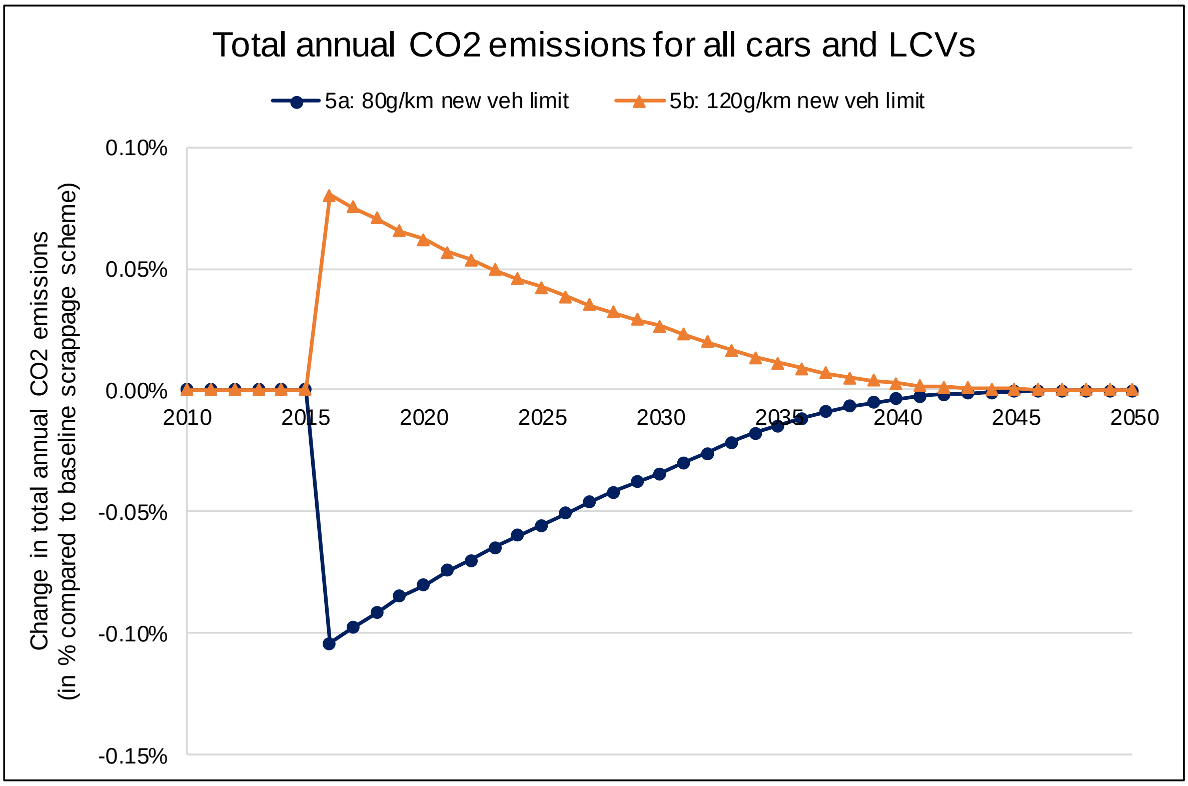

The reduction in the age limit to nine years (Scenario 4a) increases the number of vehicles in the scheme to a similar level to Scenario 3a (the 120gCO2/km limit with a 12 year minimum age). The increase in the age limit to 15 years (Scenario 4b) reduces the number of vehicles in the scheme to a similar level to Scenario 3c (the 165g$CO_2$/km limit). As expected, the impact on the $CO_2$ emissions also follows similar trends to Scenario 3 (Figure 5-9:).

**Figure 5-9: Change in annual $CO_2$ emissions for different limits on trade-in vehicle ages, relative to baseline scheme (12 year limit)**



The selection of the **maximum limit on the $CO_2$ emissions of the replacement vehicles (Scenarios 5a-b)** does not impact on the number of scrapped (and replacement) vehicles, but does affect the calculated $CO_2$ emissions. Figure 5-10: shows the variation in annual emissions for different $CO_2$ emissions limits.

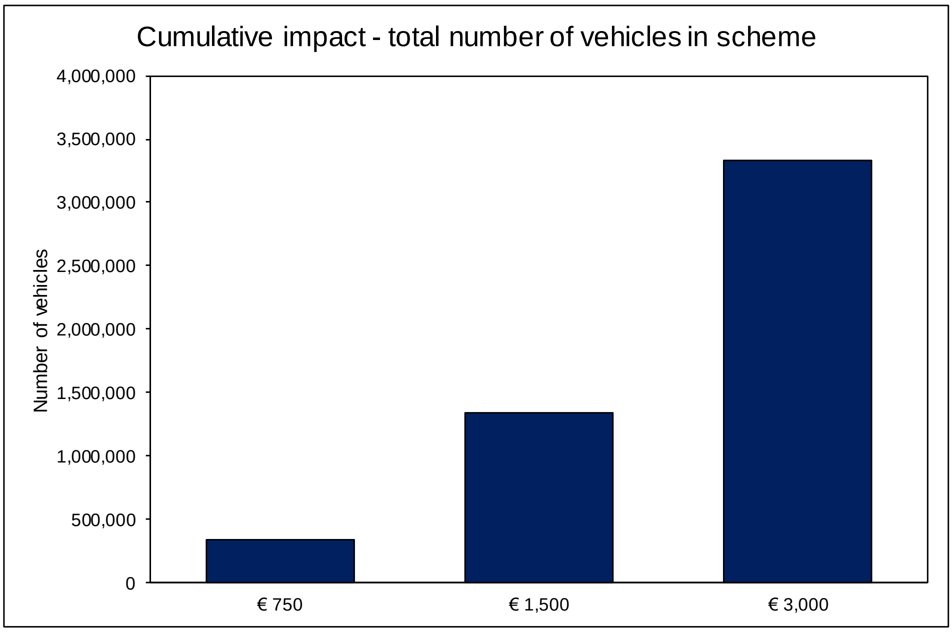
**Figure 5-10: Variation in annual CO2 emissions for different limits on the replacement vehicle emissions, relative to baseline scheme (100 g/km)**




The magnitude of the effect on the $CO_2$ emissions is quite small (e.g. in comparison with scenario 4); however, it follows the expected trend of an immediate reduction in emissions (for a lower limit), with a gradual return to the $CO_2$ emissions of the baseline scenario.

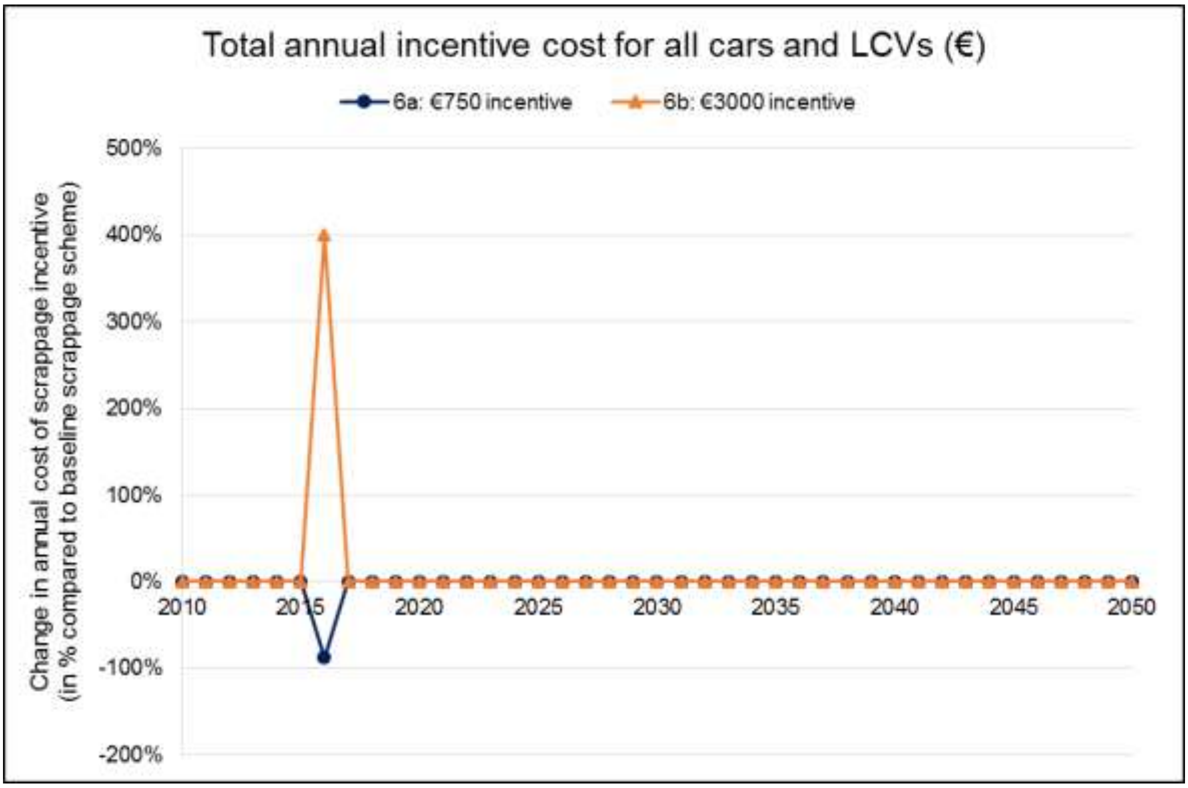
The results of the sensitivity analyses have shown that there is a high sensitivity of the number of vehicles in the scheme to the **level of the financial incentive (Scenarios 6a-b)**. Figure 5-11: illustrates this sensitivity.

**Figure 5-11: Variation of number of vehicles in the scrappage scheme with the incentive value**




The number of vehicles in the scheme varies linearly with the incentive value, reflecting the linear nature of the applied variation of take-up with incentive (see Figure 4-5). The annual $CO_2$ emissions also reflect this sensitivity; Figure 5-12: shows the annual $CO_2$ emissions as a percentage difference from the baseline case (with a €1,500 incentive).

**Figure 5-12: Effect on annual $CO_2$ emissions of different levels of incentive for the scrappage scheme compared to the baseline scrappage scenario**




A higher incentive value leads to a significant increase in the emissions in the year in which the scheme is operating (due mainly to the embedded $CO_2$), followed by quite significantly lower $CO_2$ emissions in the years immediately following the scrappage scheme. The reduction in emissions continues at a lower level for about 20 years after the scheme finishes. Conversely, a lower incentive leads to higher $CO_2$ emissions in those years. This high sensitivity to the incentive value makes it one of the more powerful parameters for adjusting the effects (and costs) of the scrappage scheme.

### 5.1.2 Sensitivity of results to assessment parameters

The sensitivity analysis of the effects of changing parameters related to the rebound effect varied the factor that defines the share of the maximal **rebound effect** that is applied **(Scenarios 7a-b)**. This parameter does not affect the trade-in vehicles selected for scrappage, nor the replacement vehicles purchased, but it does affect how those vehicles are driven. Figure 5-13 shows the effect of the rebound parameter (defined in % of the maximum allowed rebound effect) on the total annual mileage of the entire vehicle fleet. Figure 5-14: shows the effect on the annual $CO_2$ emissions of changing this parameter.

**Figure 5-13: Effect of rebound parameter on annual total mileage compared to BaU (50% max rebound)**

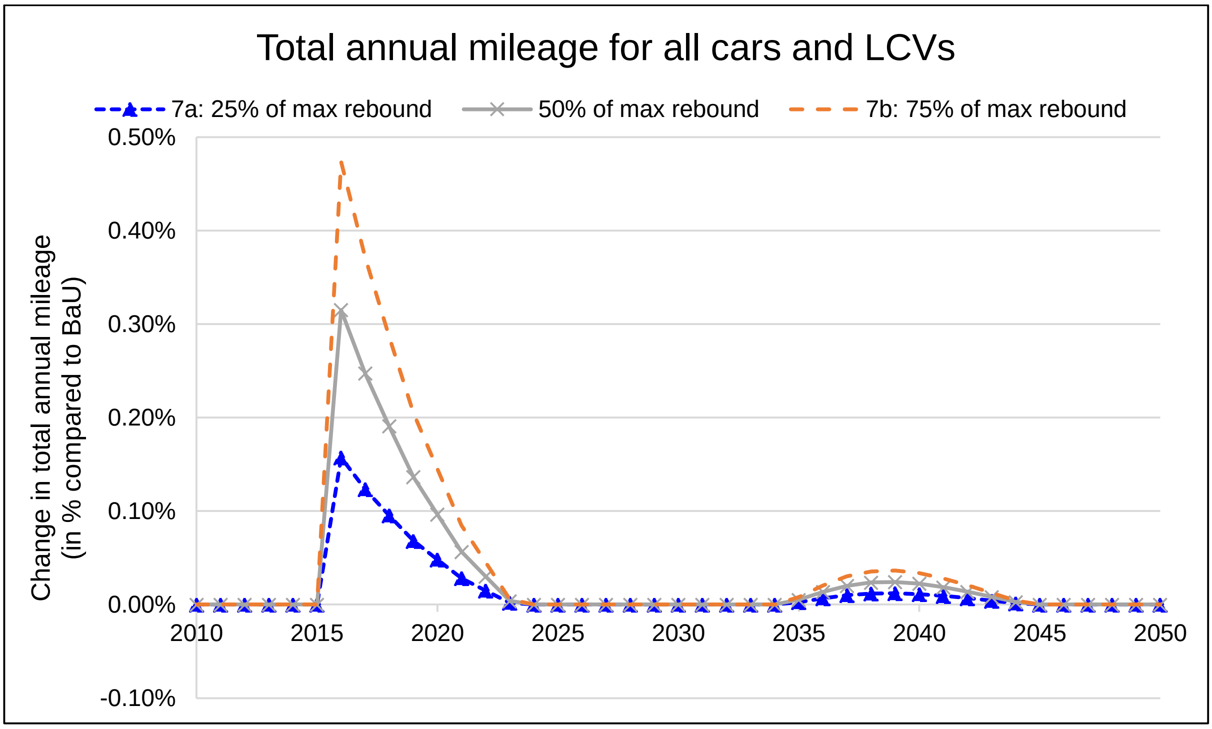
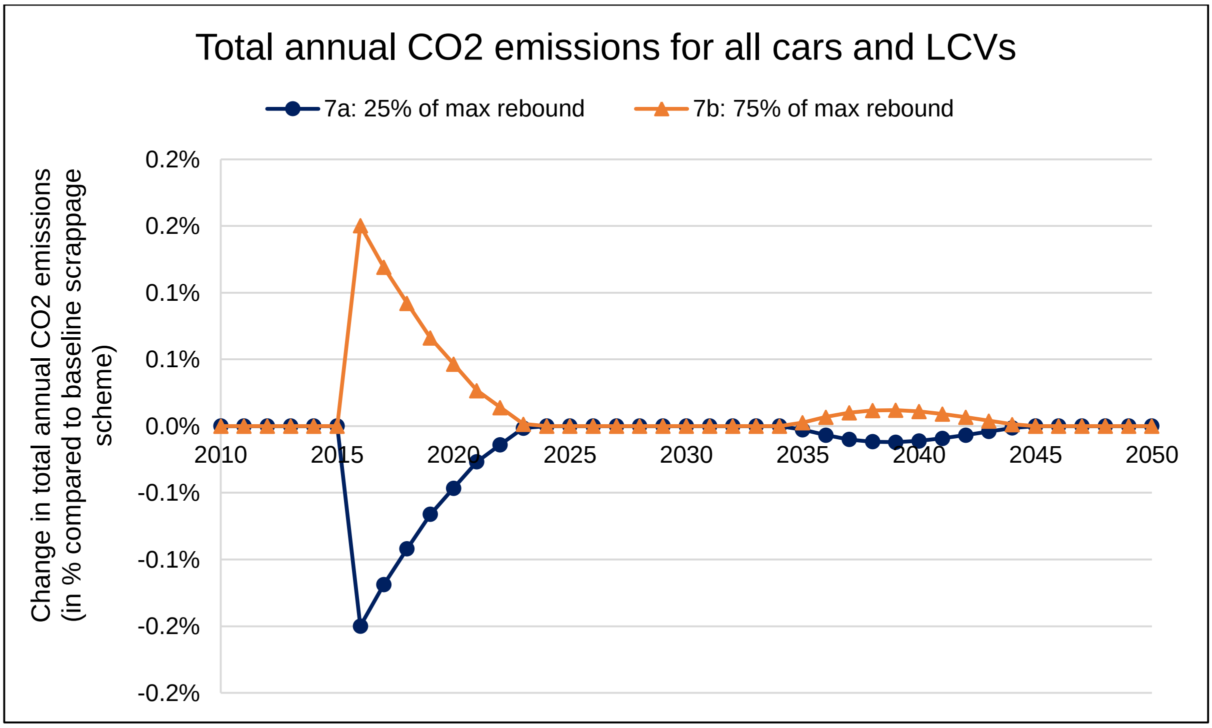


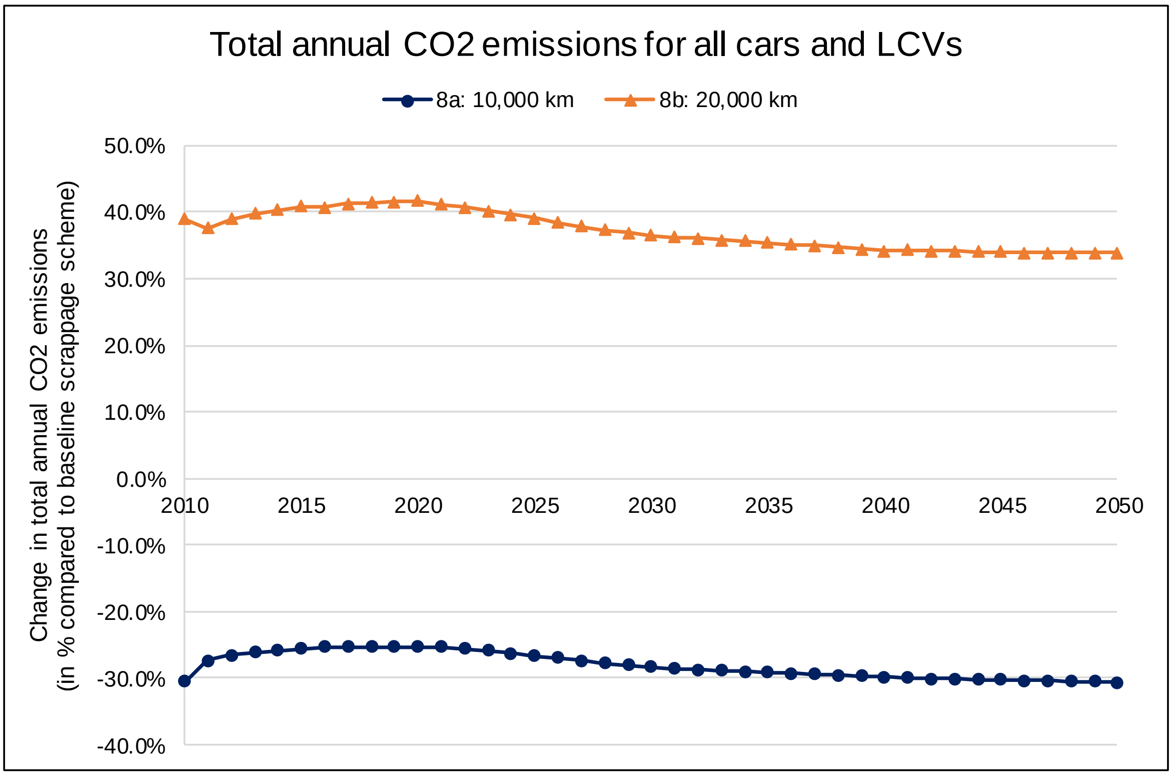
**Figure 5-14: Effect on annual $CO_2$ emissions of different mileage rebounds compared to the baseline scrappage scheme (50% of maximum rebound)**




As expected, reducing the rebound effect reduces the total annual mileage and $CO_2$ emissions. For the scenarios investigated, the $CO_2$ emissions return to the baseline scenario (and BaU scenario) value over a period of about 7 years. Later, there is another period of change in the $CO_2$ emissions, with the lower rebound effect leading again to a reduction in emissions compared to the baseline scenario – this is due to the perturbation from the original scrappage scheme showing up at the typical end of the lives of most of the vehicles introduced to the fleet then. During the period between these two changes, the effects of a simplistic accounting for the varying age profiles of the fleet and the annual mileage distribution (as a function of the vehicle age) would lead to a reduced the total annual mileage to below the BaU value (for the baseline scenario and the two scenarios being considered here). However, this judged to be an unrealistic effect; therefore, the annual mileage calculated by the model has been constrained to not fall below the BaU value. Hence during this period, the baseline scenario and scenarios 7a and 7b all have the same mileage and $CO_2$ emissions.

All results presented so far have been based on a set of age-based mileage distributions, with younger vehicles having higher annual mileages than older models. The alternative included in the model is for the user to input mileage values which are applied (separately for different vehicle segments) uniformly for all vehicle ages. The average annual mileage in the model is about 14,000km for the age-based mileage approach; therefore, **uniform annual mileages** of 10,000km and 20,000km **(Scenarios 8a-b)** have been investigated. Figure 5-15 shows the effect on the annual $CO_2$ emissions of these changes.

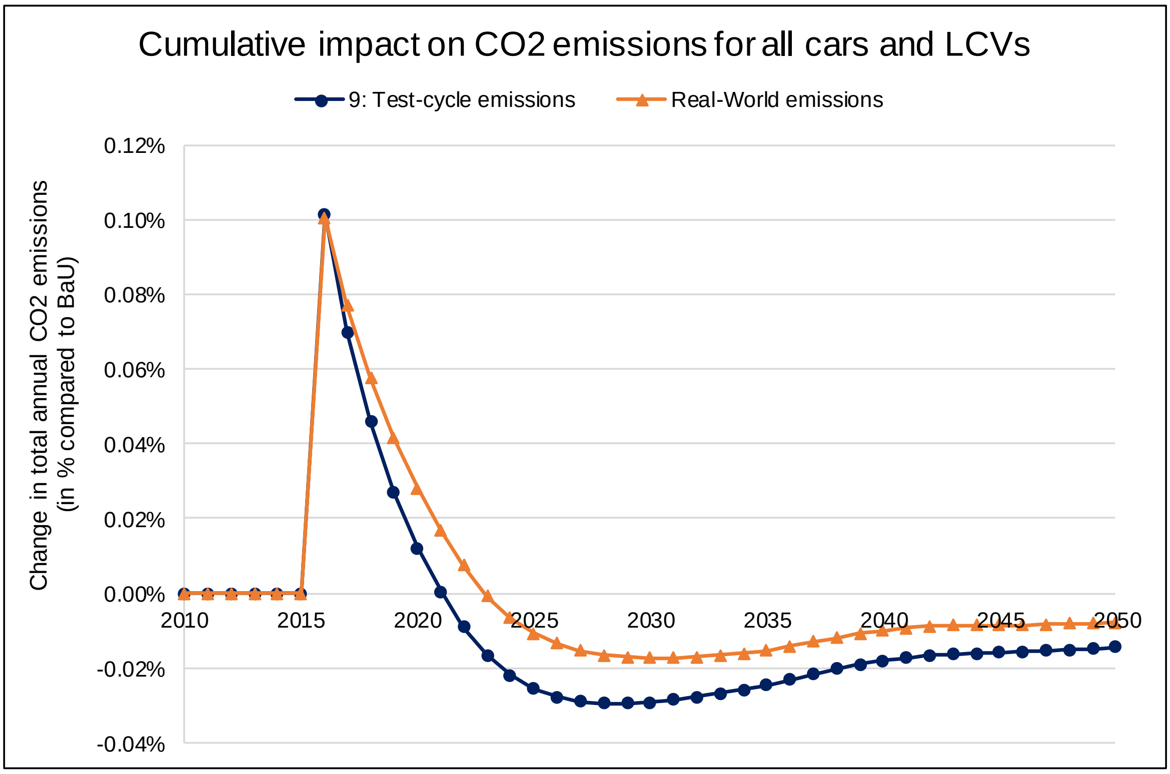
**Figure 5-15: Effect on CO2 emissions of selecting different (uniform) annual mileages compared to the baseline scrappage scenario (that assumes age-based mileage)**




The results of this sensitivity test show that the $CO_2$ emissions increase and decrease approximately in line with the ratio of the assumed annual mileage to the approximately 14,000km average of the age-based distribution; the difference is not exactly constant as the annual average of the age-based distribution used in the baseline scenario varies over time as the fleet age distribution evolves.

The effects of using **test cycle TTW vehicle emissions (Scenario 9)** (instead of real world emission values) are to change the fuel consumption and $CO_2$ emissions of all vehicles in the fleet (including in the years prior to the implementation of the scrappage scheme, rather than any selection of vehicles for the scheme or the operation of the replacement vehicles. Figure 5-16: shows the difference between the calculated change in emissions from the BaU case for both the baseline scenario and the calculation using test cycle emissions. Note that each scrappage scenario is compared to its respective BaU case (i.e. the emissions from the baseline scrappage scenario are compared to the real-world emissions from the BaU scenario while the emissions from the test-cycle scrappage scenario are compared to the test-cycle emissions from the BaU scenario).

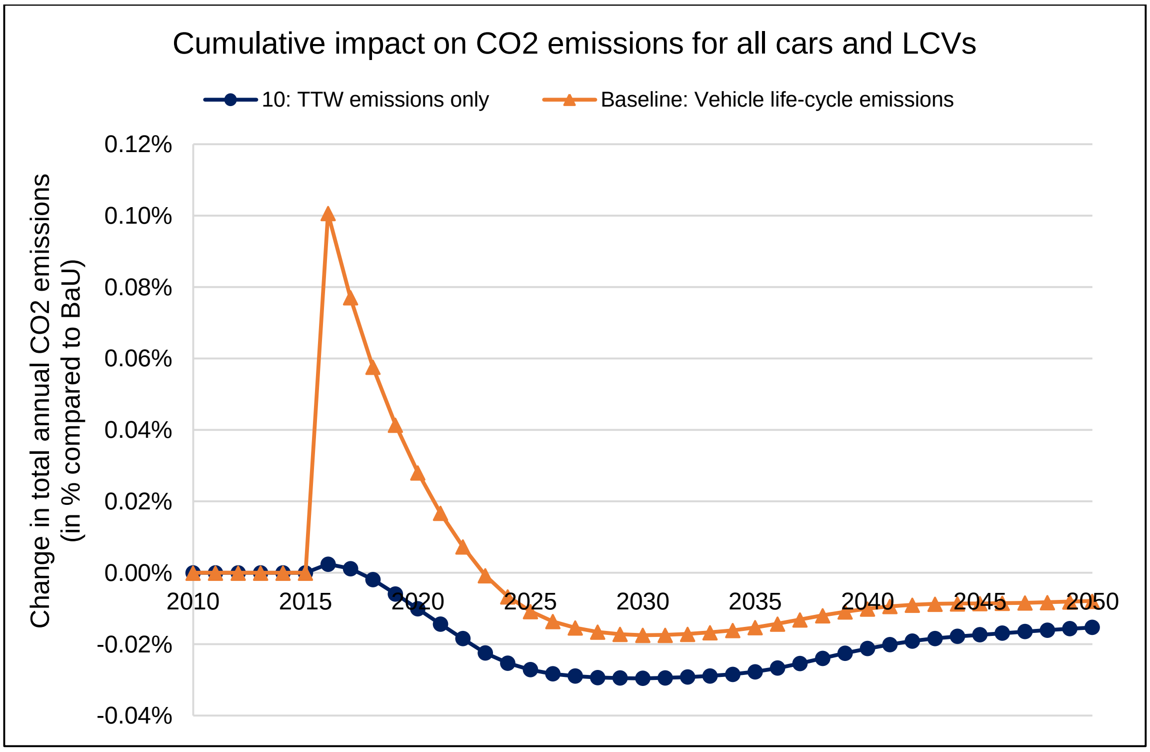
**Figure 5-16: Effect of using real-world and test-cycle vehicle efficiencies on the change in cumulative $CO_2$ emissions relative to the BaU scenario**




The use of test-cycle emissions for calculating the cumulative benefits on $CO_2$ emissions shows an apparent greater benefit (approximately double) than when the same benefits are calculated using real-world emissions.

In a similar manner to the test-cycle-based emissions calculations, the use of **only tank-to-wheel (TTW) emissions (Scenario 10)** does not affect the calculations of the fleet changes nor the mileage driven, but just the $CO_2$ emissions calculated. Figure 5-17: shows the changes in cumulative $CO_2$ emissions relative to the BaU case for the TTW-only scenario and the baseline scrappage scenario (which includes all the $CO_2$ sources in the model).

**Figure 5-17: Effect of including only TTW emissions and including all emissions on the change in cumulative $CO_2$ emissions relative to the BaU scenario**

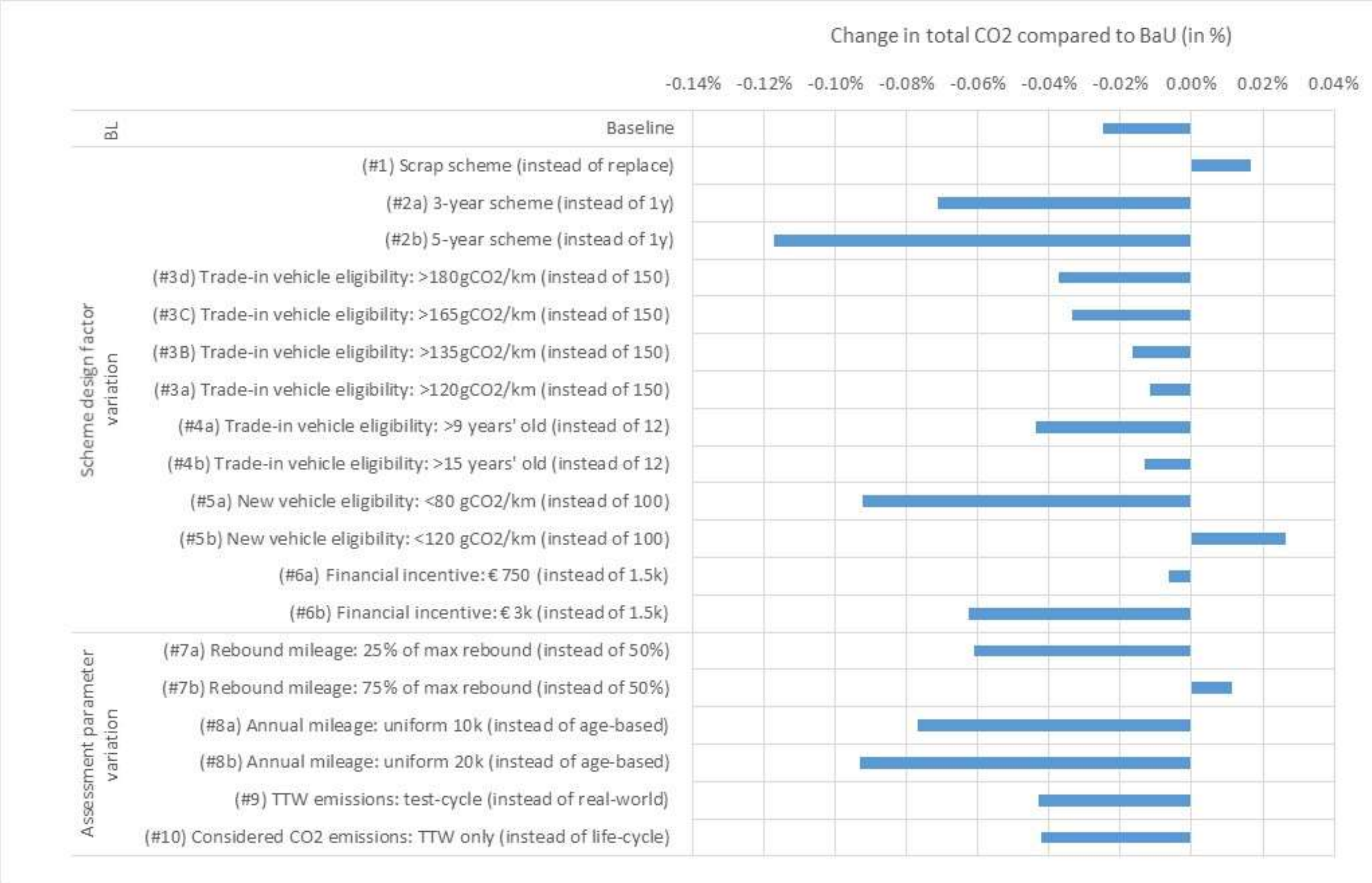



The removal of the embedded $CO_2$ from the calculation removes the large initial increase in $CO_2$ emissions that is evident in the baseline scenario and, hence, results in a smoother distribution with an increased $CO_2$ benefit relative to the BaU scenario (similarly to the test-cycle emissions scenario, this alternative approach to calculating emissions results in an approximate doubling of the benefit).

### 5.1.3 Overview of sensitivity results

Figure 5-18 summarises the above presented results per scenario in terms of their effect on cumulative $CO_2$ emissions compared to the BaU scenario by taking an assessment timeframe of 14 years (covering the period of 2016 up to 2030, and assuming that the scrappage scheme is put in place in 2016). The scenarios that reduce the total cumulative $CO_2$ emissions compared to the baseline scenario become apparent. Longer schemes with a high financial incentive and stringent selection criteria for both the trade-in vehicle and replacement vehicle in terms of the $CO_2$ performance yield the best performance in terms of the schemes' $CO_2$ reduction. As also already identified by (ITF, 2011), a more stringent age-criterion on the trade-in vehicle appears counter-productive. This is because of a reduction of the eligible vehicle stock that results in overall fewer vehicles taking part in the scheme. Also the age-based mileage assumption contributes to this counter-intuitive effect of the vehicle age criterion. The more stringent the criterion is, the more vehicles that are closer to their natural retirement (with comparatively less annual mileage) are replaced.

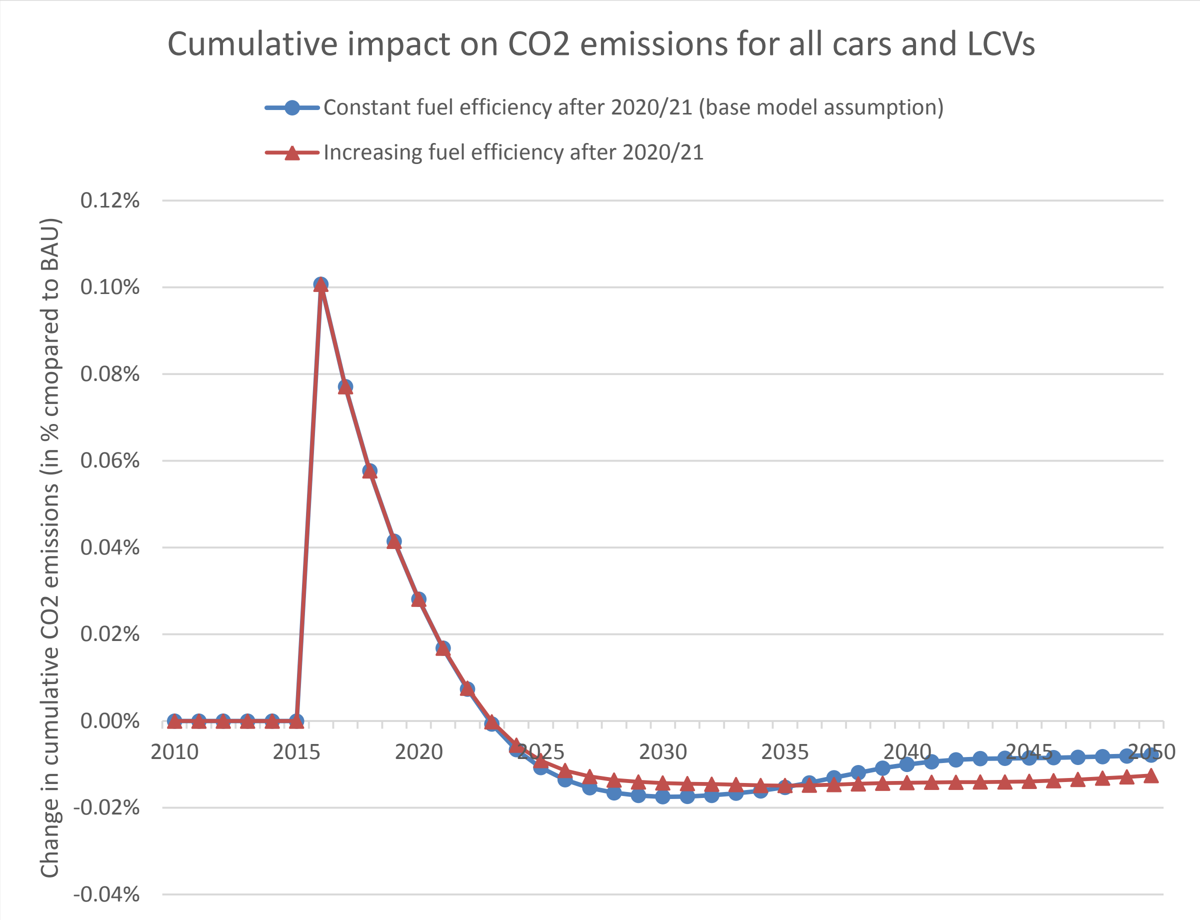
**Figure 5-18: Summary comparison of the 2030 impacts on total cumulative $CO_2$ emissions for different scenarios and sensitivities, relative to the BaU scenario**



### 5.1.4 Change in underlying fuel efficiency assumptions

A further scenario that has been developed concerns a variation in how vehicles' fuel efficiency develops after 2020/21. As shown in Section 4.2.1 (see Figure 4-4) the main assumption underlying the model is that these remain constant for the period after 2020/21. Figure 5-19 shows the effects of varying this assumption. Further improving fuel efficiencies / reducing $CO_2$ emissions from new vehicles after 2020/21 shows initially favourable $CO_2$ reduction impact of the baseline scrappage scenario reduces versus the Business as Usual scenario (also including this improvement). However, in the longer assessment timeframe (i.e. after 2035) the cumulative benefits of the scheme are lower than in the case with no further CO2 emissions performance enhancements post-2020/1.

**Figure 5-19: Cumulative $CO_2$ impact of baseline scrappage scenario compared to BAU for different vehicle fuel efficiency scenarios**




## 5.2 Case studies

To illustrate the results that might be obtained with different definitions of a scrappage scheme, three case studies have also been analysed. These packages of different design factor settings have been derived to show different possible implementations of scrappage schemes; they are not based on particular actual schemes that have been implemented. The differences in the definitions of the schemes are shown in Table 5-2, which shows only those parameters which differ between the three case studies. In general, the idea was to design schemes that differ in their stringency of which vehicles can be subject of the scheme and of which vehicles may be used as replacement vehicles. Also difference in scheme duration were explored.

**Table 5-2: Definitions of schemes investigated as part of the case studies**

| Scheme design factors subject to variation * | Scheme 1 ("Short lax scheme") | Scheme 2 ("Long stringent scheme") | Scheme 3 ("Short stringent scheme") |
|---|---|---|---|
| Scheme duration | 1 Year | 5 Years | 1 Year |
| Eligibility of trade-in vehicle: minimum TTW $CO_2$ emissions | 150g$CO_2$/km | 180 g$CO_2$/km | 180 g$CO_2$/km |
| Eligibility of trade-in vehicle: minimum age | 9 years | 12 years | 12 years |
| Eligibility of replacement vehicle: maximum TTW $CO_2$ emissions | 120 g$CO_2$/km | 100 g$CO_2$/km | 100 g$CO_2$/km |

*Notes*: *all other scheme design factor settings (as well as the assessment parameter settings) are in line with baseline scrappage scheme scenario and its assessment settings (see Table 4-3)

The results of these case studies, in terms of overall vehicle numbers and change in $CO_2$ emissions compared to the BaU scenario, are given in Table 5-3.

**Table 5-3: Results from case study analyses**

| | Scheme 1 ("Short lax scheme") | Scheme 2 ("Long stringent scheme") | Scheme 3 ("Short stringent scheme") |
|---|---|---|---|
| Number of vehicles replaced under scheme | 1,774,872 | 3,324,690 | 664,084 |
| Total scheme costs (Incentive; in million) | €2,662 | €4,987 | €996 |
| $CO_2$ change to BaU up to 2030 (million) | 3.520t | -21.899t | -4.899t |
| $CO_2$ change to BaU up to 2030 (in % to BaU for 2016-2030) | 0.03% | -0.17% | -0.04% |
| $CO_2$ change to BaU up to 2050 (million ) | 5.517t | -25.010t | -5.017t |
| $CO_2$ change to BaU up to 2050 (in % to BaU for 2016-2050) | 0.02% | -0.07% | -0.01% |

The results are illustrated further in the following Figure 5-20 and Figure 5-21.

**Figure 5-20 Change in cumulative $CO_2$ emissions between case studies and BaU scenario**

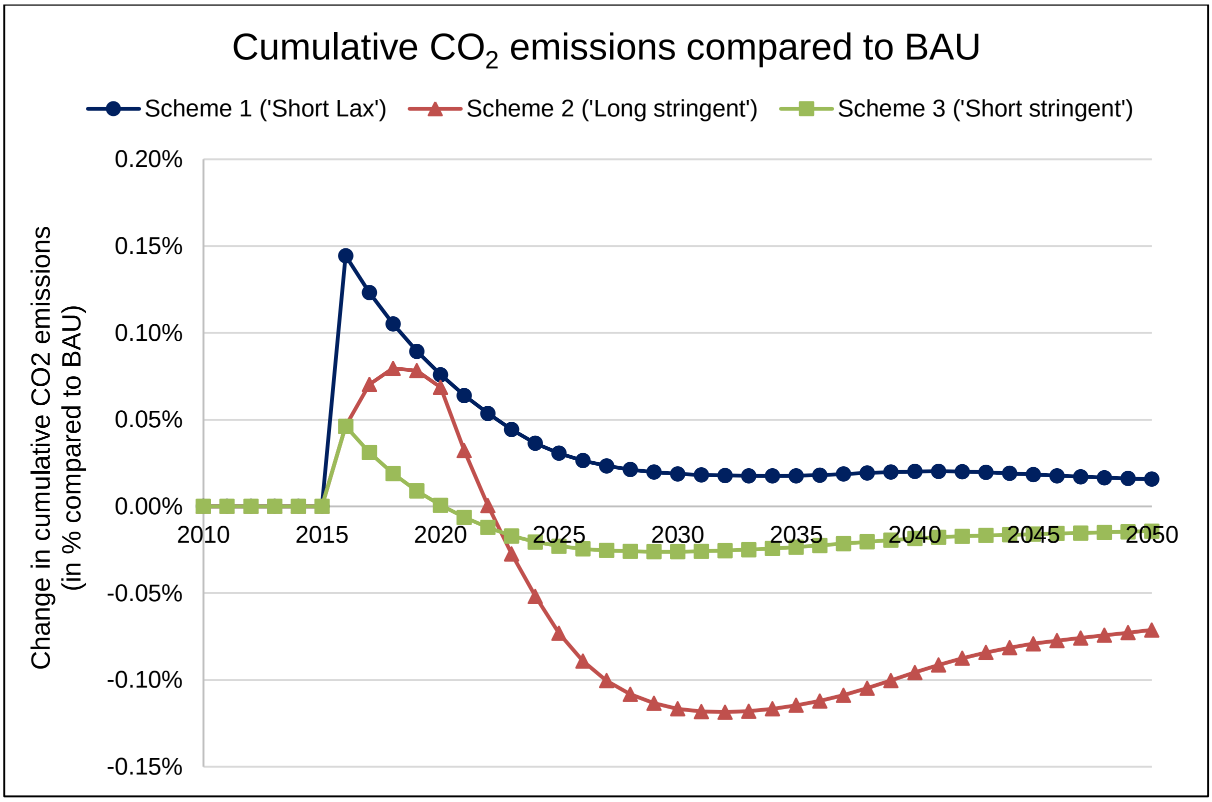
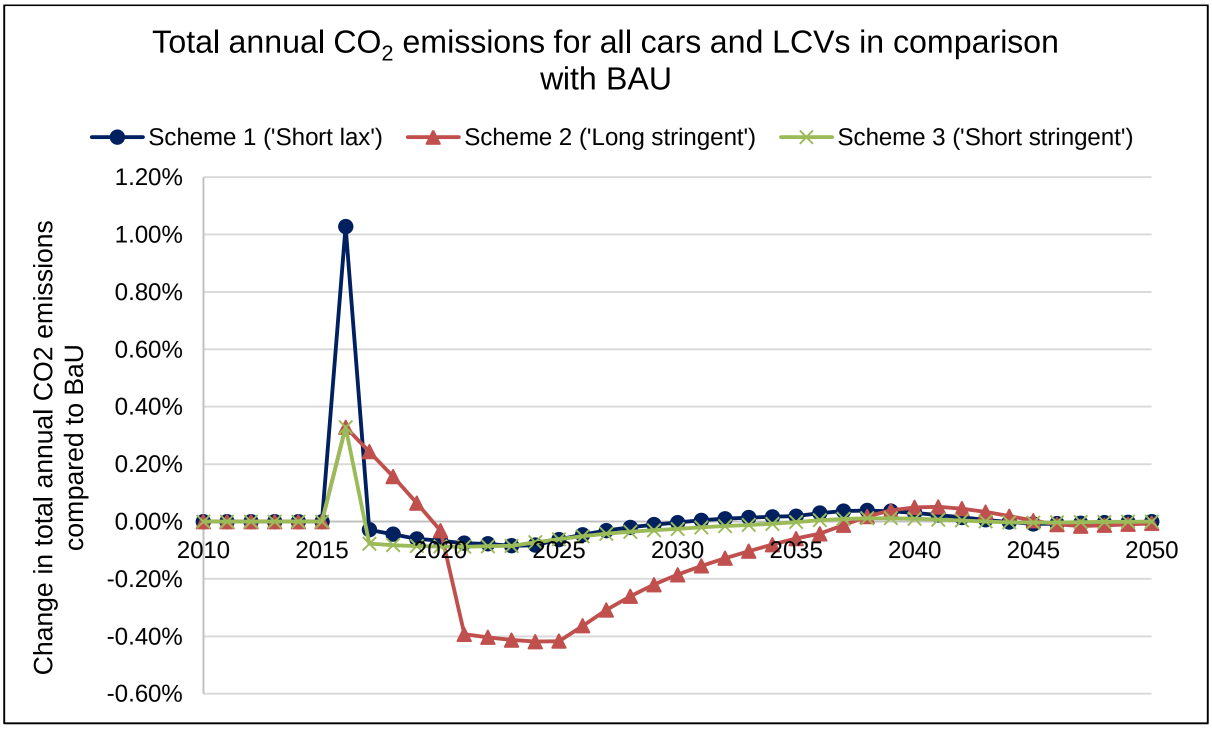



**Figure 5-21 Change in annual $CO_2$ emissions between case studies and BaU scenario**




Scheme 1, the short lax scheme, captures quite a large number of vehicles in total, but does not require a significant improvement in $CO_2$ emissions between the vehicles being scrapped and those replacing them[5]. As a result, the improvements in fuel efficiency are insufficient to outweigh the embedded $CO_2$ and the early years' increase in use and the overall result is a small increase in cumulative $CO_2$ emissions.

Scheme 2, the long stringent scheme, captures a greater number of vehicles, though at a lower rate (87% more vehicles but over a period five times as long). Importantly, it does require a greater improvement between the vehicles being scrapped and those replacing them; as a result, this scheme results in fairly significant savings in $CO_2$ emissions by 2030 (though only a small percentage of the total $CO_2$ emissions in the BaU case between the inception of the scheme in 2016 and the end of the analysis in 2030, 0.17%). The maximum saving in annual emissions for this case occurs between 2021 (when the scheme ends) and 2025, after which the benefits of the scheme reduce gradually until 2038, when there is effectively no benefit over the BaU scenario.

Scheme 3, the short stringent scheme, is very similar to Scheme 2, except that it runs for only a single year. The results are as expected, with approximately 20% of the number of vehicles included in the scrappage scheme overall and the cumulative reduction to 2030 also approximately 20% of that of the longer scheme.

## 5.3 Conclusions from the sensitivity/scenario analysis

The sensitivity of the scrappage model results to variations in a range of different input parameters, covering both scrappage scheme definition and modelling assumptions, has been investigated. The nature of the response of the results to the change in inputs was understandable and as expected.

It is clear that the embedded $CO_2$ emissions, those involved in manufacturing the new vehicle, are high in comparison with the savings in annual $CO_2$ emissions that the new vehicle brings, giving in some cases an increase in cumulative emissions over the timeframe 2016 to 2030. It is important to be aware of the contribution of these embedded emissions when assessing the results of the scrappage model.

Of the scheme design parameters analyses, the incentive value has the greatest effect on the numbers of vehicles included in the scheme (through the variation of percentage take-up with incentive value embedded in the model). From the results obtained, it is clear that care is required when considering the potential effects of low levels of incentive (the take-up model passes through zero take-up at an incentive value of about €500). The identification of further data relating to take-up of scrappage schemes, together with more complex curve fits, might enable a take-up model to be produced which would not have this difficulty at low incentive values. However, the (comparatively) high sensitivity of the results to the incentive value would probably remain for higher values, showing the importance of selecting an appropriate incentive for a scrappage scheme.

Three case studies have been presented for notional scrappage schemes including a short lax scheme, a long stringent scheme and a short stringent scheme. The results show that the short lax scheme may result in insufficient improvements in annual $CO_2$ emissions to offset the increased emissions in the implementation year (due to the embedded $CO_2$ in the additional new vehicles) and so may give an overall increase in $CO_2$ emitted. The long stringent scheme (five times the duration of the short stringent scheme) was able to provide significant reductions in annual $CO_2$ emissions for a number of years after the closure of the scheme; however, these reductions then decayed over a number of years leading to a cumulative saving in $CO_2$ emissions by 2030 of 0.17% of the BaU value.

[5] Note that the scrappage model does not track individual vehicles, so the statement relates to the difference between the average vehicle being scrapped and the average vehicle being purchased, rather than specific pairs of vehicles.

# 6 Explore the economic implications of scrappage schemes

This section explores the economic implications of scrappage schemes in terms of their cost-effectiveness for reducing vehicle $CO_2$ emissions. While Section 6.1 focuses on assessing the cost-effectiveness values as provided in the literature and on normalising these for making valid comparisons, Section 6.2 provides relevant estimates as they could be derived based on the modelling framework developed for this project. A selection of the scenarios that were already used in Section 5 are assessed in order to identify the design factor settings that appear most promising for enhancing the cost-effectiveness of scrappage schemes. Section 6.3 then makes an attempt to compare the cost-effectiveness estimates identified in this project (whether via the reviewed literature or the bespoke modelling framework) with cost-effectiveness estimates of other policy measures.

## 6.1 Analysis of the economic implications of scrappage schemes

An analysis of the literature has shown that out of the shortlisted studies considered for this project, four assessed the cost-effectiveness of scrappage schemes. However, due to the different assumptions and different costs considered the results are not directly comparable. Table 6-1 gives an overview of the figures provided, the basic concepts and moreover the type of costs that were considered in the respective cost-effectiveness calculations.

The (ECMT, 1999) report covers a detailed discussion on which costs should and should not be included in a cost-effectiveness assessment. It is argued that the costs of any public interventions should be made from the point of view of the citizen/consumer. However, any increase in public expenditure results in higher taxes for the citizen, therefore all money spent on an incentive should be accounted for. To assess the cost-effectiveness, therefore, all the public resources devoted to scrappage schemes, (incentives and the related administrative costs), were taken into account. However, the study summarises only cost-effectiveness figures for tonnes of CO, HC and $NO_x$ reduced; $CO_2$ reductions are not covered. The cost-effectiveness analysis that was provided in this study is therefore not directly useful for any effectiveness calculations carried out in this study.

The $CO_2$ cost-effectiveness of the 2009 scrappage schemes across the EU was calculated in (IHS, 2010). The net financial costs to governments (after recouping direct vehicle taxes) was compared to the cumulative tonnes of $CO_2$ saved by the scrappage schemes over three years, and was estimated at € 1,100. The authors question the validity of this figure, because it is distorted by the *"very generous German scheme"*, and because no co-benefits were taken into account.

The (ITF, 2011) report assesses societal costs. The value of all scrapped cars is compared with the total savings due to the scrappage scheme. Savings include the reductions in fuel costs, reductions in $CO_2$ and $NO_x$ emissions, and reductions in traffic casualties/ serious injuries. Monetary values for these savings are external cost estimates retrieved from the IMPACT Handbook[6]. The below table provides estimates per $tCO_2$ abated that could be derived from the above estimates (values that are not stated as such in the source).

In (Li, 2011) different scenarios are assessed based on different assumptions regarding the vehicle miles travelled (VMT) and for different subsets of the available sample. Values are provided with and without the co-benefit of reduced air pollutants.

**Table 6-1: Summary of findings of cost-effectiveness of scrappage schemes in literature**

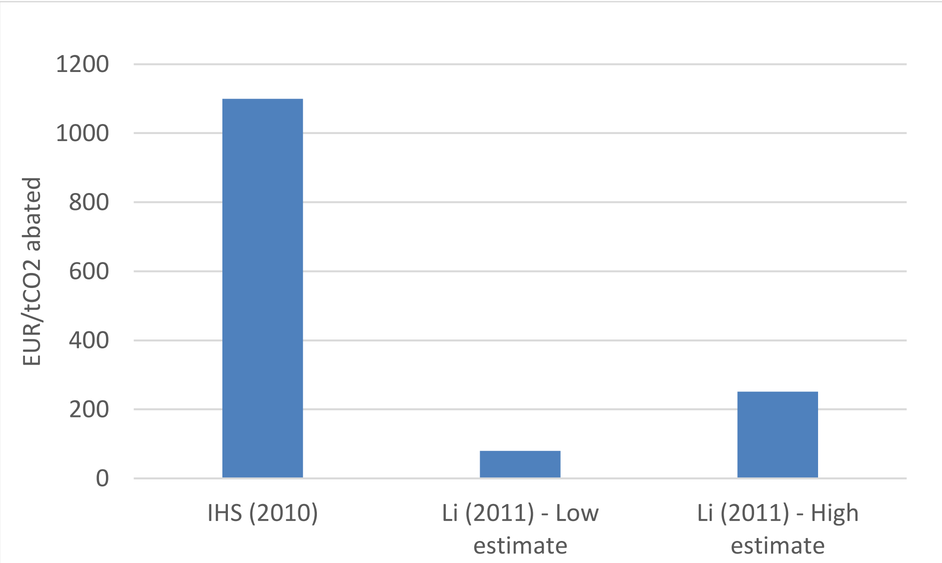
| Paper / Schemes assessed | Cost / $tCO_2$ reduced | Costs considered | Comment |
| --- | --- | --- | --- |

[6] (Internalisation Measures and Policies for All external Cost of Transport), for EC DG TREN, 2008

| Paper / Schemes assessed | Cost / $tCO_2$ reduced | Costs considered | Comment |
|---|---|---|---|
| (ECTM, 1999) **/ Various US schemes** | No $CO_2$ values provided (~ US$ 600 / tCO) | Public resources devoted to schemes (incentives + administrative costs) | Study summarises findings from other studies |
| (IHS, 2010) **/ EU 2009 schemes** | 1,100 € | **Financial costs** to governments (after recouping direct vehicle taxes) | Costs purely allocated to cumulative (test-cycle TTW) $CO_2$ reduction over the period 2009-2011 |
| (ITF, 2011) **/ 2009 schemes of stated countries** | US: 8,500 €<br>FR: 2,100 €<br>DE: 15,000 €<br>*[US: 1,900 €<br>FR: 1,200 €<br>DE: 11,200 €]* | Value **of destroyed assets** (scrapped vehicles) | Costs purely allocated to cumulative (real-word TTW) $CO_2$ reduction over the period 2010-2030 (values derived from provided overall societal cost/benefit estimates)<br>*[Costs considering co-benefits, i.e. fuel savings, NOx reductions and safety benefits]* |
| (Li, 2011) **/ 2009 US scheme** | 106-335 US$<br>*[92-288 US$ if air pollutant co-benefits considered]* | **Government expenditure** | Costs purely allocated to cumulative (test-cycle TTW) $CO_2$ reduction over assessment timeframe (defined by concerned vehicle lifetimes); scenario-dependent (mainly varying VKM assumptions)<br>*[Costs considering co-benefits of air pollutant emission reductions]* |

Due to the different underlying assumptions and types of costs considered it is challenging to compare the values directly. Only two studies ( (Li, 2011) and (IHS, 2010)) provide figures on a similar type of costs (financial costs to governments). Figure 6-1 shows how the values compare to each other (not taking any co-benefits into account that are provided in (Li, 2011)). Even compared to the upper bound of (Li, 2011), the (IHS, 2010) value is more than four times higher. Part of these differences might be due to the assumptions used in the respective modelling/assessment frameworks. The authors of (IHS, 2010) furthermore highlight that the value for the EU schemes is 'exaggerated' by a very generous German scheme.

**Figure 6-1: Cost-effectiveness of scrappage schemes as identified in the reviewed literature**



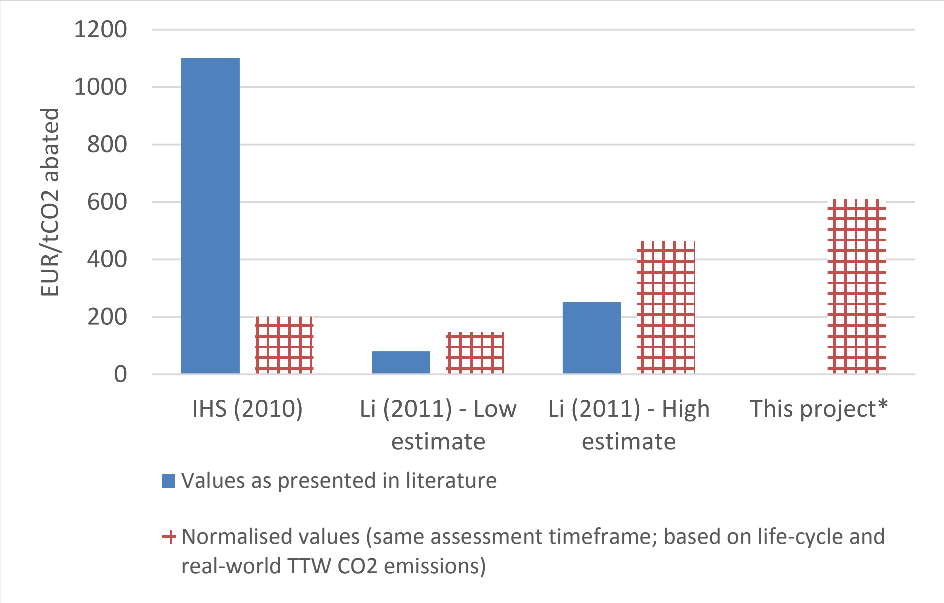
*Notes*: Costs considered are expenditures for the financial incentive (in case of IHS (2010) direct vehicle taxes are recouped); co-benefits are not considered; $CO_2$ savings are based on test-cycle TTW emission estimates

*Source*: Ricardo analysis of (Li, 2011)[7] and (IHS, 2010)

In an attempt to make the values more comparable to the estimates of the baseline scenario developed for this project, the values presented in above Figure 6-1 are normalised as far as possible by making use of the model framework. The figures of both (Li, 2011) and (IHS, 2010) are based on test-cycle TTW emissions Also the assumptions concerning the vehicle kilometres travelled are similar (both are vehicle age-based and a rebound effect is considered). However, the assessment timeframes are different: whereas (IHS, 2010) assesses the impacts over a 3-year period, the assessment timeframe of (Li, 2011) is based on the vehicle's assumed lifetime mileage (depending on the exact scenario).

For the purpose of this normalisation exercise, it is assumed that the assessment timeframe of (Li, 2011) can be approximated by 14 years. Cost-effectiveness results from (IHS, 2010) are then adjusted by applying a factor derived from the model framework. This factor reflects the difference in the cost-effectiveness of the baseline scrappage scheme scenario (as described in earlier Section 4) between a sub-scenario that assumes a 3-year assessment periods and a sub-scenario that assumes a 14-year assessment period. This factor is found to be around 10 – meaning that the cost-effectiveness of the scheme increases by a factor of 10 (or the EUR/t$CO_2$ decrease by around 90%) if the assessment timeframe is changed from 3 to 14 years. A similar procedure is followed for normalising the values to account for life-cycle emissions (rather than TTW emissions only) and real-world TTW emissions (rather than test-cycle TTW emissions) – the settings of this project's baseline scenario. As a result of the normalisation, the differences in the studies' estimates become smaller (because of the normalisation of the assessment timeframes) and more comparable to the baseline scenario of this project (thanks to accounting for life-cycle $CO_2$ emissions based on real-world TTW estimates) (see Figure 6-2).

**Figure 6-2: Cost-effectiveness of scrappage schemes – normalised estimates**




Notes: *Based on the baseline scrappage scheme scenario as described in Section 4; Source: Ricardo analysis of (Li, 2011)8, (IHS, 2010) and this project's modelling framework.

Despite the normalisation efforts, it is clear that differences remain which may not be solely due to the different scrappage schemes that were assessed in the respective studies (i.e. the 2009 European scrappage schemes in the case of (IHS, 2010) and the 2009 US scrappage scheme in the case of (Li, 2011)). They may also be due to remaining differences in assumptions that were taken in the respective assessments. Nevertheless, the analysis shows that this project's cost-effectiveness calculations are roughly in line with the magnitudes of the estimates that are found in the literature.

[7] To convert US$ into € an exchange rate of 0.75€/US$ (January 2011) was applied
[8] To convert US$ into € an exchange rate of 0.75€/US$ (January 2011) was applied

The following section explores in more detail how the cost-effectiveness of a scrappage scheme may vary with changes in scheme design and with alterations to the assumptions that are used for the assessment.

## 6.2 Illustrations of economic impacts of scheme design and assessment parameters

Section 5 provided an analysis of the impact of variations in design factors and assessment parameters on the $CO_2$ outcomes of the scrappage schemes. This section takes up a selection of the developed scenario/sensitivity tests of Section 5 to verify whether the cost-effectiveness of schemes may be improved by variations in the scheme design according to the modelling framework. Also the change of the cost-effectiveness in response to different assessment parameter settings is assessed. The 'w/o co-benefit' calculations consider the costs for the public hand in terms of the financial incentive 'only' and allocate them entirely to the $CO_2$ reductions. The second set of estimates considers the same costs, but accounts for co-benefits in terms of the pollutant emissions ($PM_{2.5}$, $NO_x$, and $SO_2$). The assessment timeframe is set to 14 years (i.e. the time period up to 2030 assuming that the scrappage scheme would be put in place in 2016).

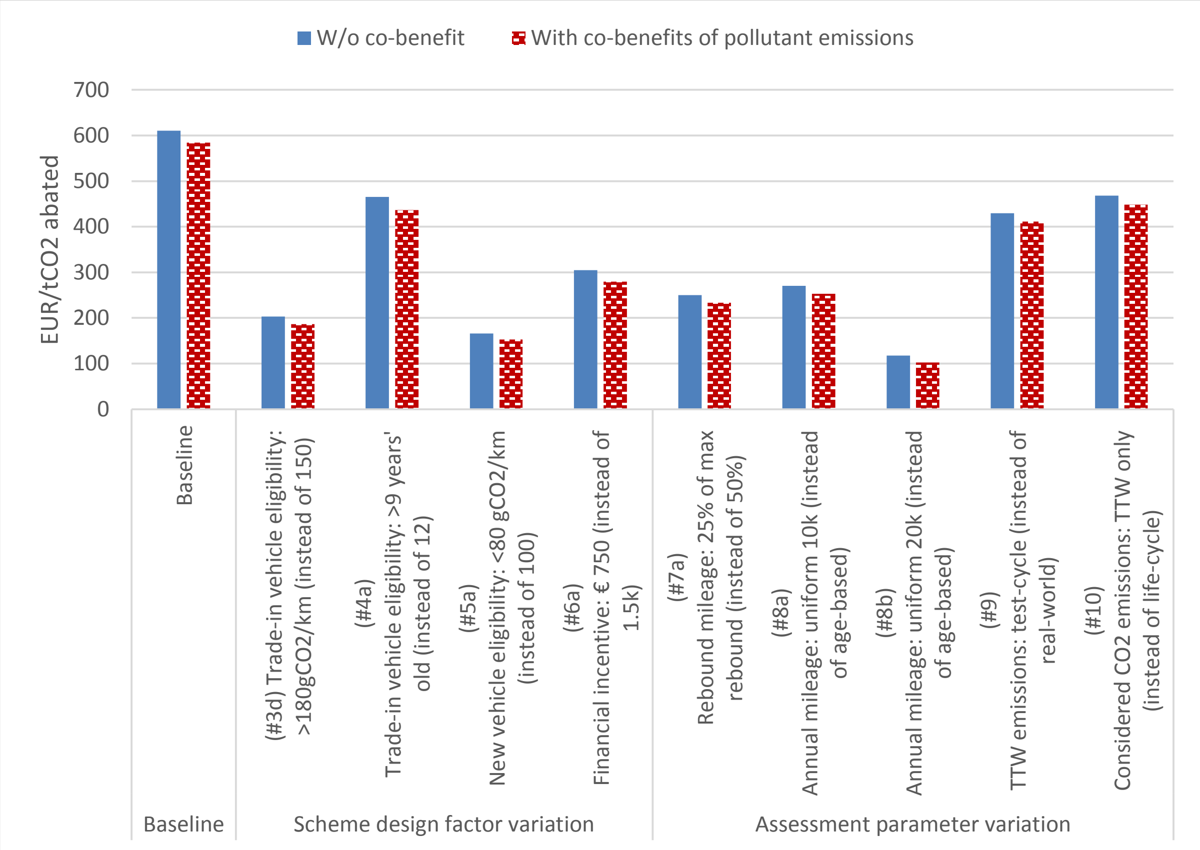
To give an overview, only the design factor/assessment parameter variations that achieved a better cost-effectiveness compared to the baseline are shown in Figure 6-3. **Annex 1** provides a comprehensive overview of the estimates for all scenarios and providers further details on the assumptions underlying the assessment.

Concerning the **variations in design factors**, it can be seen that especially the scenario with more stringent eligibility criteria in terms of the $CO_2$ performance for both trade-in vehicles and replacement vehicles result in a better cost-effectiveness compared to the baseline scenario (as described in Section 4). Increasing the age limit for trade-in vehicles has positive effect, but to a lesser extent than the variation to the $CO_2$ performance criterion. Also, a reduced purchase incentive has a positive impact on the cost-effectiveness of the scheme. A negative effect (and therefore not shown in Figure 6-3) shows a change in the type of scheme (i.e. a change from a replacement scheme to a scrappage scheme where the vehicle does not have to be replaced in order to benefit from the financial incentive). This effect is because the scrapped vehicles are assumed to be replaced at a later point in time when no eligibility restrictions on the replacement vehicle as under the scrappage scheme scenario apply. As a result, relatively more cars with higher average $CO_2$ emissions find their way onto the market.

Concerning the **variations in assessment parameters**, it can be seen that accounting for TTW $CO_2$ emissions only results in more favourable cost-effectiveness estimates than when accounting for full life-cycle $CO_2$ emission; as is the case when basing the analysis on test-cycle emission values instead of real-world emissions values. As expected, reducing the rebound effect results in an enhanced cost-effectiveness. Assuming a uniform annual mileage profile (i.e. the same annual mileage over the lifetime of a vehicle, and over all vehicle segments and powertrains) instead of an age-based mileage profile results in worse cost-effectiveness estimates (not shown in the Figure 6-3).

Figure 6-3 furthermore shows that the cost-effectiveness of schemes increases slightly if the co-benefits of air-pollutant emissions are taken into account.

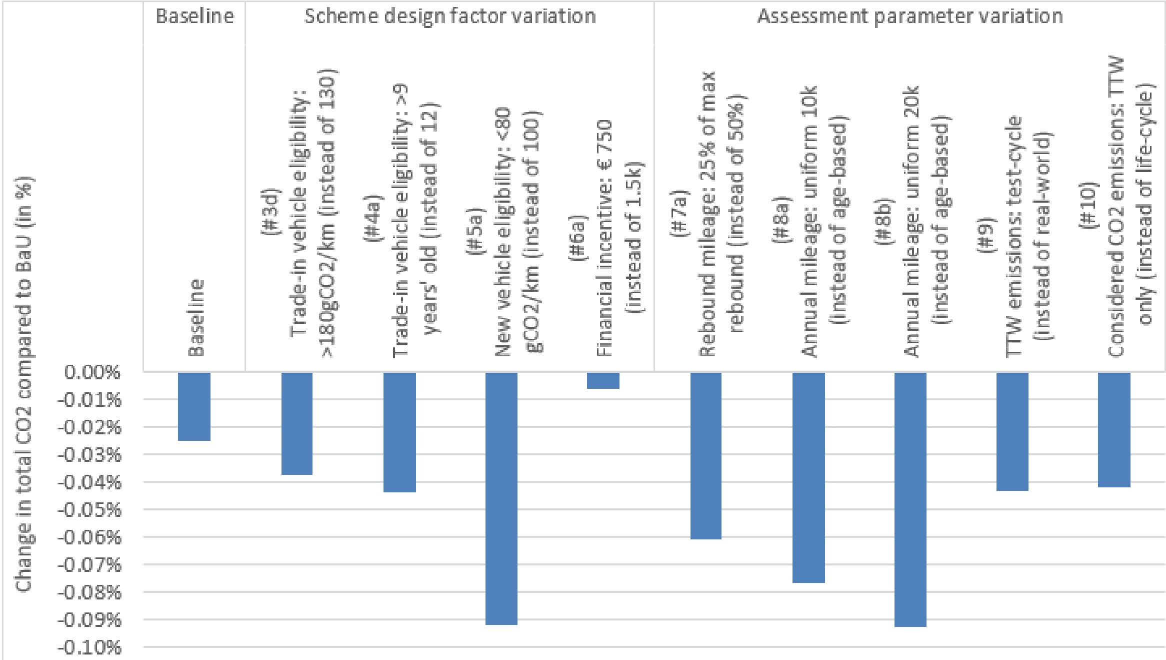
**Figure 6-3: Comparison of the cost-effectiveness of selected scrappage scheme scenarios**




*Notes*: Only public expenditures for the financial incentive are considered as costs; a 14-year assessment timeframe is applied (i.e. from 2016 to 2030); baseline scenario assumptions are in line with the description of this scenario as provided in Section 4 of this report (only indicated parameters are varied). See further details on underlying assumptions for the cost-effectiveness calculations in Annex 1.

Figure 6-4 provides an overview of the $CO_2$ emissions reductions that correspond the cost-effectiveness assessment as provided in Figure 6-3. It can be seen that increasing cost-effectiveness of a scheme may be in contradiction to the goal of increasing total emissions reductions. For example, decreasing the financial incentive leads to an increase in the cost-effectiveness. However, the overall amount of emission reductions is decreased (Scenario 6a). This conflict between the objectives of enhancing the cost-effectiveness of scrappage schemes and increasing emissions reductions was already identified in (ITF, 2011) (see Section 3.1) and is confirmed by this study's findings concerning the financial incentive. For all other parameters, an increase in cost-effectiveness appears to be in line with an increase in total emissions reductions.

**Figure 6-4: Change in $CO_2$ emissions compared to the BaU scenario across the different scheme (assessment) variations**




*Notes*: 14-year assessment timeframe (i.e. from 2016 to 2030); baseline scenario as set out in Section 4 of this report (only indicated parameters are varied).

Table 6-2 shows the cost-effectiveness of the case study schemes. Given the above results the cost-effectiveness estimates of the schemes are as expected. Schemes 2 and 3 show significant enhancements in the cost-effectiveness thanks to the increased stringency concerning the eligibility criteria of the trade-in and the replacement vehicles.

**Table 6-2: Cost-effectiveness of scheme case studies (for timeframe 2016-2030)**

| Cost-effectiveness (in EUR/t$CO_2$ saved) | Baseline scheme | Scheme 1 ("Short lax scheme") | Scheme 2 ("Long stringent scheme") | Scheme 3 ("Short stringent scheme") |
|---|---|---|---|---|
| W/o co-benefits | 610 | n/a (no emissions reductions achieved) | 228 | 203 |
| With co-benefits of air pollutants | 585 | | 206 | 186 |
| ***Change in total emissions up to 2030*** | | | | |
| Compared to BaU | -0.03% | +0.03% | -0.17% | -0.04% |

The above-provided cost-effectiveness estimates are only an indication of the real effectiveness of such schemes in terms of their performance. This is because both costs and benefits of scrappage schemes are further-reaching than ‘just’ the costs of the financial incentives on the one hand, and the benefits in terms of emissions savings on the other hand that could be assessed in the context and under the constraints of this study.

When assessing the costs more thoroughly, the scope of the cost assessment would first have to be clearly defined. For example, if the impact on the public hand were to be assessed, a more holistic **costs** approach should take impacts of scrappage schemes on tax income (e.g. in terms of fuel, vehicle purchase and vehicle running taxes) into account. If, alternatively, the focus of the analysis is the private consumer, then it would be more appropriate to (also) account for fuel cost savings, while the financial incentive may be considered as a benefit to the consumer (unless it is considered as an eventual cost to the consumer who has to pay for the incentive in the form of taxes, as argued by

(ECTM, 1999)[9] . From a societal perspective, one of the cost items that would have to be considered is the lost value due to the scrapped vehicles (as argued by (ITF, 2011)). If taking a societal approach, then also safety benefits would have to be assessed. In addition, the effects on industry and the overall market (such as in terms of effects on the second-hand car market or overall vehicle import or export volumes) would have to be assessed, which, in turn, may have an effect on the environmental performance of the vehicle fleet in other markets. A more holistic overview of such indirect effects that are to be considered is provided in Section 7. A detailed discussion of such effects and quantification of such secondary effects could not be provided within the scope of this study, however.

While the above estimates provide only a limited insight into the real cost-effectiveness of scrappage schemes, they are useful for drawing comparisons with estimates of the cost-effectiveness of other $CO_2$ reducing policy measures in the transport sector (that are typically also limited in their scope and do not take all direct and indirect costs and benefits of such measures into account) – as is attempted in the following section.

## 6.3 Comparison of the impacts of scrappage schemes with alternative GHG reduction policies

This section aims at comparing the cost-effectiveness estimates of scrappage schemes identified in the literature or derived from the model framework developed within this project with the cost-effectiveness estimates of other policy measures. While comparisons on a like-to-like basis are generally difficult to make due to the different types of cost and benefits considered in the different studies (as already mentioned above when scrappage scheme estimates were compared), a general impression can be obtained.

While there is a range of estimates available in the literature for the cost-effectiveness of technical and some behavioural options (e.g. fuel efficient driving) to reduce $CO_2$ emissions from road transport, previous work for the EU Transport GHG: Routes to 2050 II project (Schroten, et al., 2012) found that the available empirical evidence on the cost-effectiveness of policy instruments was (at least at the time) rather limited. The figures available in the literature depend heavily on the design of the instrument and the national/local context, making them difficult to transfer to a more aggregate, European level with any accuracy. Table 6-3 gives an overview of values available for a range of policy measures. The figures show that the numbers can range significantly within and across different policy options depending on the costs and the co-benefits that are included in the assessment. Also differences in the assumptions underlying the assessments and in assessment timeframes are likely to contribute to observed differences.

Indeed, the type of costs that are accounted for in the cost-effectiveness estimates as presented in Table 6-3 vary significantly. For example, while some estimates take into account public investments, others consider losses in consumer or manufacturer surplus. For the benefits the main difference is whether or not co-benefits, such as reductions in air pollution, noise, congestion or accidents are taken into account. (Brannigan, 2012) concluded that the impact of co-benefits varies depending on the GHG reduction policy, and they can be both negative and positive. Comparing the relative values of monetised co-benefits revealed that the negative impacts of accidents are the most pervasive in both passenger and freight transport. Congestion also has a large impact on passenger transport, whilst noise is a more important cost factor for freight vehicles. GHG policies that help to control traffic flow (such as speed limits and/or road user charging) could result in a “quadruple benefit” for climate change, safety, noise pollution and the economy (through reduced time wasted in traffic) in addition to alleviating air pollution problems.

Due to these differences in cost estimation methodologies **a direct comparison of cost-effectiveness values from different sources is challenging, and it is hard to draw any firm conclusions**. The identified estimates of policy instrument cost-effectiveness are included in Figure 6-5. The figure highlights the differences in estimates for the same policy instruments that are likely due to the set of reasons mentioned above. The figure should therefore only be interpreted in combination with Table 6-3, which gives more details for each cost-effectiveness estimate. As a result, no conclusion on the basis of the provided values can be derived. The Figure may suggest that scrappage schemes belong to the measures that are relatively less cost-effective in terms of $CO_2$

[9] Such cost considerations would, however, raise the question how exactly the costs to *all* taxpayers should be compared against the benefits for *some* taxpayers (i.e. those that make use of the scrappage scheme in place and replace their vehicle).

emissions reduction than many other measures. However, the relatively high costs compared to some of the other measures may also be the result of the lack of accounting for other co-benefits, differences in the assessment timeframes or other factors.

**Table 6-3: Summary of findings of effectiveness of $CO_2$ reducing policies in literature**

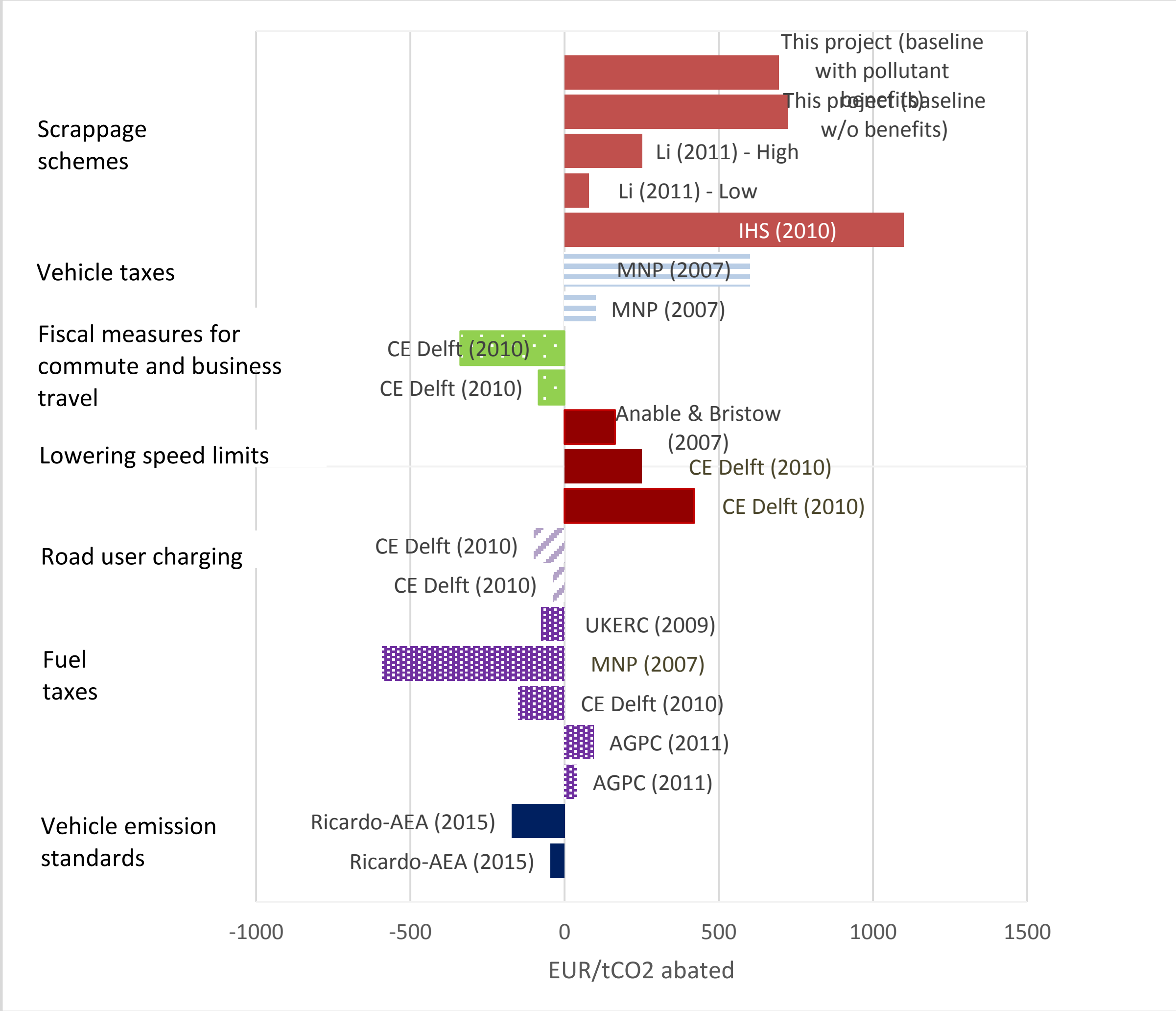
| Policy tool | Study | Costs (+) or Benefits (-) per $tCO_2$ saved | Costs considered | Co-benefits (benefits next to $CO_2$ reductions) considered in estimate | Comment |
|---|---|---|---|---|---|
| **Vehicle emission standards** | (Ricardo-AEA, 2015) | 46 € **(-)** (cars)<br>172 € **(-)** (LCVs) | Net present value costs to society | None | Calculated for the time frame 2006 to 2013 |
| **Fuel taxes** | (AGPC, 2011) | DE: 40-41 € **(+)**<br>UK: 91-97 € **(+)** | Loss in consumer surplus minus any transfers to the government through tax revenues | Fuel savings | Values available for DE and UK and a range of other countries worldwide<br>No co-benefits taken into account |
| **Fuel taxes** | (CE Delft, 2010) | 150 € **(-)** | Reduction in consumer surplus | Fuel savings, reduction in congestion, pollution, road accidents and noise | Based on a hypothetical fuel tax increase in The Netherlands.<br>A net benefit was found implying that the fuel savings and co-benefits outweigh the loss in consumer surplus |
| **Fuel taxes** | (MNP, 2007) | 592 € **(-)** | Reduction in consumer surplus | Fuel savings, reduction in congestion, other environmental impacts | Dutch fuel tax increase |
| **Fuel taxes** | (UKERC, 2009) | 76 €[10] **(-)** | n/a | Air pollutant emissions | Estimation of the UK fuel duty escalator |
| **Road user charging** | (Anable J. , 2008) | 2,552-3,464 € **(+)** | Investment costs, operational costs | None | Road user charging system in the UK.<br>No co-benefits are taken into account |
| **Road user charging** | (CE Delft, 2010) | 38-99 € **(-)** | Investment costs, net operational costs | Reduction in travel time losses | Dutch road user charge for passenger<br>Values depend on the design of the scheme<br>Costs are taking co-benefits into account |
| **Lowering speed limits** | (CE Delft, 2010) | 250-420 € **(+)** | Travel time losses, welfare impacts of the reduction in total mobility | Reduced infrastructure costs, improved road safety, other environmental impacts | Low value for reduction of existing motorway speed limits of 120 km/h to 100 km/h, upper value for a reduction of existing motorway speed limits of 120 and 100 km/h to respectively 100 and 80 km/h |

[10] Using an exchange rate of 1.2€/£

| Policy tool | Study | Costs (+) or Benefits (-) per $tCO_2$ saved | Costs considered | Co-benefits (benefits next to $CO_2$ reductions) considered in estimate | Comment |
|---|---|---|---|---|---|
| **Lowering speed limits** | (Anable & Bristow, 2007) | 164 €[11] (+) | Cost of enforcement | None | 70 mph speed limit in the UK;<br>Estimate is based on relatively old speed camera technology and may be grossly exaggerated as a result. |
| **Fiscal measures for commuter and business travel** | (CE Delft, 2010) | 84-338 € **(-)** | Costs of public travel, reduction of customer surplus | Reduction of travel costs, in congestion, noise, air pollution and accidents | Reduction of the tax-free compensation for commuter and business travel in The Netherlands.<br>Compensation for car users is reduced to € 0.12 per kilometre |
| **Vehicle taxes** | (MNP, 2007) | 100-600 € **(+)** | Change in consumer and producer surplus | Fuel savings, changes in government income, reduction in air pollution, increased traffic safety | Cost-effectiveness of a tax exemption for the Toyota Prius in The Netherlands.<br>Lower value for tax exemption of 50%, upper value for a tax exemption of 100%. |
| **Vehicle taxes** | (Klier & Linn, 2012) | 24 € (+) / vehicle | Costs to manufacturers | None | For a reduction of 5 $gCO_2$ / km |

[11] Using an exchange rate of 1.46 €/£ and a conversion factor of **3.67 (1tC = 3.67 $tCO_2$)**

**Figure 6-5: Estimates of the effectiveness of policy instruments (benefits provided as negative values)**




*Notes:* Values for scrappage schemes have not been normalised as provided in Section 6.1 since none of the estimates for the other policy measures have been normalised to a common base. *Source*: Ricardo Analysis

## 6.4 Conclusion on the cost-effectiveness of scrappage schemes

The above analysis has shown that it is a complex task to assess the economic implications of scrappage schemes. This is mainly due to i) the many assessment variables and scheme design factor settings on the basis of which estimates are established, ii) the multitude and complexity of the impacts of scrappage schemes (whether this concerns only their environmental performance or broader market impacts), and iii) the various different cost items that may be taken into account in a cost-effectiveness assessment. An attempt was made to assess the cost-effectiveness of scrappage schemes in terms of $CO_2$ reductions (with and without the co-benefits of reductions in air pollutant emissions), and by considering only governmental expenditures for the financial incentives as costs. The baseline scenario found a cost-effectiveness of 610 EUR/t $CO_2$ abated if an assessment timeframe of 14 years (up until the year 2030) is considered and no co-benefits are considered. Considering air-pollutant co-benefits, this value reduces to 585 EUR/t $CO_2$ abated. However, this value varies significantly depending on the underlying assessment assumptions and also on the design of the scrappage scheme. For example, assuming an assessment timeframe of 20 years results in a reduced cost of 409 EUR/t $CO_2$; if the assessment timeframe is further reduced to only 3 years, the cost increases to 5,000 EUR/t $CO_2$ (reflecting that in the very first years of the scheme the total emissions increase compared to the BaU scenario due to the increased use of the renewed fleet). Assuming that the financial incentive is doubled (i.e. increased from EUR 1,500 to EUR 3,000) the cost per tonne $CO_2$ abated increases to around EUR 1,200 (when keeping the assessment timeframe constant at 14 years).

The cost-effectiveness values that were identified on the basis of this project's modelling framework are difficult to compare with cost-effectiveness estimates of other policy measures. This is mostly because the estimates found in literature either consider different cost impacts or a different set of co-benefits. Identified values suggest that scrappage schemes are relatively less cost-effective than a set of other measures, however, this cannot be concluded with certainty. A more detailed analysis of the magnitude of the co-benefits that were considered in other studies and their impact on the cost-effectiveness calculation would be required. However, typically the information available in the literature does not allow for a detailed analysis that would facilitate a like-to-like comparison of the different estimates.

# 7 Consideration of the implications for scheme design

This section draws on the illustrations of the main factors that influence the GHG benefits of scrappage schemes and the economic implications of scrappage schemes, as well as other sections of relevance, including the literature discussed in Section 2 and 3. It discusses the implications of the findings of these earlier sections on scheme design and on associated policy, including considerations with respect to the potential for optimising GHG emissions reductions and the associated risk factors resulting from any uncertainties.

## 7.1 Implications of the scheme design

The baseline scrappage scheme, as defined by Table 4-3, delivered cumulative reductions in $CO_2$ and of various air pollutant emissions of around 0.03% of those of the entire LDV fleet compared to the BaU scenario in which there was no scrappage scheme and assuming a 14-year assessment timeframe (see Figure 5-18). This took account of embedded, end-of-life and WTT $CO_2$ emissions, as well as the $CO_2$ emissions associated with operation and maintenance of vehicles. This suggests that scrappage schemes can deliver $CO_2$ benefits when all $CO_2$ emissions are accounted for.

The baseline scrappage scheme selected was a one-year long replacement scheme, with no limit on the number of vehicles and a €1500 incentive. The analysis assumed that there was a limited rebound effect and that cars are driven differently according to their age (see Table 4-3).

When various different scheme design factors were varied, a scenario that had significant impact on the environmental performance was the one that increased the stringency of the eligibility criterion for the replacement vehicle (i.e. an enhancement of the vehicles' performance from 100g$CO_2$/km (in the baseline scenario) to 80g$CO_2$/km). This reduced $CO_2$ emissions by around 0.1% compared to the BaU scenario (and compared to around 0.03% in the baseline scrappage scenario) (see Figure 5-18). Increasing the scheme duration from 1 to 5 years had most positive effect on the total amount of CO2 reduced (0.12% compared to the BaU scenario). Of the other variations presented in this Figure and the corresponding Annex 1, a scrappage-only scheme had a negative impact on $CO_2$ emissions compared to the BaU scenario (as it was assumed that in subsequent years new car purchases would be higher as the size of the fleet recovered to its BaU trajectory). Similarly, a less stringent minimum $CO_2$ emissions for the replacement vehicle and a more stringent age criterion for the trade-in vehicle also resulted in less favourable $CO_2$ impacts; as did the scenario that assumed a relatively high mileage rebound effect (i.e. the vehicle mileage increases due to the increased efficiency of the replacement vehicles). From the perspective of environmental performance, the results suggests that the most appropriate scheme design for a one-year scheme is one that puts stringent $CO_2$ eligibility criteria on the trade-in and the replacement vehicles and provides a high financial incentive. However, the cost-effectiveness of the scheme may be increased by limiting the financial incentive.

When taking account of costs, the cost-effectiveness of several variations as presented in Figure 6-3 are better than the baseline scrappage scheme. In order to improve the cost-effectiveness of a scrappage scheme, it appears that a focus should be the $CO_2$ stringency of the eligibility criteria of both the trade-in vehicles and the replacement vehicles. In practice, these criteria will have to be aligned with the vehicle fleet that is currently on the market (e.g. too stringent criteria on the replacement vehicle will in practice jeopardise the effect of the scheme if there is no appropriate offer of such vehicles on the market).

The figure for cost-effectiveness estimated in this study only includes the total cost of all of the incentives handed out, while the benefits considered are the reductions in $CO_2$ emissions and of air pollutant emissions. Also benefits in terms of reductions in wider environmental and safety benefits (see Section 7.2) may be expected from scrappage schemes. It is clear from Table 6-1 that there are different approaches to the estimation of costs. Estimating a wider range of costs and benefits would provide a different estimate for the cost-effectiveness of the baseline scrappage scheme considered in Sections 4-6.

As discussed in Section 6.3, for these reasons it is difficult to directly compare the cost-effectiveness estimate produced in this study with those of other studies on scrappage schemes, and with estimates of the cost-effectiveness of other measures for reducing the $CO_2$ emissions of transport. Compared to other measures for reducing $CO_2$ emissions from transport, Figure 6-5 suggests that scrappage schemes might be considered to be one of those measures that are relatively less cost-effective.

## 7.2 Wider considerations

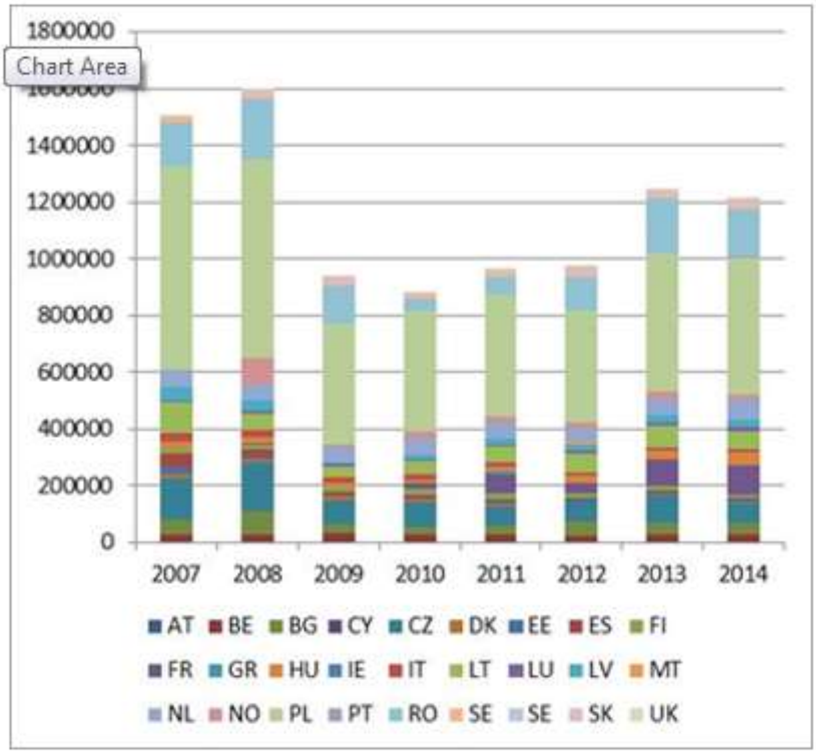
More generally, other effects were noted in the literature that are worth mentioning as part of a broader discussion of the considerations of the design and implications of scrappage schemes, but which were not possible to model in this study. For the other environmental (i.e. excluding $CO_2$ emissions) and safety considerations covered in the literature, (Wee, 2011) considered that scrappage schemes would bring noise benefits (see Section 2.4), while (ITF, 2011) and (IHS, 2010) concluded that there would be safety benefits (see Section 3.4.1). The reason for these benefits is simply that over time cars become safer and quieter, partially as a result of regulatory requirements, but also through general technological developments. However, as (IHS, 2010) also noted in relation to air pollution, the timing of the scheme can be important if such (co-)benefits are to be realised. The report estimated that, as a result of the scrappage schemes that it assessed, there would be fewer Euro V vehicles on the road in the short-term than would otherwise have been the case. This was due to the fact that the purchases that were bought forward were not yet compliant with Euro V standards, whereas a larger proportion of the vehicles on the market in the years after the scheme(s) had ended were Euro V compliant. However, the number of vehicles sold in these years was less than would otherwise have been the case as a result of the purchases brought forward by the scrappage schemes. It is not difficult to imagine similar issues arising with respect to badly timed schemes undermining potential noise or safety benefits where improvements were required by a certain date by regulation.

There are also wider potential economic considerations of scrappage schemes that are worth mentioning, although which are not straightforward to prove conclusively in practice. The first consideration is that if more money is being spent on car purchases, less is being spent on something else, whether this is in other sectors, for investment purposes or for savings. (Schweinfurth, 2009) noted that losses in the retail sector in Germany in early 2009 were blamed on the national scrappage incentive, while it had been demonstrated in the US that a scrappage scheme had diverted money to car purchases that would otherwise have been invested. The assessment of the impacts of a pan-European scrappage scheme by (JRC, 2009) concluded that while a scrappage scheme would lead to increased employment in the automotive sector, most of this benefit would be offset by employment losses in other sectors. The fact that more old cars are scrapped also has the potential to affect related sectors, as there might be fewer cars to repair, but more scrap to process. (IHS, 2010) also estimated the number of jobs in the automotive sector that scrappage schemes had saved, but focused on the short-term (only three years) and did not consider the impact on other sectors.

There is also the potential for price effects, as a result of the subsidy provided. In a paper investigating the price impacts of the German car scrappage scheme between 2007 and 2010, Kaul et al (2012) concluded that on average prices decreased for buyers that received a subsidy compared to those that did not. However, this effect was not consistent for all prices of car. They found that buyers of cheaper cars that received a subsidy paid more for their vehicles than buyers of similar cars who did not receive a subsidy, whereas for more expensive cars the situation was reversed. For example, for a car of around €32,000, a buyer with a subsidy would pay around €1,100 less than a buyer who did not receive a subsidy. In evaluating the experience with the Spanish scrappage programme of 2009/10, (Jimenez, 2011) concluded that prices of cars sold that benefited from the subsidy were increased by a similar amount. From a theoretical perspective, (Wee, 2011) suggested that prices of older cars could increase as the accelerated scrappage reduces their supply, and also that prices of younger cars could increase if they could potentially be a replacement car (depending on the design of the scheme). It is also possible that such price impacts occur in related sectors, e.g. scrap metal prices could decline as a result of the increased supply.

There is also the potential for a scrappage scheme in one country to have impacts in other countries, although again this is difficult to prove conclusively. In evaluating the various schemes that were put in place across the EU, both (Leheyda, 2013) and (IHS, 2010) conclude that the increased sales were largely met by cars manufactured in the EU, so potentially improved the position of EU-based manufacturers compared to non-EU manufacturers. Within the EU, it is also important to note that there is a large trade in second-hand cars. Evidence from a recent report (TML, 2016 (forthcoming)) shows that German used car exports declined substantially in 2009 at the time of the German scrappage scheme and by 2014 were still 25% less than 2008 levels (Figure 7-1).

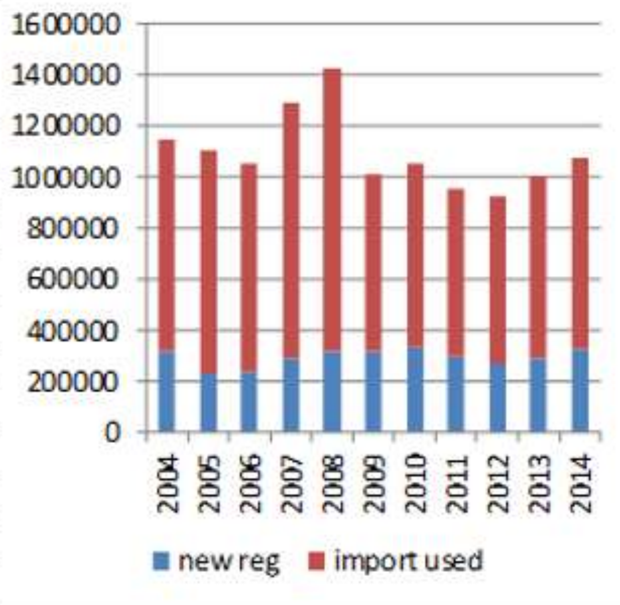
**Figure 7-1: The destination of Germany used car exports by country**




As can be seen from this figure, Poland is the destination of nearly half of German used car exports. The decline in the import of new cars from Germany in 2009, did not result in an increase in the registration of new cars in Poland (see Figure 7-2). Instead the number of cars registered per year declined. This suggests that German scrappage scheme could be contributing to a delay in the replacement of the car stock in Poland. This would mean that older, more polluting vehicles could be kept on the road for longer than they would otherwise have been. Such an effect could be a consequence of scrappage schemes in any country that has a large export market in used vehicles.

**Figure 7-2: The relative shares of new registrations and used imports of 'new' cars in Poland**

| | new reg | import used | % import/ new reg |
|---|---|---|---|
| 2004 | 318111 | 828142 | 260% |
| 2005 | 235522 | 870777 | 370% |
| 2006 | 238993 | 816789 | 342% |
| 2007 | 293305 | 994564 | 339% |
| 2008 | 320040 | 1103970 | 345% |
| 2009 | 320206 | 693324 | 217% |
| 2010 | 333490 | 718286 | 215% |
| 2011 | 297937 | 655314 | 220% |
| 2012 | 270895 | 657392 | 243% |
| 2013 | 288998 | 711865 | 246% |
| 2014 | 327709 | 748863 | 229% |



## 7.3 Concluding remarks

Modelling the environmental impact of scrappage schemes requires a range of assumptions on the development of vehicle fleets and vehicle usage behaviour with and without a scheme in place. Sensitivity analyses showed that variations in these assumptions have the potential to turn scrappage schemes from a relatively low impact and relatively costly policy measure (from a cost-effectiveness perspective in terms of costs per $tCO_2$ abated) to a relative effective policy measure. However, a number of potential negative secondary environmental effects (such as effects on the vehicle use in export markets) could not be quantitatively assessed in this project, and studies that have done so could not be identified in the literature, leading to some uncertainty in this area. Scrappage schemes also have effects on the automotive industry, and therefore on the economy of a country and its import/export countries as a whole. In addition to other potential safety benefits, such effects could not be assessed in the context of this project either, but could potentially significantly influence the overall outcome.

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# 9 Annex 1 – Cost-effectiveness estimates

**Table 9-1: External cost values assumed for co-benefits of air pollutants**

| **in EUR per t** | | |
|---|---|---|
| **NOx** | **$SO_2$** | **PM** |
| 10,640 | 10,241 | 9,604 |

*Notes*: Values assumed to be constant over assessment timeframe; no discount factor applied; *Source*: Update of the Handbook on External Costs of Transport (Ricardo-AEA, 2010)

**Table 9-2: Changes compared to the BaU scenario for all design factor / assessment parameter variations (see Section 6.1) (for assessment period 2016-2030)**

| | | Changes compared to Business as Usual (BaU) scenario (no scrappage scenario in place) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Pollutant emissions | | | Monetised pollutants | | | Cost effectiveness | |
| | **Scenario** | Incentive costs (m€) | CO2 emissions (kt) | CO2 emissions (%) | NOx (kt) | SO2 (t) | PM (kt) | NOx (m€) | SO2 (m€) | PM (m€) | w/o co-benefits | Benefit of pollutants |
| | Baseline | 2,001 | - 3,277 | -0.025% | - 6.26 | - 15.20 | - 0.43 | - 67 | - 0.16 | - 17 | 610 | 585 |
| Scheme design factor variations | (#1) Scrap scheme (instead of replace) | 2,001 | 2,171 | 0.017% | - 4.3 | 6.1 | - 0.3 | - 46 | 0.1 | - 11 | n/a | n/a |
| | (#2a) 3-year scheme (instead of 1y) | 5,992 | - 9,296 | -0.071% | - 22.4 | - 43.6 | - 1.6 | - 238 | - 0.4 | - 62 | 645 | 612 |
| | (#2b) 5-year scheme (instead of 1y) | 9,883 | - 15,315 | -0.117% | - 43.1 | - 71.6 | - 3.0 | - 458 | - 0.7 | - 119 | 645 | 608 |
| | (#3a) Trade-in vehicle eligibility: >120gCO2/km (instead of 150) | 2,736 | - 1,513 | -0.012% | - 6.1 | - 10.5 | - 0.4 | - 65 | - 0.1 | - 16 | 1,809 | 1,755 |
| | (#3B) Trade-in vehicle eligibility: >135gCO2/km (instead of 150) | 2,491 | - 2,152 | -0.016% | - 6.2 | - 12.2 | - 0.4 | - 66 | - 0.1 | - 16 | 1,157 | 1,119 |
| | (#3C) Trade-in vehicle eligibility: >165gCO2/km (instead of 150) | 1,422 | - 4,393 | -0.034% | - 6.3 | - 18.1 | - 0.5 | - 67 | - 0.2 | - 18 | 324 | 304 |
| | (#3d) Trade-in vehicle eligibility: >180gCO2/km (instead of 150) | 996 | - 4,899 | -0.037% | - 6.1 | - 19.2 | - 0.4 | - 65 | - 0.2 | - 18 | 203 | 186 |
| | (#4a) Trade-in vehicle eligibility: >9 years' old (instead of 12) | 2,662 | - 5,718 | -0.044% | - 12.4 | - 26.1 | - 0.9 | - 132 | - 0.3 | - 34 | 466 | 436 |
| | (#4b) Trade-in vehicle eligibility: >15 years' old (instead of 12) | 1,398 | - 1,717 | -0.013% | - 2.6 | - 8.0 | - 0.2 | - 27 | - 0.1 | - 7 | 814 | 794 |
| | (#5a) New vehicle eligibility: <80 gCO2/km (instead of 100) | 2,001 | - 12,058 | -0.092% | - 11.5 | - 44.8 | - 0.8 | - 123 | - 0.5 | - 32 | 166 | 153 |
| | (#5b) New vehicle eligibility: <120 gCO2/km (instead of 100) | 2,001 | 3,467 | 0.027% | - 2.2 | 7.4 | - 0.1 | - 23 | 0.1 | - 6 | n/a | n/a |
| | (#6a) Financial incentive: € 750 (instead of 1.5k) | 249 | - 817 | -0.006% | - 1.6 | - 3.8 | - 0.1 | - 17 | - 0.0 | - 4 | 305 | 279 |
| | (#6b) Financial incentive: € 3k (instead of 1.5k) | 10,009 | - 8,193 | -0.063% | - 15.6 | - 38.0 | - 1.1 | - 166 | - 0.4 | - 43 | 1,222 | 1,196 |
| Assessment variations | (#7a) Rebound mileage: 25% of max rebound (instead of 50%) | 2,001 | - 8,000 | -0.061% | - 10.1 | - 30.6 | - 0.7 | - 108 | - 0.3 | - 28 | 250 | 233 |
| | (#7b) Rebound mileage: 75% of max rebound (instead of 50%) | 2,001 | 1,456 | 0.011% | - 2.4 | 0.2 | - 0.2 | - 26 | 0.0 | - 7 | n/a | n/a |
| | (#8a) Annual mileage: uniform 10k (instead of age-based) | 2,001 | - 7,403 | -0.077% | - 9.9 | - 26.3 | - 0.6 | - 106 | - 0.3 | - 24 | 270 | 253 |
| | (#8b) Annual mileage: uniform 20k (instead of age-based) | 2,001 | - 16,997 | -0.093% | - 19.9 | - 52.7 | - 1.2 | - 212 | - 0.5 | - 48 | 118 | 102 |
| | (#9) TTW emissions: test-cycle (instead of real-world) | 2,001 | - 4,660 | -0.043% | - 6.3 | - 20.8 | - 0.4 | - 67 | - 0.2 | - 17 | 429 | 411 |
| | (#10) Considered CO2 emissions: TTW only (instead of life-cycle) | 2,001 | - 4,273 | -0.042% | - 6.3 | - 15.2 | - 0.4 | - 67 | - 0.2 | - 17 | 468 | 449 |

**Table 9-3: Changes compared to the BaU scenario for the case studies (see Section 6.2) (for assessment period 2016-2030)**

| Case studies | | Changes compared to Business as usual scenario (no scrappage scenario in place) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Incentive costs (m€) | CO2 emissions (kt) | CO2 emissions (%) | Pollutant emissions | | | Monetised pollutants | | | Cost effectiveness | |
| | | | | | NOx (kt) | SO2 (t) | PM (kt) | NOx (m€) | SO2 (m€) | PM (m€) | w/o co-benefits | Benefit of pollutants |
| Baseline | | 2,001 | - 3,277 | -0.025% | - 6.3 | - 15.2 | - 0.4 | - 67 | - 0.16 | - 17 | 610.4 | 584.8 |
| Case Study 1 | Short lax scheme | 2,662 | 3,520 | 0.027% | - 6.8 | 5.0 | - 0.5 | - 72 | 0.05 | - 19 | n/a | n/a |
| Case Study 2 | Long stringent scheme | 4,987 | - 21,899 | -0.167% | - 35.5 | - 86.3 | - 2.7 | - 378 | - 0.88 | - 106 | 227.73 | 205.6 |
| Case Study 3 | Short stringent scheme | 996 | - 4,899 | -0.037% | - 6.1 | - 19.2 | - 0.4 | - 65 | - 0.20 | - 18 | 203.33 | 186.4 |

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