Cost-benefit and break-even analysis of Xenon Headlights in Germany and in EU 27

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1. Introduction

Increasing needs for mobility and transport require action to improve road safety, a major concern for European transport policy. The European Commission published in 2001 the White Paper on Transport [EC 2001]. In this publication the political goal was set to halve the number of road deaths till 2010. Based on the EU 25 member states the goal is a maximum number of road deaths of 25,000 in 2010.

Although the development has been distinctly positive in recent years, over 40,000 people still lose their lives on European roads each year, and more than 1.5 million become injured. The costs of those damages amount to 200 billion EUR, representing about 2% of the EU Gross Domestic Product (GDP). In addition, congestion also impairs the European economy by means of time losses and higher fuel consumption.

Despite of the downward trend in the accident data the fatality reduction goal will not be reached without new strategies. Recent forecasts for 2010 expect figures of more than 30,000 fatalities [WILMINK ET AL. 2008]. Thus, additional efforts are necessary. A possible strategy to reach the goal is the development respectively the deployment of Intelligent Vehicle Safety Systems (IVSS).

It is worldwide consensus that the improvement of road safety requires a holistic approach which covers all three contributing pillars: vehicle technology, infrastructure and the human driver. On European Union level, this view is broadly adopted in the Road Safety Action Programme and the eSafety initiative, in the CARS 21 process and the ITS Action Plan.

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In the past years the focus within the vehicle technology area was clearly on systems to improve the controllability of the vehicle (i.e. Electronic Stability Control [ESC]) and assisting drivers to perform the driving tasks properly. Many of the IVSS show significant potential to save lives and reduce the severity of injuries. This potential is also reflected in positive (above 1) benefit-cost ratios (BCR), i.e. where the benefits on society level outweigh the costs of the systems. The eIMPACT project (FP 6 project, finished in 2008) has performed cost-benefit analyses for twelve IVSS, including Electronic Stability Control, Full Speed Range ACC, Emergency Braking, Lane Keeping Support, Night Vision Warn, Wireless Local Danger Warning, eCall and Speed Alert. The majority of the systems are distinctly profitable from the society point of view with benefit-cost ratios up to 4.

On the other hand, most of the systems – except ESC – are not yet widely deployed on European level. The reasons for the slow market take-up involve the lack of user awareness and understanding of the IVSS capabilities, the stakeholder mismatch between beneficiaries and cost bearers because of external effects, the network externalities for co-operative systems, the cost reduction potential in mass production which cannot be realised at the existing equipment rates as well as legal and liability issues. This environment makes the IVSS deployment a complicated case for public-private partnership.

The difficult market environment draws the attention towards other mature live-saving technologies which are already used in the market for quite a bit of time although market penetration in most European markets leaves much room for improvement. Xenon headlights represent such a candidate. Introduced more than a decade ago, the Xenon take rates in new passenger cars are currently about 25% in Germany – which represents the pioneering market for Xenon – and 5-10% in other European member states. Xenon headlights promise important safety benefits because they improve the visibility in situations with limited sight (twilight and darkness).

Objective of the study is to determine the costs and benefits of using Xenon headlights in road traffic. This study analyses the safety and traffic effects of Xenon for EU 27 and Germany. These effects are monetised. This reflects the socio-economic benefit of Xenon. Afterwards, the consumption of resources is calculated which is linked to the usage of Xenon. On the basis of these two figures, an assessment of the socio-economic and on the user profitability can be performed.

The report is organised as follows. In chapter 2 Xenon is briefly introduced. Chapter 3 handles the data which is relevant for the Xenon socio-economic assessment. In chapter 4 the effectiveness of Xenon is covered. The used methodology for socio-economic impact assessment is handled in chapter 5. It is then executed in chapter 6 on societal level. Whereas chapter 7 contains the break-even analysis, the results of this study are discussed in chapter 8.

2. Xenon

Similar to inappropriate speed and bad technical vehicle conditions (tyres, brakes) bad visual conditions represent an important risk factor for road safety. This was recently proven by a study which investigated the Xenon safety effects [SCHÄBE 2007]: the risk of being involved in a severe accident is higher for bad visual conditions.

Most vehicles are still equipped with halogen light systems. In 1991, a new light system has introduced on the market, the Xenon light system. Its light is brighter than the one of the halogen lamps (see also Figure 1).

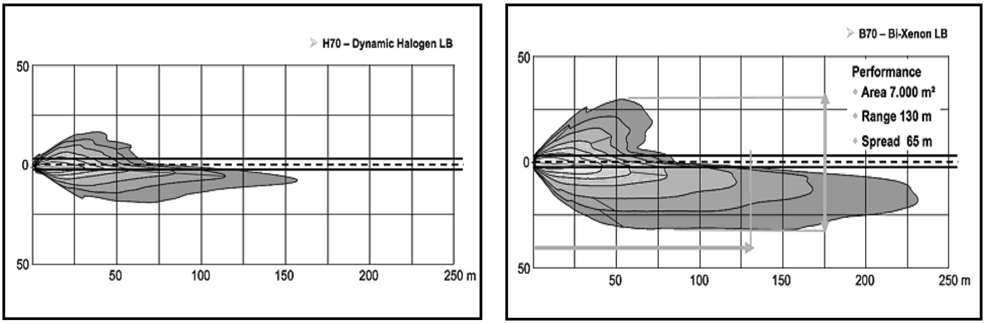

Figure 1: Halogen versus Xenon lamps [Clepa 2007]

It can be seen that the road is better illuminated. Further, the areas beside the road are also better illuminated. Other traffic participants as pedestrians or non-illuminated cyclists can be better and – more important – earlier seen by the vehicle driver. Due to the better lighting the driver has more time to react and thus the risk of getting in a critical situation is lower.

Besides the safety benefits of Xenon, Xenon has also environmental benefits. Xenon lamps have less consumption of electricity. This leads to a reduction of fuel and thus to less CO_2 emissions. Another advantage is the longer service life time of a Xenon lamp in comparison to the halogen lamp.

Xenon is also a comfort system. It illuminates the road and the areas beside better. This leads to a more comfortable driving. In addition, a Xenon system includes a headlight cleaning system which is activated if the driver switches on the windscreen cleaning system. Another feature of Xenon is the headlight range adjustment. Both components guarantee a constant illumination on a high level and they are reducing the risk of glaring another traffic participant.

The trend goes to advanced Xenon systems with different lighting modes (e.g. for curves, for urban areas or for motorways). Linked with LED back lights the electricity consumption can be reduced further.

3. Data

Before a cost-benefit analysis can be performed the data needs have to be specified. Xenon avoids accidents, thus, the traffic data is important. In chapter 3.1 the traffic data is developed for the target year. Chapter 3.2 handles the accident data, the full version in the calculation can be found in Annex 2 of the study. Chapter 3.3 covers the equipment rates of Xenon. Further, Xenon has traffic impacts. This is handled in 3.4. In the last chapter the cost-unit rates which are used are introduced.

The cost-benefit analysis is performed for the year 2010 for Germany and for EU 27.

The study makes use of the methodology of the eIMPACT project. The advantage of this approach is that the results are comparable to the ones from the eIMPACT project. The difference to the eIMPACT project is that the two new EU member states, Bulgaria and Romania, are also considered. Both states are now members of the eIMPACT cluster 3. Thus, the data base used is the one of eIMPACT plus Bulgaria and Romania.

3.1 Traffic data

Out of the traffic data the vehicle stock and the vehicle service lifetime is relevant. Both figures are determining the socio-economical costs. The benefits are linked with the vehicle mileage due to a linkage between mileage and accidents. Thus, the vehicle mileage is the last figure which is handled in this chapter.

3.1.1 Vehicle stock

In Germany about 51.5 mill. vehicles are registered in 2010. In the complete EU the vehicle stock is 282 mill. vehicles. The share of passenger vehicles is about 94 % (48.3 mill. vehicles) in Germany and 86.3 % (243.4 mill. vehicles) in EU 27 [PROGTRANS 2007].

	Germany		EU 27	
passenger cars	48,342.6	93.9%	243,361.3	86.3%
good vehicles	3,042.1	5.9%	37,761.7	13.4%
busses	82.6	0.2%	838.7	0.3%
total	51,467.3	100.0%	281,961.7	100.0%

Table 1: Vehicle stock (in 1,000) in Germany and in EU 27 in 2010

3.1.2 Vehicle service time

The vehicle service time is considered as 12 years [Baum et al. 2008].

3.1.3 Vehicle mileage

The vehicle mileage is relevant for determining the accident data and the traffic data. In the year 2010 the vehicle mileage is estimated as 678.3 billion vehicle-km for Germany and as 3.506.1 bill. vehicle-km for EU 27 [PROGTRANS 2007].

	Germany		EU 27	
passenger cars	593.8	87.5%	2,889.3	82.4%
good vehicles	81.1	12.0%	587.8	16.8%
busses	3.4	0.5%	29.0	0.8%
total	678.3	100.0%	3,506.1	100.0%

Table 2: Vehicle mileage (in bill. veh-km) for Germany and EU 27 for 2010

A passenger vehicle has an annual mileage of 11,872 km (2,889 bn. Veh.-km / 243 million vehicles) in EU 27 and of 12,283 km in Germany.

3.2 Accident data

The accident data is relevant for calculating the number of fatalities, injuries and accidents which can be avoided due to Xenon. These numbers have to be evaluated monetarily to determine the socio-economical benefits.

The accident data for Germany and for EU 25 is taken from the eIMPACT project. This data base has to be enlarged by the data for Bulgaria and for Romania. Both countries are considered to be member of the eIMPACT cluster 3 (New EU 10 + Greece + Portugal). Cluster 3 contains EU member states with high accident risk. The accident data is considered to be dependent of the vehicle mileage [Wilmink et al. 2008]. Thus, the increase of the vehicle mileage in cluster 3 due to the inclusion of Bulgaria and Romania is used to scale up the accident data in cluster 3. The scaling up factor is 115.9 % (see Table 3).

	passenger cars	trucks	busses	total
cluster 3	388.0	103.3	6.5	497.8
Romania	38.5	15.7	0.3	54.5
Bulgaria	22.7	1.6	0.4	24.7
sum	449.2	120.6	7.2	577.0
sum/cluster 3	115.8%	116.8%	112.4%	115.9%

Table 3: Up scaling factor for the accident data of cluster 3

Afterwards the adjusted accident data of cluster 3 is added to the accident data of cluster 1 and 2. The accident data in eIMPACT contains accidents due to passenger cars, goods vehicles and busses (“relevant accidents”). In addition the accidents due to other traffic participants are also in the total accident numbers. In eIMPACT the total number of accidents and casualties is given for accidents, fatalities and injuries. The relevant number of accidents is also given for severe and slight injuries. The number of relevant accident types (accidents, fatalities etc.) is divided by the total number of accident types (see Table 4)

	injury accidents	fatalities	injuries
relevant accidents (EU 25)	945,191	30,536	1,250,050
all accidents (EU 25)	1,057,033	33,895	1,409,415
all accidents / relevant	111.8%	111.0%	112.7%

Table 4: Percentage all accidents / relevant accidents in EU 25

It is assumed that the percentage for injuries (112.7 %) is also valid for severe and for slight injuries. The percentages are then multiplied with the relevant accident dates for EU 27. Thus, the percentages of traffic accidents due to at least four-wheelers are determined. Afterwards the accident data are scaled up to get the overall accident data which is displayed in Table 5.

	injury Accidents	fatalities	injuries	of which seriously inj	slightly inj
relevant	965,661	32,001	1,276,624	242,673	1,033,951
percentage	111.8%	111.0%	112.7%	112.7%	112.7%
result EU 27	**1,079,926**	**35,521**	**1,439,377**	**273,611**	**1,165,766**

Table 5: Accident data for EU 27 in the year 2010

Germany is included in the eIMPACT cluster 1. To determine the German accident data for 2010, the share of Germany within cluster 1 is taken from the year 2005. This share is then multiplied with the accident data from cluster 1 for 2010. The results are displayed in Table 6.

Table 6: Accident data for Germany in the year 2010

Injury Accidents	Fatalities	Injuries	of which seriously inj	slightly inj
282,367	4,919	365,275	66,633	298,982

3.2.1 Number of fatalities

Xenon avoids accidents on rural roads and motorways. In 2010, the number of fatalities in twilight or darkness is estimated as 779 (thereof 541 in passenger cars) on motorways and as 6,313 (thereof 5,596 in passenger cars) on rural roads [WILMINK ET AL. 2008, own calculation].

The share of accidents and casualties by twilight or darkness is calculated for Germany for 2005 [Destatis 2006] and for cluster 1 for 2005 and for 2010. Afterwards the ratio between the German shares and the shares of cluster 1 is determined for 2005. These factors (for each accident group one) is multiplied with the share of cluster 1 in 2010. The result is the share for Germany in 2010. This share is multiplied with the accident base (Table 6).

The number of fatalities in Germany in twilight or darkness is 884 on rural roads and 188 on motorways.

3.2.2 Number of injuries

The number of severe injuries in twilight respectively in darkness is 3,720 on motorways and 27,465 on rural roads in EU 27.

The values for slight injuries are 12,790 on motorways and 73,241 on rural roads in EU 27.

The number of injuries for Germany is calculated as described for the number of fatalities. 921 serious injuries are due to accidents of passenger cars on motorways and 197 are due to accidents of passenger cars and goods vehicles. The accordant numbers for rural roads are 6,509 and 208.

The numbers of slight injuries in 2010 in Germany are 3,504 due to passenger car accidents on motorways, 619 due to passenger car and goods vehicle accidents on motorways, 18,379 due to passenger cars accidents on rural roads and 562 due to passenger car and goods vehicle on rural roads.

3.2.3 Number of accidents with personal damages

The numbers of accidents with personal damages are 11,653 on motorways (9,294 due to passenger cars accidents and 1,503 due to passenger car and goods vehicle accidents) and 68,671 on rural roads (64,439 respectively 2,639) in EU 27.

The accordant values for Germany are on motorways 3,200 due to passenger car accidents and 642 due to passenger car and goods vehicle accidents. On rural roads the numbers are 20,640 respectively 650.

3.3 Equipment rates of Xenon

Xenon was introduced into the market in 1991 in the BMW 7 series. In 2001 the function of Xenon was enlarged by introducing the Bi-Xenon light system [Jebas et al. 2008]. In 2007 the penetration rate of the fleet is 13.5 % in Germany and 6.04 % in EU 27. The values for 2010 are estimated as 16.25 % for Germany and as 7.45 % for EU 27 [Light.Sight.Safety 2008].

3.4 Cost-unit rates

The cost-unit rates for the cost-benefit analysis (Table 7) are based on the eIMPACT project.

Cost-unit rates	[Euro]	[unit]
fatality	1,282,302.00	per casualty
severe injury	178,859.32	per casualty
slight injury	28,944.90	per casualty
diesel / petrol	350.00	per t
CO_2	71.40	per t

Table 7: Cost-unit rates

For the break-even analysis the end-market prices including VAT are used – or if not available – the cost-unit rates are approximated by the willingness-to-pay approach.

The use of Xenon reduces the fuel consumption. For the break-even analysis the end market price of fuel is used. It is estimated that the prices for one litre benzine and diesel is increasing in the next years. Further it is assumed that the price for benzine and diesel are equal. For the year 2010 a market price of 1,50 Euro per litre fuel (benzine or diesel) is estimated.

Linked to the reduction of fuel is less carbon dioxide exhaust. This issue would be considered if there are any monetary advantages to the end user. But at the moment the monetary advantage is already included in the fuel price. Thus, the CO2 advantage is not considered.

The last benefit channel of Xenon is a longer service time of the lamps. The lifetime of a Xenon lamp is comparable with the service time of the vehicle (12 years), the lifetime of a halogen lamp is 1.75 years on average [BAUM ET AL. 2009]. Changing a halogen lamp in the garage costs about 50 Euro [ANMB 2004, own calculation]. This value is considered as being valid also in 2010.

The last relevant cost-related information is the estimated end market price of a Xenon system for 2010. This price is estimated as 898 Euro [CLEPA 2009]. It is assumed further that the end user finances Xenon with a deferred payment credit. So, the end user has to pay each year the same amount during the complete service time of his car (12 years). The discount rate is considered as 8 %. So the share the end user has to pay per year equals 13.27 % (see below). The end user has hence to pay 119.16 Euro per year for equipping his vehicle with Xenon.

$$AR = \frac{d * (1+d)^n}{(1+d)^n - 1} = \frac{0.08 * 1.08^{12}}{1.08^{12} - 1} = 0.1327$$

AR annuity rate,
d discount rate and
n vehicle service time.

4. Effectiveness of Xenon

This chapter handles in its first part the safety impacts and then the traffic impacts. In the last part the lifetime is covered. This is due to the fact that Xenon lamps are maintenance free while the halogen lamps need a replacement after a few years.

4.1 Safety impacts

In 2007 the TÜV Rheinland published a study concerning the safety benefit of Xenon [SCHÄBE 2007]. Xenon has no effects on urban roads. On rural roads and on motorways Xenon can avoid night accidents respectively accidents in twilight. The full potential of Xenon for passenger cars is an avoidance of 60 % of all accidents on rural roads in twilight or darkness.

The second effect is on motorways. Here, the share of accidents in darkness to accidents at day is decreasing significantly but not as strong as for rural roads. The difference is measured for the cases low penetration and high penetration (0.0804). This difference is compared with the difference for rural roads (0.111). Out of both values the share motorways over rural roads is determined (0.0804/0.111). This share is 73 %. It is assumed that the effectiveness on motorways is the product of the mentioned share and the effectiveness on rural rods. Under this assumption, the effectiveness is 44 % (73 % * 60 %).

The effect for goods vehicles was not calculated. It is assumed that this effect is much lower than for passenger cars. Accidents between passenger cars and goods vehicles are assumed to be avoided with the halve effectiveness rate. Thus, the effectiveness for accidents between passenger cars and goods vehicles is assumed as 30 % on rural roads and as 22 % on motorways.

	passenger vehicles	pass. veh. vs. goods veh.	goods vehicles
urban roads	0%	0%	0%
motorways	44%	22%	0%
rural roads	60%	30%	0%

Table 8: Effectiveness rates for avoiding accidents

For the end-user the monetary benefit per 1,000 km can be computed. If every passenger vehicle would be equipped with Xenon in 2010, about 46,756 accidents with 3,970 fatalities, 18,187 severe injuries and 50,344 slight injuries could be avoided in EU 27. In Germany the values are 16,152 accidents with 521 fatalities, 5,050 severe injuries and 14,706 slight injuries.

These safety benefits are divided by the total vehicle mileage for EU 27 and Germany. The result is the reduced risk per driven km. This value is then multiplied with the accordant cost-unit rate from chapter 3.4. The result is the monetary benefit per driven km. Because this value is very low, the result is expressed in Euro / 1,000 km. For the EU 27 the benefit is 4.51 Euro per 1,000 km and for Germany the benefit is 4.52 Euro per 1,000 km.

		EU 27	Germany
Fatalities	[Euro / 1,000 km]	2.26	1.44
Severe injuries	[Euro / 1,000 km]	1.75	2.37
Slight injuries	[Euro / 1,000 km]	0.50	0.71
Benefit	**[Euro / 1,000 km]**	**4.51**	**4.52**

Table 9: Monetary benefit per 1,000 km: safety

4.2 Traffic impacts

Xenon lamps have a reduced power consumption in comparison with standard halogen lamps. This leads to lower fuel consumption. About 0.03 l fuel per 100 km driving with lights can be saved (low beam). The usage of high beam provides further fuel saving potential. The difference in power consumption for Xenon low beams is 30 W, for Xenon high beams even 130 W. Given a total mileage of 150,000 km per vehicle, the high beams are working 75 hours, the low beams 1,380 hours [DECKER 1999]. Thus, further 23.6 % can be saved (75/1,380*130/30). Overall, about 0.037 l fuel per 100 km driving with lights can be saved [DECKER / KLEINKES 2009].

Linked to the reduction of 0.37 l fuel is a reduction of 0.925 kg CO2 per 1,000 km driving with lights. A litre diesel emits 2.65 kg $CO_{2,}$ a litre benzine emits 2.36 kg CO2.

29.2 % of the mileage is driven with lights in Germany [SCHÖNEBECK ET AL. 2005]. It is assumed that this value is also valid for EU 27.

Given an annual mileage of 12,000 km, a passenger car reduces its fuel consumption by 1.3 l (0.037*120*0.292) and it reduces its CO2 emission by 3.3 kg.

For the end-user it is interesting how many money he can save while driving 1,000 km with Xenon. Given a fuel price of 1.50 Euro per litre, the end-user saves 0.14 Euro by driving 1,000 km with Xenon.

4.3 Lifetime in comparison to a H7 halogen lamp

The lifetime of a Xenon lamp is as long as the service time of a vehicle [Mihatsch et. al. 2005]. In contrast, the service time of a H7 halogen lamp is shorter. Thus, the driver whose vehicle is equipped with Xenon light system will never change a lamp in general. Linked to this he saves time and money.

The lifetime of a lamp is determined by a Weibull distribution. Given the Weibull distribution, a H7 halogen lamp has a lifetime between 4 and 5 years [MIHATSCH ET AL. 2005] which leads to a mean of 4.5 years. Hella estimates the service time of a H7 halogen lamp as between 250 and 300 hours [HELLA W.Y.]. Given the fact that per 150,000 driven km the light is switched on for 1,380 hours, the service time is between 2.3 and 2.7 years which leads to a mean of 2.5 years. Given an annual mileage of 12,000 km, 150,000 km are linked with 12.5 years (150,000 km / 12,000 km). The service time can be determined by dividing 12.5 years by 1,380 hours and multiplying this division with 250 hours respectively 300 hours. Thus, it is considered, that the service time is the mean of the stated value out of the literature (4.5 years) and the calculated value (2.5 years): 3.5 years.

The costs for replacements are estimated between 31 Euro and 52 Euro depending on the vehicle class. The average cost for a single H7 halogen lamp is estimated as 31 Euro [MIHATSCH ET AL. 2005]. Together with additional labour costs the replacement costs are estimated as 37 Euro.

Thus, during a service lifetime of 12 years 6.9 lamp replacements are average (12/3.5*2). Each produces costs in amount of 37 Euro.

For the break-even analysis the benefit per 1,000 km is calculated. As calculated, 6.9 lamp replacements are estimated for a service life time of 12 years on average. The service life time on average is 12 years for EU 27 and Germany. During these 12 years, the mileage on average is 142 thousand km in EU 27 and 147 thousand in Germany. Each lamp replacement in a garage costs 50 Euro. Thus, within the complete lifetime lamp replacement costs of 345 Euro (50 Euro * 6.9) accrue. Given the total mileage for a service life time of 12 years, the costs per 1,000 km are 2.42 Euro for EU 27 (345/142) and 2.34 Euro for Germany.

5. Cost-Benefit-Methodology

Economic theory provides several methodologies for assessing and quantifying the specific values of (potential) socio-economic impacts. Besides the cost-effectiveness analysis (CEA), the cost-benefit analysis (CBA) is broadly-accepted as a sophisticated, objective evaluation instrument. In general, the CBA compares the potential economic benefits across a set of impacts with all relevant potential costs deriving from the implementation of a technology/measure. Since the CBA estimates benefits and costs in monetary terms by multiplying impact units by prices per unit, it can be used to assess the absolute efficiency of a technology/measure. Hence, the CBA aims at finding whether a proposed objective is economically efficient and how efficient it is. As a result of the analysis a quantitative relationship between benefits and costs is calculated. Although there are a number of indicators expressing the comparison between benefits and costs the most common is the benefit-cost-ratio.

The economic CBA originates from welfare economics. The increase of the overall economic production potential is used as a standard for evaluating a technology/measure ("resource-oriented approach”). The costs of the regarded measure are confronted with this overall economic effect. The benefits are defined in terms of productive re-sources saved within an economy (“cost-savings approach“). Given this definition, the implementation and deployment of technologies/measures should demonstrate profitability, which at least means in economic terms allocative efficiency.

In theory, the principle of allocative efficiency is determined by the situation that by introducing any kind of technology/measure at least one individual is made better off and no individual is made worse off (Pareto optimum). Since the consequent application of this criterion is impractical due to the impossibility of identifying all winners and losers, a potential Pareto optimum – the Kaldor-Hicks criterion – is generally applied. This criterion considers a measure as acceptable if the amount by which some individuals gain is greater than the amount that others lose for suffering higher costs. Hence, it is important to reach a net-benefit which allows – in principle – losers to be compensated by winners of the measure. No actual cash transfer is required. A measure may therefore be considered efficient even if some individuals lose, as long it generates net benefits [BOARDMAN ET AL. 1996]. Consequently, social welfare may be enhanced by the reallocation of resources within society.

The Kaldor-Hicks criterion is commonly accepted and widely applied in welfare economics as well as in managerial economics. The criterion forms an underlying rationale for the cost-benefit analysis.

In the assessment of economic efficiency of road safety technologies/measures the evaluation of accident savings plays an important role, because these technologies/measures specifically aim to reduce the number and severity of current accidents. Avoiding accidents and achieving mitigation represent the direct benefits of road safety technologies/measures. In addition, the benefits encompass other savings of resources used within an economy, which also have to be taken into account. Due to avoided accidents the congestion is reduced. Linked to this issue there is a change in fuel consumption, emission exhausts and pollution.

5.1 Cost-benefit analysis process

In general the CBA consists of a four step process. These four basic steps can be characterised as follows:

In the first step of the procedure the relevant alternatives that will be compared within the analysis have to be defined. For the CBA two cases are introduced:

- The “with-case“, which means that a road safety technology/measure like Xenon will be introduced.
- The “without-case“, which assumes that there will be no implementation of the technology/measure to be evaluated.

Within the second step the potential safety impact has to be quantified. Conceptually, the main effect of road safety technologies/measures is the reduction of hazardous situations which affects the number and/or the severity of accidents. As a consequence, accident costs can be lowered.

Within the third step of the CBA process, the benefits are calculated in monetary terms by valuing the annual physical effects with standardised cost-unit rates. In addition to the monetarization of the physical benefits, the costs of the technology/measure have to be determined. The costs comprise the costs to be borne for implementation, operation and maintenance.

The result of the economic evaluation is obtained in the fourth step by comparing economic benefits with costs. For this comparison several measures can be calculated.

5.1.1 Benefit-cost-ratio (BCR)

The most common one is the benefit-cost-ratio (BCR) according to which a technology/measure is macro-economically profitable, if the calculated ratio is greater than one.

$$BCR = \frac{B_t}{C_t}, \text{ with}$$

BCR	Benefit-cost ratio,
t	Time horizon defined,
B	Estimated value of benefits for t and
C	Estimated value of costs for the year t.

The value of the ratio indicates whether the implementation of Xenon is favourable from a socio-economic point of view. A BCR of more than “1“ indicates that benefits exceed the costs. Thus, the introduction of Xenon would be beneficial to society. Furthermore, the value of the BCR expresses the absolute profitability of Xenon which can be interpreted as the socio-economic return for every monetary unit (e.g. Euro) invested in the implementation of Xenon. For example, a BCR of “3.5” would show that 3.5 monetary units can be gained for society for every monetary unit provided for the investment evaluated. Setting absolute, monetised values of benefits and costs into relation, the BCR is a reliable indicator of efficient resource allocation.

The results of the CBA for Xenon in terms of the BCR are most important for every kind of decision-maker interested in the evaluation of Xenon before deciding on market introduction, deployment or promotion of the safety systems. Thus, the results should be presented in a way that is both comprehensive and coherent. As a consequence, ranges of BCR are given which illustrate the variance of evaluation results. In this context, classes for CBA results are introduced to expose a grading of the results. The following classes are used in the table (BAUM ET AL. 2007):

- 0 < BCR < 1: The BCR is rated “poor” showing that a socio-economic inefficiency of Xenon is given,
- BCR < 3: The BCR is rated “acceptable” meaning that the social benefits associated with the implementation of a safety system exceed the costs up to three-times which can be labelled as an acceptable absolute efficiency,
- BCR ≥ 3: The BCR is higher than “3” indicating an “excellent” result of the socio-economic assessment. The system evaluated as “excellent” should be in first line for market deployment.

5.1.2 Internal Rate of Return (IRR)

Another figure which can be computed in the cost-benefit analysis is the internal rate of return (IRR). The IRR is comparable with the return of an investment. The result of the IRR is an interest loan. The higher the interest loan the better is the project.

The advantage of the IRR concept in comparison to the BCR is the independency of the discount rate. The BCR needs a discount rate. The height of the discount rate is often matter of discussion. Thus, in the most CBA the discount rate is changed in the sensitivity analysis. This step is not necessary in the IRR approach. In the IRR approach the result is one interest rate which has to be compared with an external given discount rate by the principal.

The disadvantage of the IRR concept is that there is no biunique result for the case that the algebraic sign of the net benefits is changing more than one time. In this study this is not the case, because the CBA is only a snapshot analysis.

The IRR can be determined by reorganising the formula for the BCR:

$$BCR = \frac{B_t}{C_t} = \frac{B}{C * AR(d,t)}\text{, with}$$

AR	annuity rate,
d	discount rate and
t	service lifetime.

The IRR is the special discount rate for which the BCR is 1. Thus, the formula has to be solved for the discount rate. There is no analytical solution for this. An iterative procedure has to be started. Thus, it is more pragmatically to solve this formula for the annuity rate and to compare the result with annuity rates and the accordant IRR.

The formula is as follows:

$$AR(IRR, t) = \frac{B}{C}$$

5.1.3 Monetary assessment

In the cost-benefit analysis the costs and the benefits have to be determined. While the calculation of the physical benefits of Xenon on basis of accident statistics and accident research is rather straightforward, the monetary valuation of accidents – that means the monetary valuation of injuries and human life – is a controversial matter. In this study the cost-of-damage approach in connection with the cost-of-avoidance approach is used to assess the value of the resource savings for the benefit categories.

The cost-of-damage approach is state of the art for cost-benefit analyses which are performed for the EU. The cost-of-damage approach is based on the total estimated amount of economic losses caused by any physical impact. Generally, the losses are quantified via the decline of gross product. For instance, the costs of an accident include the vehicle damage, medical and emergency costs and lost productivity of killed or disabled persons.

There are different benefits due to accident savings which have to be assessed:

- Benefits due to the safety potential: The accident is avoided respectively the severity class of the accident is reduced. Thus, the number of casualties and the property damage can be reduced.
- Benefits due to avoided congestion: An accident implies congestion. If the accident is avoided or the severity class of the accident is reduced, there is no congestion respectively there are less time losses for the other traffic participants.
- Benefits due to less fuel consumption in linked to that less emission output (pollutants and carbon dioxide): Linked to the point mentioned above there is less congestion. The fuel consumption and linked to this the emission is very high in congestion. If there is less congestion the fuel consumption and the emissions can be reduced.
- Benefits due to the longer service time of Xenon lamps in comparison to halogen lamps. A Xenon lamp has a service time which is comparable with the service time of a passenger vehicle while a halogen lamp has only a service time of 3.5 years on average.

In this study the first and the last mentioned points are the most important ones. Due to the use of Xenon accidents can be avoided. Thus, a congestion which is linked to an accident will also be avoided. For these congestions the costs are a part of the cost-unit rates for casualties. Xenon does not influence the traffic flow. Hence, there is no additional potential in saving fuel or in saving emission outcast respectively pollution besides the savings which are due to the avoided accident and due to lower electricity consumption. Thus, the only relevant benefit channels are the safety effects and the longer service time of a Xenon lamp compared to a halogen lamp.

5.2 Scenario analysis

The break even analysis is a method of business administration used to determine from which production output an investment is getting profitable for the producer. Therefore, benefits and costs in dependence of output are put in contrast. Then the extent of output is being investigated which just brings benefits to the same level as costs. So the point is being determined where neither profits nor losses occur (=break-even point). With lower output, costs are higher than benefits (=losses), with higher output, benefits are higher than costs (=profits).

The break even analysis is used in order to determine the benefits on user level and end consumer prices and to clarify if Xenon is profitable for users and OEMs. Benefits and end consumer prices are being examined in dependence of the covered passenger vehicle mileage per year. It is assumed that benefits and end consumer prices are linear to the mileage. A low mileage means relatively high fixed end consumer prices and little benefit for Xenon, so that a loss occurs. A high mileage results in high benefits and low end consumer prices which is followed by a profit. In the break-even point, benefits equal end consumer prices.

The private-individual benefits of the user accrue from the following cost savings:

- savings regarding avoided accident costs which are not covered by insurances,
- savings through a reduced fuel consumption,
- savings through the longer service life time of Xenon lamps compared to halogen lamps, and
- benefits of comfort for users.

In contrast to that, there are the investment costs for Xenon on user level to be seen.

The benefit and cost components used in the break even analysis are partly also present in the cost-benefit analysis. The difference is that in the cost-benefit analysis only the actual benefits and costs are included, while the break-even analysis considers the effective monetary savings and expenditures. This means in particular that in the break-even analysis the flows of benefits and costs including taxes (value added tax) are calculated, while in the cost-benefit analysis taxes are treated as transfer payments and do not contribute to the parameters.

The result is expressed as passenger vehicle kilometres for which the costs are equal to the benefits. The cost-unit rates for the assessment of avoiding an accident are found with the willingness-to-pay approach. With this approach the calculation is based on an individual level. The value of the own life is individual for every person. The average value is higher than for the cost-of-damage approach which considers the economical losses. The willingness-to-pay approach displays a value on average which is generally accepted by the users. The Xenon system is financed by credit taking (discount rate: 8 %).

Furthermore, the break-even analysis provides information about the willingness-to-pay of Xenon-users. The willingness-to-pay is limited by the prices for Xenon charged by passenger vehicle manufacturers which may not be higher than the benefits for the users. A surcharge on benefits via benefits of comfort is allowed. In this study the comfort issue is not considered. In this respect, the price limit for Xenon is defined by the break even analysis.

The break-even analysis is done for two approaches. In the first one, the fair end market price is calculated for an average driver. This driver has an average mileage of 11,872 km per year for EU 27 and of 12,283 km per year for Germany. This approach is called: fair market price. In the second approach the end market price is given. In this approach, the annual mileage is calculated, from which on Xenon is worthwhile for the user. This approach is called: critical mileage from which on Xenon is worthwhile.

6. Cost-Benefit Analysis

In this chapter the cost-benefit analysis of Xenon for EU 27 is performed. In the first subchapter the assumptions for the analysis are introduced. In 6.2 the socio-economical benefits of Xenon are determined; in 6.3 the accordant consumption of resources is calculated. Afterwards the benefit-cost ratio and the IRR are computed. In 6.6 the scenario analysis is performed.

6.1 Assumptions

The regional focus of this study is Germany and EU 27. Xenon was introduced in the European automobile market in 1991. The year for which the cost-benefit analysis is performed is 2010.

For determining the safety benefits the accident data is relevant. This is based on the project eIMPACT. These numbers have to be combined with the effectiveness rates of Xenon. Afterwards they have to be multiplied with the accordant cost-unit rates from Table 10.

Cost-unit rates	[Euro]	[unit]
fatality	1,282,302.00	per casualty
severe injury	178,859.32	per casualty
slight injury	28,944.90	per casualty
diesel / petrol	350.00	per t
CO_2	71.40	per t

Table 10: Cost-unit rates

The traffic data which is necessary for calculating the costs are the vehicle stock and the vehicle service time. These numbers have to be combined with the system costs of Xenon and with the annuity rate.

The accident and the traffic data is displayed in Table 11.

	accidents	fatalities	severe injuries	slight injuries	pen. rate	share of mil.
EU 27	1,079,926	35,521	273,611	1,165,766	6.04%	7.45%
Germany	282,367	4,919	66,633	298,982	8.29%	21.71%

Table 11: Accident and traffic data for the year 2010

For performing the cost-benefit analysis the discount rate has to be set. In the EU a discount rate of 3 % is state of the art. The vehicle service time of a passenger is about 12 years. Thus, the annuity rate can be calculated as follows:

$$AR = \frac{d*(1+d)^n}{(1+d)^n - 1} = \frac{0.03 * 1.03^{12}}{1.03^{12} - 1} = 0.1046 \text{ , with}$$

AR	annuity rate,
d	discount rate and
n	vehicle service time.

Table 12 displays the effectiveness rates of Xenon for avoiding traffic accidents, fatalities and injuries. These effectiveness rates have to be multiplied with the share of driven mileage. In the year 2010, this share is estimated as 10.7 % for EU 27 and as 21.7 % for Germany.

	passenger vehicles	pass. veh. vs. goods veh.	goods vehicles
urban roads	0%	0%	0%
motorways	44%	22%	0%
rural roads	60%	30%	0%

Table 12: Effectiveness rates of Xenon

6.2 Benefits

The benefit of Xenon is the avoiding potential of accidents. Due to avoiding an accident, the accordant congestion can be also avoided. Xenon will not influence the traffic flow because it works most efficiently in situations without traffic. Nevertheless, Xenon influences the fuel consumption and the emission of carbon dioxide or other pollutants in a positive way because the Xenon lamps consume less power compared to halogen lamps. In addition, Xenon profits from the longer service time of Xenon lamps compared to halogen lamps and thus Xenon leads to lower operation costs.

The safety benefit can be determined by multiplying the estimated accident data with the estimated share of mileage driven with Xenon and the effectiveness rate of Xenon. Furthermore, it has to be considered that Xenon is available on the market since 1991 in the EU. Thus, Xenon had already an influence on the accident base which was used for the estimation. This influence has to be considered when the benefits are determined.

Therefore, a correction term has to be introduced. It is considered, that the realised benefits of Xenon are dependent of the share of driven mileage with the system. Xenon was introduced on the market in 1991. Hence, since 1991 Xenon avoids accidents. These avoiding potential was realised already. Thus, the accident base for the case that Xenon would never have been introduced on the market, would be higher.

The estimated accident base is valid for the estimated penetration rate of Xenon which is linked with the share of mileage. This is due to the fact, that the penetration rate of Xenon is estimated by using market data. This means, that the estimated penetration rate of Xenon is the same as the one which stands behind the estimated accident data.

Due to the circumstance that a system is assessed which is already available on the market, the number of accidents which will have been avoided for the considered year is calculated and not the number of accidents which can be avoided. This means, that the used accident base contains the number of avoided accidents already. Thus, if Xenon avoids 35 % of all accidents by the given share of mileage, the number of avoided accidents is not the product of 35 % and the accident base. It is the difference between the quotient accident base over (100 % - 35 %) and the accident base.

As a formula the adjusted accident base can be determined as follows:

$$adjusted\ base_m = \frac{base_m}{(1 - effe_m * share\ of\ mileage}\text{, with}$$

m	mode {accidents, fatalities, injuries}
base	accident base
effe	effectiveness rate.

The quotient displays the accident base for the case that Xenon has never been introduced on the market. The base is the number of accidents which are estimated for the case that Xenon is available on the market and that the penetration rate of Xenon follows the recent trend. Using the accident data out of Table 13 and out of Table 14 the adjusted accident base can be calculated for the case that Xenon never was introduced into the markets. This is displayed in Table 13 respectively Table 14. This approach was used in different European studies concerning the cost-benefit analysis of ESC [BAUM / GRAWENHOFF 2006, BAUM ET AL. 2008].

EU 27, year 2010			injuries		
	accidents	fatalities		severe inj	slight inj
with Xenon	1,079,926	35,521	1,439,377	273,611	1,165,766
without Xenon	1,084,924	35,869	1,446,635	275,457	1,171,178
avoided	4,998	348	7,258	1,846	5,412

Table 13: Accident data for the case with Xenon and without Xenon EU 27

For each mode – accidents, fatalities, and injuries – the safety effect is determined. Afterwards, these safety effects are multiplied with the accordant cost-unit rate. The sum of the three values is the monetised benefit of Xenon for the year 2010.

Germany 2010			injuries		
	accidents	fatalities		severe inj	slight inj
with Xenon	282,367	4,919	365,275	66,633	298,982
without Xenon	285,873	5,032	369,570	67,729	302,174
avoided	3,506	113	4,295	1,096	3,192

Table 14: Accident data for the case with Xenon and without Xenon Germany

6.2.1 Safety effect for accidents

In the year 2010 the number of accidents in the case of Xenon was 1,079,926 (Table) in EU 27. Regarding the share of driven mileage with Xenon as 10.7 %, the number of accidents in the without case is 1,084,924. The difference between both values is the number of accidents, Xenon could avoid in 2010. This number is 4,998.

In Germany, the number of accidents is 282,367 in the world with Xenon. The share of equipped mileage is 21.7 %. Thus, Xenon avoids in 2010 about 3,506 accidents (Table).

6.2.2 Safety effect for fatalities

The calculation for the number of avoided fatalities is analogue. In 2010 Xenon could avoid 348 fatalities in EU 27 and to 113 fatalities in Germany.

6.2.3 Safety effect for severe injuries

The number of avoided severe and slight injuries can be determined by subtracting the accident data for the with Xenon case from the accident data for the without Xenon case. In 2010 due to the usage of Xenon 1,846 severe injuries in EU 27 and 1,096 in Germany can be avoided.

6.2.4 Safety effect for slight injuries

The number of avoided severe and slight injuries can be determined by subtracting the accident data for the with Xenon case from the accident data for the without Xenon case. In 2010 due to the usage of Xenon 5,412 slight injuries in EU 27 and 3,192 in Germany can be avoided.

6.2.5 Aggregated safety benefit

The number of avoided casualties respectively accidents is multiplied with the accordant cost-unit rate. Afterwards, the values for avoiding accidents, fatalities and injuries are summed up. The saved value due to avoiding fatalities in EU 27 is 445.7 million Euro, due to avoided severe injuries 330.1 million Euro and due to avoided slight injuries 156.7 million Euro. In sum the safety benefits amounts to 932.5 million Euro.

For Germany the overall safety benefit is 433.6 million Euro (145.1 + 196.1 + 93.4).

6.2.6 Traffic Benefits

Each equipped vehicle saves 0.037 l fuel per 100 km. Linked to this is a reduction of CO2 emission of 0.0925 kg per 100 km.

In EU 27 the penetration rate of the fleet is estimated as 7.45 % in 2010. These 7.45 % are driving 10.71 % of the total vehicle mileage. Thus, about 309.5 bill. veh-km are driven with Xenon, thereof the lights are switched on in 90.3 bill veh-km (309.5*0.292). The avoidance potential in fuel consumption is 33.4 t (90.3/100*0.037*1000) and 83.5 t CO2 can be saved (90.3/100*0.0925*1000).
The cost-unit rate for one ton of petrol respectively diesel is 350 Euro. The cost-unit rate for one ton CO2 is 71.40 Euro [BAUM ET AL. 2008].

The economical benefit in terms of reduced fuel consumption is 11.7 thousand Euro per year and the benefit in terms of avoided CO2 emission is 6.0 thousand Euro per year.

In Germany both benefits are lower. The share of driven vehicle mileage of Xenon equipped vehicles is 21.7 %. Thus, 7.86 million equipped vehicles have a mileage of 128.9 bill. veh-km. About 37.6 bill. veh-km (128.9*0.292) are driven with lights. That means that about 13.9 t fuel can be saved (37.6/100*0.037*1000). This leads to a financial benefit of 4.8 thousand Euro (13.9*350). In addition, 34.8 t CO2 can be avoided (37.6/100*0.0925*1000) which leads to a benefit of 2.5 thousand Euro (34.8 * 71.4).

6.2.7 Operation costs

Per vehicle life 6.9 lamp replacements can be avoided due to Xenon lights. Each replacement costs 37 Euro. The replacement costs are allocated for 1.75 years (vehicle service time / estimated number of replacements within the vehicle service time). The accordant annuity rate is 0.6. The estimated replacement costs are 37 Euro. Thus, 22.02 Euro (37*0.6) per year can be saved by Xenon per passenger car.

In 2010 the penetration rate of Xenon is 7.45 %. Thus, 18.1 mill. vehicles are equipped with Xenon in 2010. The share of mileage which is driven by these vehicles is higher than 7.45 %. Thus, it is likely that these vehicles have a higher exchange rate than vehicles on average due to their higher mileage. In order to correct the savings in operating costs, the saved costs per vehicle are multiplied with a correcting factor which considers the mileage which is driven by the equipped vehicles. The correcting factor is the share of driven mileage over the penetration rate (10.71 % / 7.45 %). This leads to saved costs of 574 mill. Euro in 2010 (18.1 mill. vehicles * 22.02 Euro * 10.71 % / 7.45 %).

In Germany the penetration rate of Xenon in 2010 is estimated as 16.25 %. This means that 7.9 million passenger cars are equipped with Xenon. Per vehicle and year 22.02 Euro can be saved due to the longer lifetime of the Xenon lamps for a driver with a mileage on average. The correcting factor is 21.71 % / 16.25 %. This leads to a benefit of 231.1 million Euro.

6.2.8 Aggregated benefits

The benefits amount to 1,506.5 million Euro in EU 27 (932.5 + 0.0 + 574) respectively to 664.6 million Euro for Germany (433.5 + 0.0 + 231.1).

6.3 Costs

A Xenon system consists out of 2 Xenon lamps, a washing system and a levelling system. In contrast, the two standard halogen lamps can be subtracted from the system costs.

In total, the system costs are estimated as 236.75 Euro per system. The annuity rate is 0.1046 for a service time of 12 years and a discount rate of 3 %.

The penetration rate of EU 27 is 7.45 % of the fleet. Thus, 18.12 mill. vehicles are equipped with Xenon in 2010. This leads to costs of 431 mill. Euro per year (18.12*236.75*0.1).

In Germany the equipment rate is 16.25 % or in other words 7.86 million passenger cars have Xenon lights in 2010. The total costs in 2010 are 186.8 million Euro (7.86*236.75*0.1).

6.4 Benefit-Cost ratio

The benefits are confronted with the accordant costs. In the year 2010, the benefits were 1,506.5 mill. Euro, while the costs amount to 431 mill. Euro in EU 27. Thus, the benefit-cost ratio is 3.5 (1,506.5/431). Is the ratio benefits over costs higher than 1, the system is worthwhile out of society view. For every Euro which is invested in the system, 3.5 Euro are gained by the society. Hence, Xenon is worthwhile out of societal view.

Another assessment value which can be computed is the net benefit. Therefore the costs are subtracted of the benefits. For Xenon the net benefit is 1,075.5 mill. Euro (1,506.5 – 431).

The accordant benefit-cost-ratio for Germany is 3.6 (664.6 / 188.8) respectively the net benefit is 477.8 mill. Euro (664.6 - 186.8).

6.5 Internal Rate of Return

The disadvantage of the benefit-cost ratio is the dependence from the discount rate. If the discount rate is changed, the ratio has to be adjusted. Thus, the sensitivity of changing the discount rate has to be calculated.

Another approach for assessing an intelligent vehicle system is to calculate the internal rate of return. This figure is independent from the discount rate. The result is the annual return of the system. If this figure is higher than an external given discount rate respectively benchmark, the system is worthwhile. A further sensitivity analysis is not necessary.

The internal rate of return can be determined as follows: The benefits are divided by the overall costs. The result is the annuity rate with the lifetime 12 years and the IRR as discount rate. Afterwards this annuity rate has to be compared with the values of the IRR. This is due to the fact that the internal rate of return can only be calculated in an iterative procedure.

The product of the benefit-cost ratio and the annuity rate is 0.35 for EU 27 and 0.36 for Germany. Thus, the accordant internal rate of return is 34 % for EU 27 and 34.5 % for Germany. Thus, the system is worthwhile as long as the discount rate is less than 34 %.

6.6 Sensitivity Analysis

In the sensitivity analysis a scenario is considered in which the whole passenger vehicle fleet is equipped with Xenon. Although this scenario is hypothetical, it can show the real potential of Xenon. This scenario is performed for EU 27 and for Germany.

Germany 2010			injuries		
	accidents	fatalities		severe inj	slight inj
without Xenon	285,873	5,032	369,570	67,729	302,174
Potential	16,152	521	19,790	5,050	14,706

Table 15: Accident avoiding potential of Xenon if every passenger vehicle is equipped, EU 27, year 2010

Xenon can realize its potential in darkness and in twilight. It can avoid:

- 60 % of all accidents between passenger vehicles on rural roads

- 30 % between a passenger vehicle and a goods vehicle on rural roads,
- 44 % of all accidents between passenger vehicles on motorways and
- 22 % between a passenger vehicle and a goods vehicle on motorways.

In Table 15 the accident data for the case that no Xenon is available and the potential of Xenon for a full market penetration is stated for EU 27. Nearly 4,000 fatalities or 11.1 % of all fatalities and almost 87,000 injuries or 4.7 % of all injuries can be avoided due to the use of Xenon. These values have to be assessed monetarily to compute the safety benefit in Euro. In sum, the benefit amounts to 9,800.3 million Euro.

EU 27, year 2010			injuries		
	accidents	fatalities		severe inj	slight inj
without Xenon	1,084,924	35,869	1,446,635	275,457	1,171,178
Potential	46,756	3,970	68,530	18,187	50,344

Table 16: Accident data for the cases no Xenon available and full market penetration rate of Xenon, Germany 2010

For Germany the values are similar. Here, about 10.4 % of all fatalities or 521 and 5.4 % of all injuries or almost 20,000 injuries can be avoided if every passenger vehicle within the vehicle fleet would be equipped with Xenon in 2010 (Table). In monetary units, the safety benefit is 1,997.4 million Euro.

Using Xenon saves fuel and therewith CO_2. In EU 27 the passenger vehicle mileage is 2,889 bn. veh-km. 29.2 % of that is driven with lights. Per 100 km driving with lights Xenon saves 0.037 l fuel. One ton of fuel costs 350 Euro. Thus, multiplying all values leads to the total saving in Euro: 109.2 thousand Euro. In addition, per 100 km driving with lights, 0.0925 kg CO_2 can be saved. For EU 27, cost savings of 55.7 thousand Euro can be realized.

In Germany the passenger vehicle mileage is 594 bn. veh-km in 2010. Thus, 22.4 thousand Euro can be saved due to less fuel consumption and further 11.4 thousand Euro due to saved CO_2 emissions.

The savings of operating costs due to the longer service vehicle time is calculated as follows: the annuity of changing one halogen lamp per year is 22.02 Euro. This value is multiplied with the vehicle stock of EU 27 (243.3 million) respectively of Germany (48.3 million). In sum, the benefit amounts to 5,358.8 million Euro for EU 27 respectively to 1,064.5 million Euro for Germany.

These benefits have to be summed up to get the total benefit. This value is 15,159.3 million Euro for EU 27 respectively 3,062.0 million Euro for Germany.

These benefits have to be confronted with the accordant equipment costs of Xenon for the whole fleet. As mentioned, the vehicle fleet of EU 27 is 243.3 million passenger vehicles. The system costs per unit will decrease for full equipment by 26.25 %. Thus, the system costs per unit are 174.60 Euro or – in terms of annuity – 17.54 Euro per year. Equipping the complete fleet is linked with annual costs of 4,268.8 million Euro for EU 27 respectively of 848.0 million Euro for Germany (48.34 million vehicles * 17.54 Euro).

The accordant benefit-cost-ratio is 3.6 for EU 27 (15,159.3 million Euro / 4,268.8 million Euro) respectively 3.6 for Germany (3,062.0 million Euro / 848 million Euro).

In EU 27 the net benefit of Xenon is 10,890.5 million Euro and 2,214.0 million Euro for Germany.

7. Break-even analysis of Xenon

In this chapter Xenon is analysed from the end user's point of view. The physical effects of the cost-benefit analysis can be used. But the break-even analysis uses end market prices including taxes if available. In all other cases, the willingness-to-pay approach is used to determine the cost-unit rate. In this case, the willingness-to-pay approach is used for the safety effects.

A driver who has equipped his vehicle with Xenon saves 7.07 Euro per 1,000 km in EU 27 respectively 7.00 Euro per 1,000 km in Germany. On the other hand, the driver has to buy Xenon. If his annual expenditures for Xenon are lower than his annual gain, Xenon is worthwhile for him.

In chapter 7.1 the fair market price for Xenon is calculated. For this market price, the annual expenditures for Xenon are as high as the annual gain due to the usage of Xenon for an average driver. In 7.2 the end market price for Xenon is given. Thus, for a fixed annual expenditure for Xenon the corresponding mileage ("critical mileage") is calculated for which the annual gain is as high as the annual expenditure. For all drivers with a higher annual mileage than the critical mileage Xenon is worthwhile. In chapter 7.3 a sensitivity analysis of chapter 7.2 is done. The critical mileage is determined for a range of possible end market prices. This approach has the advantage for the driver, that he can take the price for Xenon from his vehicle purchaser and then read off the graph which critical mileage is linked to the price.

7.1 Fair end market price for the driver on average

In EU 27 the average driver has an annual mileage of 11,872 km. Per each driven 1,000 km he has a monetary benefit of 7.07 Euro due to the usage of Xenon. Thus, per year the average benefit is 83.93 Euro per year (7.07*11.872). This is the fair annual expenditure for a driver for having his vehicle equipped with Xenon. The fair end market price is determined by dividing the fair annual expenditure with the annuity rate: 632.53 Euro (83.93/13.27%). Thus, Xenon is worthwhile for the average European driver if it is sold for equal or less than 632.53 Euro.

The same calculation is done for the average German driver. He has an annual mileage of 12,283 km on average. Per driven 1,000 km he has a benefit of 7.00 Euro. Thus, his fair annual expenditure for having his vehicle equipped with Xenon is 85.95 Euro. This value is also divided by the annuity. The result is the fair end market price of 647.74 Euro. Thus, Xenon is worthwhile for the average German driver if it is sold for equal or less than 647.74 Euro.

7.2 Annual mileage from which on Xenon is worthwhile

The end user has to pay the end-market price for equipping his vehicle with Xenon. The end-market price is estimated as 898 Euro.

Xenon avoids accidents, it saves fuel and it saves operating costs due to the longer service life time of Xenon lamps. All these effects have to be considered to calculate the annual mileage from which on Xenon is worthwhile given the end-market prices of 898 Euro.
It is assumed that the end user finances Xenon with a deferred payment credit with the following conditions: maturity: 12 years, interest rate: 8 %. Thus, the end user has to pay the product of the end-market price and the annuity rate with 8 % discount rate and 12 years maturity. The annuity rate is 0.1327. Per year, the end user has to pay 119.16 Euro.

The annual rate, the end user has to pay for Xenon is divided by the benefits of using Xenon for driving 1,000 km: 7.07 Euro for EU 27. The result is the mileage per year, from which on Xenon is worthwhile: 16.9 thousand km (119.16 / 7.07).

The same calculation is done for Germany. The end market price is the same as before, but the benefit per 1,000 km is 7.00 Euro. Thus, the critical mileage from which on Xenon is worthwhile for the driver is 17.0 thousand km.

7.3 Sensitivity analysis

In this chapter the critical mileage is determined for a range of possible end market prices: between 300 and 1,000 Euro per Xenon system. Each price within this range is multiplied with the annuity rate of 13.27 % and afterwards divided by the benefit for driving 1,000 km with Xenon in EU 27 (7.07 Euro). The result is the critical mileage per year in thousand km. For every driver with a higher mileage, Xenon is worthwhile. The results are valid for EU 27. The critical mileages for Germany are 1 % higher than for EU 27, thus, the results are similar. **Figure 2** displays the critical mileages in dependence of the end market price.

As an example, if the end market price is 600 Euro, the critical mileage is 11.3 thousand km. On the other hand, if the driver has an annual mileage of 10 thousand km, the accordant end market price for Xenon is roundabout 535 Euro.

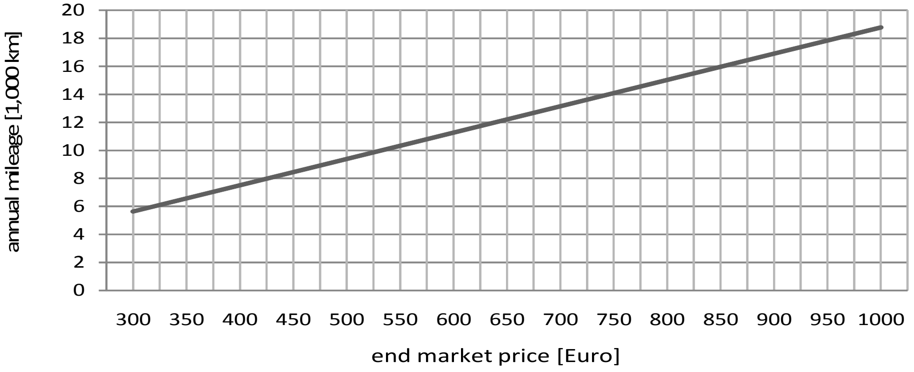

Figure 2: Critical mileage in dependence of the end market price for EU 27

The distribution of the mileage for EU 27 and Germany is known for the classes over 30,000 km, over 20,000 km, over 15,000 km, over 10,000 km and over 5,000 km. In Table this distribution is displayed. In the lower part the fair prices which are linked with the accordant mileage is given for EU 25 and for Germany. It is assumed that the values for EU 25 and for EU 27 are the same.

	Mileage (in 1.000 km)				
	over 5	over 10	over 15	over 20	over 30
EU 25	84.2%	55.8%	31.6%	15.8%	6.3%
Germany	85.9%	51.5%	27.2%	14.1%	5.0%
according price EU 25	266	533	799	1,066	1,598
Germany	264	527	791	1,055	1,582

Table 17: Share of driver with an annual mileage ... and according price in Euro

The market price of Xenon is estimated as 898 Euro. Thus, in EU 27 Xenon is worthwhile for between 15.8 % and 31.6 % of all drivers. If the market price is reduced to 800 Euro, the potential market share of Xenon would be 31.6 %. For a price of 898 Euro the accordant market share for Germany is lower: between 14.1 % and 27.2 %.

8. Conclusions

According to recent safety forecasts more than 35,500 people die due to traffic accidents in 2010 in EU 27. Thus, the goal of the European Commission of reducing the number of fatalities due to traffic accidents below 25,000 will be clearly failed. Further efforts to reach this goal are necessary. One possible system for this is Xenon which reduces the accidents while twilight and darkness.

Xenon is in conditions of bad visibility, i.e. twilight or darkness, a very **effective system in avoiding accidents and reducing impacts** on personal injuries and on property damage. In relative terms, it can avoid in EU 27 (Germany in brackets)

- 11.1 % of all fatalities (10.4 %),
- 6.6 % of all severe injuries (7.5 %) and
- 4.3 % of all slight injuries (4.9 %).

In absolute numbers, Xenon headlights can avoid the following impacts in EU 27 (Germany in brackets):

- ➢ If every passenger car is equipped with Xenon in 2010
- 46,756 accidents (16,152)
- with 3,970 fatalities (521),
- with 18,187 severe injuries (5,050) and
- with 50,344 slight injuries (14,706).

- ➢ Given the fleet penetration rate in 2010 (EU 7.45 %, Germany 16.25 %), Xenon will realize a reduction of
- 348 fatalities (113),
- 1,846 less severe injuries (5,412) and
- 5,412 less slight injuries (3,192).

The **results of the cost-benefit assessment** can be summarized as follows:

- ➢ Converted to monetised values Xenon will realize socio-economic benefits of 1,506.5 million Euro in EU 27 and of 664.6 million Euro in Germany.

- ➢ These benefits have to be confronted with accordant costs in amount of 431 million Euro in EU 27 and of 186.9 million Euro in Germany.

- ➢ For EU 27 the resulting net-benefit of Xenon is 1,075.5 million Euro and the benefit-cost ratio is 3.5, i.e. per invested Euro a benefit of 3.5 Euro is linked. The values for Germany are a net-benefit of 477.8 million Euro and a benefit-cost ratio of 3.6.

- ➢ In case of full penetration rate, the net-benefit is 10,890.5 million Euro and the benefit-cost ratio is 3.6 for EU 27. The values for Germany are a net-benefit of 2,214.0 million Euro and a benefit-cost ratio of 3.6.

When the socio-economic profitability is compared to the eIMPACT systems (Figure 3), Xenon is one of the most promising systems. Only ESC shows a better performance from the socio-economic point of view. Given that Xenon is a mature technology it becomes obvious that quick wins for safety and efficiency can be realized by supporting the speeding up of the deployment.

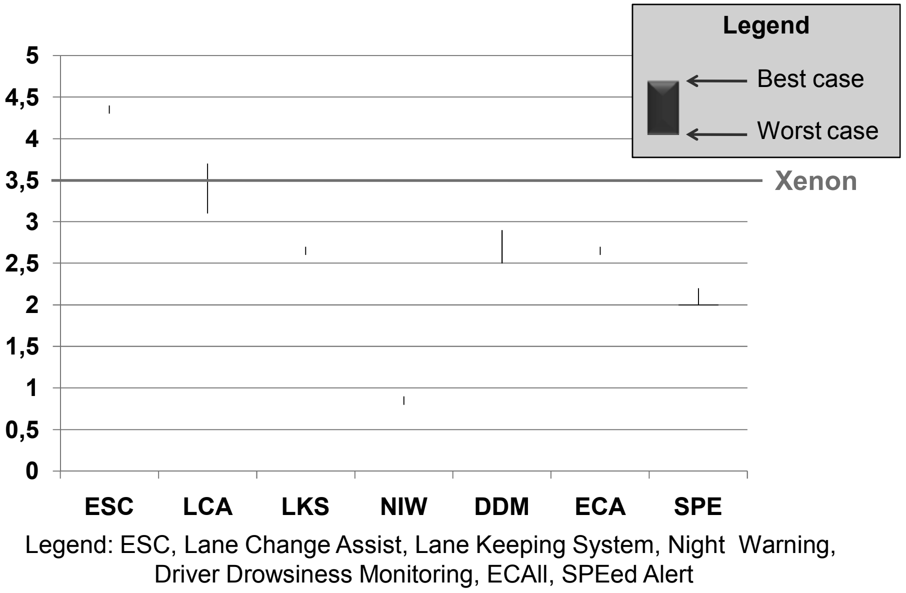

Figure 3: BCR of Xenon compared with eIMPACT results of the year 2010

From the end-users' point of view, using Xenon leads to a higher safety level and to savings of operation costs (fuel and lamp exchanges). Saving fuel and having no lamp exchanges anymore can be expressed in monetary terms easily. The safety effect is also expressed in Euro per driven 1,000 km by using information about the vehicle mileage in EU 27 respectively Germany and by using cost-unit rates for avoiding fatalities, severe injuries and slight injuries. These cost-unit rates are based on the willingness-to-pay approach. For this approach people are asked how many money they would spend for not being killed or injured.

In EU 27 the benefit for driving 1,000 km with Xenon on board is 7.07 Euro, the value for Germany is 7.00 Euro. The European driver on average has an annual mileage of about 12,000 km. For the driver on average the market price can be calculated for which Xenon is worthwhile. This is the highest price, the driver would pay for equipping his vehicle with Xenon. This price is 632.53 Euro for EU 27 and 647.74 Euro for Germany. In comparison: the price for Xenon is estimated as 898 Euro in 2010. Thus, Xenon has a market potential of below 30 %.

In the second analysis, the critical mileage per driver is determined from which on Xenon is worthwhile for a price of 898 Euro. The result is 16,850 km per year for EU 27 and 17,030 km per year for Germany.

Only for few systems a break-even analysis was done. With the same approach an analysis was done for ABS for motorcycles (BAUM ET AL. 2007). ABS is worthwhile for every driver who has an annual mileage of above 2,200 km. This value is valid for Germany in the year 2015. The annual mileage on average is estimated as 3,900 km.

A break-even analysis was also done for several eIMPACT systems (Westerkamp 2009). The best system – Emergency Brake – is worthwhile for every driver who has an annual mileage of above 16,000 km. This value is underestimating. This is due to the fact that the approach is different. Thus, the comparable value is higher than the critical mileages of Xenon.

It can be stated that Xenon has a lower critical mileage than the eIMPACT systems Full Speed Range ACC, Emergency Brake, Pre-Crash Safety for Vulnerable Road Users, Lane Change Assist, Lane Keeping Assist and Driver Drowsiness Monitoring and is thus worthwhile for more drivers.

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Abstract

This paper explores the socio-economic impacts of using Xenon headlights in road traffic. The benefits comprise the safety improvement due to a better visibility and the longer service times of the Xenon lamps compared to conventional halogen lamps. The cost-benefit analysis and the break-even analysis for the users is carried out for EU-27 in the year 2010. The effects for Germany are particularly shown because the Xenon penetration in the fleet is most advanced in Germany. Regarding road safety, about 4,000 lives per year could be saved and 70,000 injuries could be avoided if every passenger car would be equipped with Xenon in EU 27. At the estimated penetration rate (7.45%) the total benefits of 1.5 Bn Euro are composed of nearly 1 Bn Euro of safety benefits and another 500 Mill. Euro due to longer service times of the lamps. With costs of approx. 430 Mill. Euro the benefit-cost ratio amounts to 3.5. This illustrates that Xenon headlights represent a promising system compared to other Intelligent Vehicle Safety Systems.