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How Profitable are Intelligent Cars for Society? – Methodology and Results from eIMPACT

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Abstract: Intelligent Cars can make road transport safer, cleaner and more efficient. This paper provides – based on the eIMPACT project (FP 6) – a methodology for assessing the socio-economic impacts of Intelligent Vehicle Safety Systems (IVSS). The assessment framework addresses in a comprehensive way the society perspective and stakeholder perspectives on IVSS. In its core the framework relies on cost-benefit analysis which is in the focus of the paper. Results are presented for all twelve systems for which cost-benefit analyses were performed. The benefit-cost results are also tested on sensitivity of results. Overall, it can be concluded that the analysed systems are profitable from the society point of view. The results are mainly driven by the safety benefits. In a temporal perspective, a wider uptake of systems is going to happen in the next decade, which helps to realise the benefits.

1. Introduction

Intelligent Vehicle Safety Systems (IVSS) promise a large potential to reduce the negative societal impacts of road traffic by informing drivers about traffic conditions and assisting them in hazardous situations. As a result, the road transport will be safer, more efficient in terms of time and energy use, and environmental friendly.

Increasing needs for mobility and transport require action to improve road safety, a major concern for European transport policy. 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. The delay costs are conservatively estimated up to 50 bn EUR per year [1]. Other sources calculate them to roughly another 2% of the EU GDP [2]. Along with this go environmental damages in terms of air pollution and contribution to climate change.

In contrast to the potential, IVSS are not yet widely deployed. The reasons for the slow market take-up involve a lack of user awareness and understanding of the IVSS capabilities, a stakeholder mismatch between beneficiaries and cost bearers because of external effects, network externalities for co-operative systems as well as legal and liability issues. This environment makes the IVSS deployment a complicated case for public-private partnership.

The knowledge about the socio-economic impacts of Intelligent Vehicle Safety Systems is limited so far. Although studies do exist which prove the profitability of particular systems on national or regional level, there is only very limited EU-wide evidence about the socio-economic impacts of intelligent vehicles.

Fundaments for the analysis were laid in the SEiSS study [3] which aimed at exploring the socio-economic impact of IVSS methodologically and demonstrate the workability of the approach by some cost-benefit case studies. A study carried out by COWI made use of the SEiSS framework and covered more than 20 systems [4].

The socio-economic impact assessment within eIMPACT has got two focal points. The first is to develop a broader framework on methodology which integrates the overall society perspective of cost-benefit analysis with economic stakeholder analyses which provide information on individual stakeholders' benefits and costs. The key interest groups within eIMPACT comprise system users, OEMs and suppliers, insurance companies and public authorities. The second focus is to carry out fully-fledged cost-benefit analyses for twelve IVSS and to test the sensitivity of the results. This is made possible by bringing together the latest evidence in system engineering, forecast of safety and traffic data, safety assessment incl. behavioural research, traffic modelling and simulation as well as cost-benefit assessment.

The profitability proof of the systems for the overall society and for key stakeholder groups will actively contribute to a reduction of implementation barriers related to IVSS. With that, guidance for policy measures to facilitate the IVSS market take-up will be provided and the work under the eSafety initiative and the Intelligent Car Initiative of the European Commission is supported [1].

2. Objectives

The objective of the paper is to describe a comprehensive methodological framework for socio-economic impact assessment and to discuss the results of the cost-benefit analyses for all twelve investigated systems. So clearly, stakeholder analyses have been an important part of the eIMPACT project and the findings are well documented [5]. However, this paper concentrates on the social perspective of CBA. This means, the focus of the analysis is on assessing whether the welfare of the society is improved or not, regardless of the fact who profits and who does not. In order to arrive at this point, the costs of the regarded measure are confronted with this overall economic effect. The benefits are defined in terms of productive resources saved within an economy ("cost-savings approach").

The paper is organised as follows. Chapter 3 gives a brief overview over the methodological framework. It reports about the systems that have been selected for impact assessment throughout eIMPACT. Moreover, the impact channels and the necessary background data for the assessment are explained. Next to methodology, chapter 4 presents the results of the cost-benefit analyses. Furthermore, the main drivers for the results are discussed and the sensitivity of the results is examined. The paper concludes with discussing the conclusions and recommendations, including directions for further research.

3. Methodological Framework

The goal of the assessment framework is to provide a comprehensive standardised methodology, which enables to perform a socio-economic impact assessment of a set of IVSS in the European Union in pre-selected target years (2010, 2020). Similar to former research, the assessment framework of eIMPACT relies in its core also on cost-benefit analysis. Because of the complex deployment issues, the overall society perspective is complemented by stakeholder analyses for key interest groups [6]. However, as outlined above, the focus of this paper is on the methodology and the results of cost-benefit analysis.

A crucial first step in the overall assessment process is the identification of the most promising vehicle safety technologies for the near- to mid-term future. A workshop in Cologne in March 2006 brought together the relevant expertise inside and outside the consortium. The three-stage selection process (overview over potentially beneficial systems, ranking of the systems according to the criteria "Technical and economic feasibility", "Consumer satisfaction" and "Public concerns", consistency check in order to ensure a balanced choice of systems) ended up in a list of twelve IVSS which formed the basis for the impact assessment throughout the eIMPACT project [7]. The systems comprise (1) Electronic Stability Control (ESC), (2) Full Speed Range ACC (FSR), (3) Emergency Braking (EBR), (4) Pre-Crash Protection of Vulnerable Road Users (PCV), (5) Lane Keeping Support (LKS), (6) Lane Change Assistant (Warning) (LCA), (7) Night Vision Warn (NIW), (8) Driver Drowsiness Monitoring and Warning (DDM), (9) Wireless Local Danger Warning (WLD), (10) eCall (ECA), (11) Intersection Safety (INS) and (12) Speed Alert (SPE).

The assessment on society level relies on information input on impacts, costs and background data (Figure 1). The cost side information comprises the costs of vehicle equipment and infrastructure equipment (where applicable) as well as operating and maintenance costs. The background data set consists of the functional system specification, the forecasted traffic performance (in vehicle kilometres) and safety performance (fatalities and injuries). Moreover, the impact assessment is based on realistic market penetration rates for the reference years 2010 and 2020, reflecting for both years a low scenario representing business-as-usual conditions, and a high scenario which involves focused policy incentives.

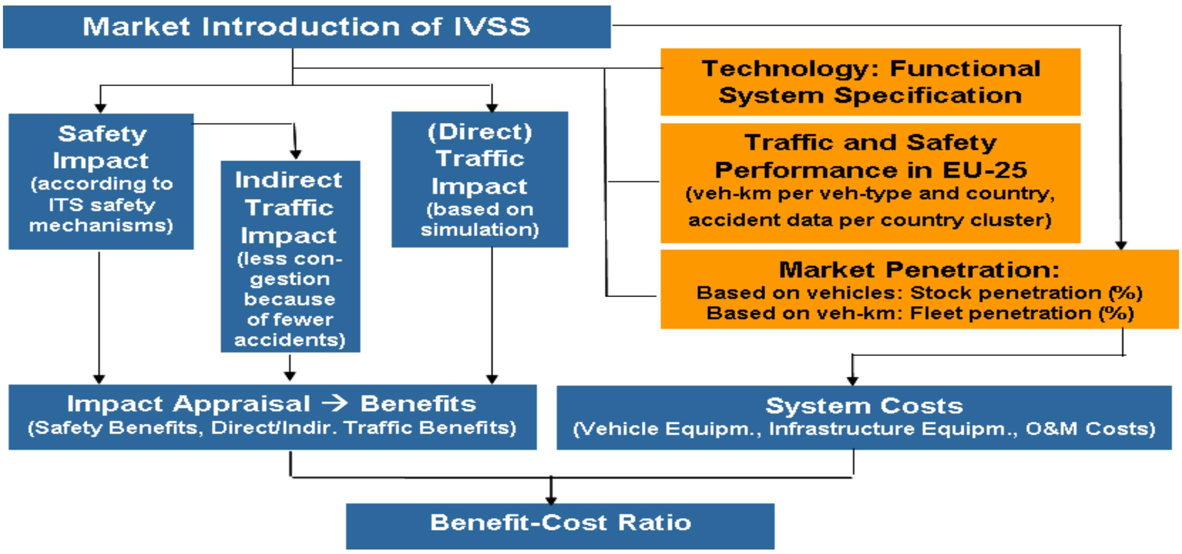

Figure 1: Procedure of the Socio-Economic Impact Assessment

The benefits result from three different impact channels. Most important, at least constitutional for Intelligent Vehicle Safety Systems, is the safety impact channel. It analyses the safety impact of IVSS according to the ITS safety mechanisms [8], including direct effects on accident avoidance and injury mitigation and indirect effects due to behavioural adaptations and exposure. As road safety improvements also release congestion, this add-on effect to the safety impact is also considered. Cost-unit rates for congestion for each of the twelve IVSS are determined. In addition to that, direct traffic impacts are calculated by using micro-simulations such as the ITS modeller [8]. Based on this, effects on travel time, on fuel consumption, on the CO_2 emission, and on the NO_x-equivalent emission can be derived. For each of these categories the corresponding cost-unit rates are applied in order to determine the cost savings. These figures expressed in Euro represent resource savings which can be used elsewhere in the economy to increase the Gross Domestic Product. Thus, this change influences the welfare of the overall society. When the welfare gain is larger than the costs, the system implementation is profitable from the society point of view, indicated by a benefit-cost ratio higher than 1.

4. Results of the Cost-Benefit Analyses

The results of the cost-benefit analyses show that the use of Intelligent Vehicle Safety Systems will contribute actively to the reduction of fatalities and injuries. Hence, IVSS are effective in improving road safety. Moreover, as the benefit-cost ratios prove, they are mostly efficient. In particular, the results can be condensed to the following statements [9].

4.1. All systems contribute actively to the societal goal of improving road safety.

The systems which are considered in eIMPACT are safety systems. Their aim is to reduce the number of accidents and linked to this the number of fatalities and of injuries. As Table 1 illustrates, the safety impact of the IVSS is significant. For instance, Electronic Stability Control in the year 2010 can avoid about 2,000 fatalities (1,914 – 2,240 fatalities, depending on the market penetration secenario). Among the group of the twelve IVSS, Electronic Stability Control, Lane Keeping Support and Speed Alert show the highest absolute numbers in avoiding fatalities and injuries at the estimated penetration rates. The potential of eCall (implying 100% penetration for a fair distribution of infrastructure equipment costs) represents also a significant reduction of fatalities and severe injuries. Overall it becomes clear that improving road safety must include the contributions from all technologies which are analysed here.

Table 1: The number of saved lives and avoided injuries for each IVSS
(The values for eCall and Intersection Safety are only valid for the potential case!)

	Fatalities				Injuries			
	2010		2020		2010		2020	
	low	high	low	high	low	high	low	high
ESC	1,914	2,240	2,577	3,253	32,792	38,265	41,549	52,182
FSR	n.a.	n.a.	49	101	n.a.	n.a.	3,668	9,774
EBR	n.a.	n.a.	72	193	n.a.	n.a.	4,241	10,925
PCV	n.a.	n.a.	14	39	n.a.	n.a.	718	1,918
LCA	2	11	33	86	264	1,189	3,449	8,596
LKS	56	149	197	678	1,420	3,784	5,109	17,296
NIW	2	10	30	73	87	367	1,046	2,542
DDM	4	13	20	94	153	367	682	2,715
ECA	*1,955*		*1,199*		*severe: 13,691* *slight: -15,647*		*severe: 8,398* *slight: -9,598*	
INS	*n.a.*		*803*		*n.a.*		*63,700*	
WLD	n.a.	n.a.	29	66	n.a.	n.a.	989	1,906
SPE	77	119	753	1,076	2,405	3,463	24,643	34,887
Base	33,895		20,791		1,409,415		873,695	

4.2. The improved road safety leads to a significant reduction of accident costs. This means, there are huge safety benefits to be realised.

The reduction of accident costs (= safety benefits) is displayed for the 2020 high scenario in Figure 2. Besides the safety impact in absolute numbers it is also represented to which extent the results accrue to avoided fatalities and avoided injuries. The figures show that Electronic Stability Control, Lane Keeping Support, Speed Alert and eCall lead to the highest safety benefits. The benefits of Electronic Stability Control add up to about 9 Bn EUR. The benefits of Lane Keeping Support, Speed Alert and eCall amount also to more than 1 Bn EUR. In terms of safety benefits distribution, it becomes obvious that for some systems (e.g. Electronic Stability Control, eCall) the majority of safety benefits origins in avoided fatalities whereas other systems (e.g. Full Speed Range ACC, Lane Change Assistance) do merely benefit from avoiding injuries.

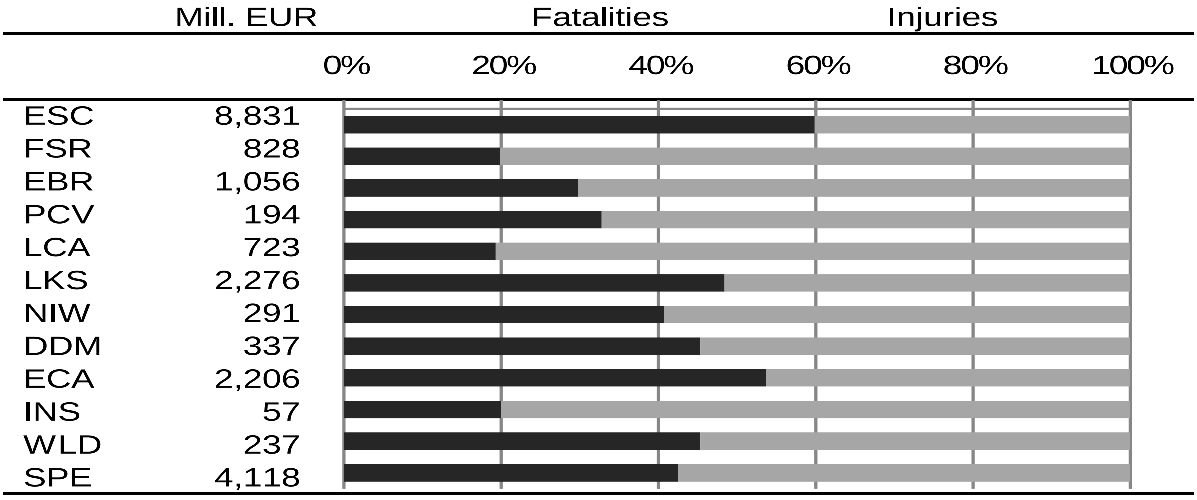

Figure 2: Safety Benefits and Distribution for 2020 High Scenario

4.3. The benefits are dominated by the safety benefits. Traffic impacts however represent for all IVSS a considerable add-on to the safety benefits.

The prevention and/or mitigation of accidents reduce congestion caused by accidents. Traffic disturbances are reduced and road transport becomes more efficient. This indirect traffic effect represents a mark-up to the safety benefits of up to 8%. Moreover, at the estimated penetration rates direct effects on the traffic flow can only be expected for the Speed Alert system in the year 2020. The direct traffic benefit represents another 2% mark-up to the safety benefits.

4.4. The safety benefits grow strongly with maturity of systems and policy support.

In the next decade many systems will either enter or penetrate the market. Figure 3 shows the development of the safety benefits in the temporal perspective exemplarily for the Lane Keeping Support system. It becomes clear that the benefits grow strongly in the next decade. Moreover, the achievable benefits in the scenario high (including focused policy incentives) are much higher than in the low scenario for each of the target years.

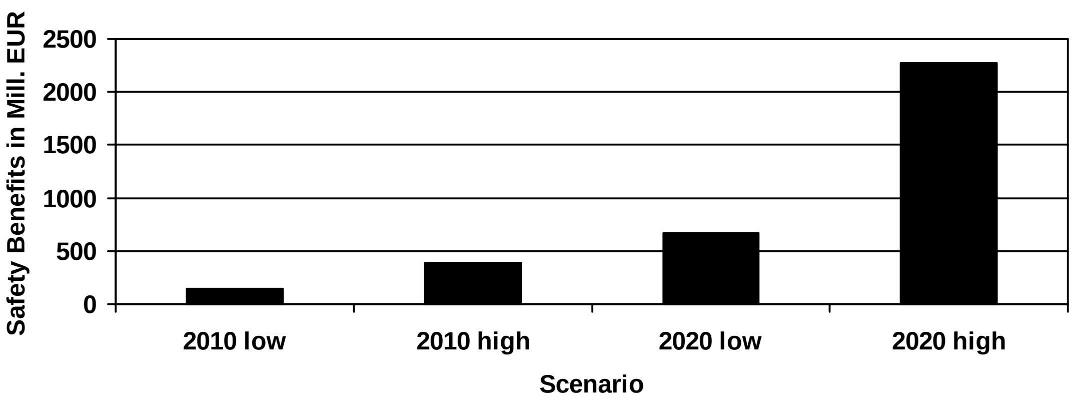

Figure 3: Development of Safety Benefits in Mill. Euro for Lane Keeping Support

4.5. On the basis of benefit-cost ratios, the clear majority of the investigated Intelligent Vehicle Safety Systems is distinctly profitable from the society point of view.

Table 2 provides an overview over the benefit-cost ratios for all scenarios at the estimated penetration rates and share of driven kilometers with the systems. For eCall and Intersection safety – which both require infrastructure investment – the benefit-cost ratio is displayed only for the potential case (equipment of the total vehicle fleet, 100% penetration) for reasons of a fair allocation of infrastructure investment costs.

Table 2: Synopsis of the Benefit-Cost Ratios

Scenario		ESC	FSR	EBR	PCV	LCA	LKS	NIW	DDM	ECA	INS	WLD	SPE
2010	**Low**	4.4	n.a.	n.a.	n.a.	3.1	2.7	0.8	2.5	2.7	n.a.	n.a.	2.2
	High	4.3	n.a.	n.a.	n.a.	3.7	2.7	0.9	2.9			n.a.	2.0
2020	**Low**	3.0	1.6	3.6	0.5	2.9	1.9	0.7	1.7	1.9	0.2	1.8	1.9
	High	2.8	1.8	4.1	0.6	2.6	1.9	0.6	2.1			1.6	1.7

n.a. … not available in this year

Looking at the results for the year 2010, all introduced systems – except Night Vision Warn, which is close to 1 – are fairly above the BC-threshold of 1 which indicates the profitability of a system from the society point of view. Electronic Stability Control and Lane Change Assistant are the two systems which achieve BCR’s of more than 3. The result of 4.4 for Electronic Stability Control implies that every spent Euro leads to societal benefit of 4.40 Euro. Four systems are above 2: Lane Keeping Support, Driver Drowsiness Monitoring and Warning, eCall and SpeedAlert. NightVisionWarn is round about 1. The other systems are not available or have no significant market penetration in the year 2010.

In the year 2020 all twelve systems are available on the market. Again, the clear majority of the systems prove their profitability from the society point of view. The best system is Emergency Braking with which has a benefit-cost ratio of above 3. Lane Change Assistant and Electronic Stability Control are in both scenarios close to 3. Six systems have a BCR of between 1.5 and 1.9: eCall, Lane Keeping Support, Driver Drowsiness Monitoring and Warning, Full Speed Range ACC, Wireless Local Danger Warning and SpeedAlert. The remaining systems are – under the estimated conditions – below 1: NightVisionWarn, Pre-Crash Protection of Vulnerable Road Users and Intersection Safety. However, there should not be made any premature conclusions about the profitability of those systems. The result only indicates that from the society point of view they are less efficient than other systems and they are not efficient under the current estimated conditions.

For the less efficient systems the benefit-cost ratio may be significantly higher in the future due to enriched system functionalities or decline of system costs. It is also noteworthy that the results of Table 2 incorporate a considerable safety progress, indicated by the e.g. reduction of fatalities (accident base, see Table 1) from 34,000 (2010) to 21,000 (2020). Sensitivity analyses can provide some indication on the influence of these effects.

4.6. Results react sensitive to changes of input variables. This holds especially true for the eIMPACT accident trend but also for the estimated safety impact.

Different input variables to the CBA have been tested for their influence on the benefit-cost ratios. Among them, the accident trend reveals the highest sensitivity. When the accident trend between 2010 and 2020 is disregarded, the benefit-cost ratio is changed by more than +1.0. This represents – according to the results classification of the sensitivity analysis – a significant change. The other tested variables (pessimistic / optimistic estimation of the safety impact, based on [4], change of discount rate in CBA from 3% to 8% p.a., change of vehicle lifetime from 12 years to 16 years) change the benefit-cost ratios b more than +/-0.1 which represents a considerable change.

In the following figure the sensitivity of results is exemplarily displayed for the SpeedAlert system under the conditions of 2020 low scenario. The value for the mean BCR (represented by the rectangle) is 1.9. The positive or negative deviations (highest/lowest BCR) represented by the triangle and circle symbol. Generally, the benefit-cost ratios react more sensitive on the tested variables coming from the impact assessment than on those which are core assumptions of the socio-economic assessment.

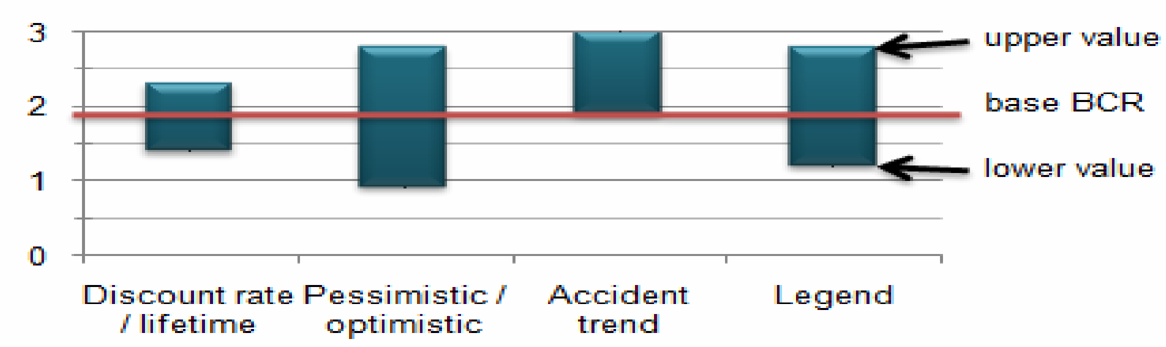

Figure 4: Change of benefit-cost ratios depending on variations of CBA input parameters (Base case: Speed Alert, 2020 low scenario)

5. Conclusions and Recommendations

The paper presented a methodology to assess the socio-economic impact of Intelligent Vehicle Safety Systems, which is comprehensive and re-usable for future assessment activities. Furthermore, the results of cost-benefit analyses for twelve pre-selected Intelligent Vehicle Safety Systems were discussed.

The results prove that IVSS contribute to improve road safety and that the use of IVSS is profitable from the society point of view. The benefit-cost ratios are distinctly above the threshold of 1. Moreover, the sensitivity analysis reveals that the results react quite sensitive to the accident trend forecast and the estimated safety impact. Overall, it can be concluded that applying IVSS improves the efficiency of road traffic.

Because benefits grow with the maturity of the systems and the level of policy support, measures to enhance the user awareness and understanding of the systems as well as initiatives to support the deployment of the systems [10] can be recommended based on the CBA findings. A deeper discussion of available instruments and the situation in individual EU member states can be found in recent studies [11, 12].

Moreover, the socio-economic impact assessment arrives at some important conclusions, which provide guidance for further research directions:

- In the deployment process of IVSS, bundling strategies will make it possible to realise synergies on the cost side. Within the eIMPACT project, the socio-economic impact of IVSS was assessed assuming that the systems are stand-alone versions. A promising approach for the future is the evaluation of system bundles. System bundles can share components, leading to cost synergies. With that, a stronger decrease of system costs might be possible. When this effect is strong enough, this would also offset the tendency to lower benefit-cost ratios (introduced by the trend reduction of fatalities and injuries) in the long-term. It should also be noted that this analysis has to take into account the path dependency of market introduction. This means, some advanced systems use components from predecessor systems, e.g. Emergency Braking can only be introduced when Electronic Stability Control is on board [13]. Prerequisite for the analysis of system bundles however is the availability of recent in-depth accident data. Foremost it must be clear how systems interact and what this implies for the safety impact (e.g. the bundle impact could represent the sum of impacts from individual systems, it could also be more or less).
- The socio-economic assessment of different deployment strategies represents a promising field for future research. When technologies become mature, the research interest naturally moves from investigating the profitability of a developed system in general to the question of an adequate deployment program. This question is

particularly important because IVSS are related to several deployment barriers (involving aspects of market failure such as congruency of beneficiaries and cost bearers, critical mass of systems, hold up problems in the insurance industry, deployment risks and ramping-up effects of the automotive industry). The socio-economic assessment of deployment strategies needs a broader scope than CBA. It has to consider different stakeholder perspectives in its assessment methodology [14]. Multi criteria analysis could represent an appropriate tool for evaluating deployment programs. Assessment criteria could comprise e.g. the cost-efficiency of the deployment strategy, its practicability, the benefit-cost congruency, the financial resources needed for subsidies by the public, the incentives on industrial R&D etc.

- The robustness of CBA results can be improved by considering explicitly the occurrence probability of scenarios. The risk analysis approach in eIMPACT was based on scenarios and on sensitivity analysis. This leads to a wide range of possible BCR. To make the BCR values more robust, it is necessary to determine the probability of occurrence for each scenario. With this information it is possible to get a mean and a variance for the BCR and to get the BCR for the value-at-risk, i.e. the threshold under which BCR will not fall with a certain probability. Monte-Carlo-simulation represents an adequate approach to calculate this distribution of BCR.

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