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Accelerating C-ITS Mobility Innovation and deployment in Europe

D2.1 Ex-ante Cost-Benefit Analysis

Status	Final
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Work Package	WP2 – Needs and requirements for implementation
Task	T2.1 – In-depth analysis and determination of use cases
Dissemination level	Public
Issue date	28/02/2018

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Revision and history sheet

Version	Date	Authors	Summary of changes	Status
1.0	09/02/2018	Evangelos Mitsakis (CERTH-HIT) Areti Kotsi (CERTH-HIT)	Draft final version (before quality review)	Prepared
	17/02/2018	Meng Lu (Dynniq)		Reviewed
	19/02/2018	Oleh SHCHURYK (IRU Projects)		Reviewed
	22/02/2018	Kerry Malone (TNO)		Reviewed
1.1	26/02/2018	Evangelos Mitsakis (CERTH-HIT) Areti Kotsi (CERTH-HIT)	Final version (after quality review) (Task Leader)	Prepared
	27/02/2018	Meng Lu (Dynniq)	Review (Work Package Leader)	Approved
	28/02/2018	Marcos Pillado (Applus+ IDIADA)	Review (Project Coordinator)	Approved

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Abbreviations

Abbreviation	Definition
ACC	Adaptive Cruise Control
BCR	Benefit Cost Ratio
BSD	Blind spot detection/ warning (VRUs)
BSM	Basic Safety Message
BSW	Blind Spot Warning
CACC	Cooperative (Adaptive) cruise control (Urban ACC)
CBA	Cost-Benefit Analysis
CEA	Cost-Effectiveness analysis
C-ITS	Cooperative Intelligent Transport Systems
CTLP	Cooperative traffic light for pedestrian
CU	Cost-unit
CV	Connected Vehicles
DOT	Department of Transportation
DSRC	Dedicated Short-Range Communications
DT	Direct traffic
EBL	Emergency Brake Light
EC	European Commission
EU	European Union
EVW	Emergency Vehicle Warning
FCW	Forward Collision Warning
FI	Flexible infrastructure (HOV, peak-hour lanes)
FOT	Field Operational Test
GLOSA	Green light optimal speed advisory
GP	Green priority
HOV	High Occupancy Vehicle
IMA	Intersection Movement Assist
INS	Intersection Safety
IRR	Internal Rate of Return
ITS	Intelligent Transport Systems
ITS-G5	Access technology to be used in frequency bands dedicated for European Intelligent Transport Systems (ITS)
IVS	In-vehicle signage
IVSL	In-vehicle (dynamic) speed limits
IVSS	Intelligent Vehicle Safety Systems
KPI	Key Performance Indicator
LCW	Land Change Warning
LTA	Left Turn Assist
MAI	Motorcycle approaching indication
MCA	Multi-Criteria Analysis
MPA	Motorway parking
MTTA	Mode & trip time advice
NHTSA	National Highway Traffic Safety Administration
NPV	Net Present Value
NRA	National Road Authority
O&M	Operation & Maintenance
OBE	On-Board Equipment
OBU	On-Board Unit
PND	Satnav-type personal navigation device
PN	Present Value
PV	Project Value
PVD	Probe Vehicle Data
RHW	Road hazard warning
RSE	Roadside Equipment
RSU	Roadside Unit
RTM	Rest time management
RWW	Road works warning
SCMS	Security Credential Management System
SPE	SpeedAlert
SSVW	Slow or Stationary Vehicle Warning
SVW	Signal Violation Warning
TJAW	Traffic Jam Ahead Warning

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TLC	Traffic Light Controller
TMC	Traffic Management Centre
TWs	Two Wheelers
UPA	Urban Parking availability
V2I	Vehicle-to-Infrastructure
V2V	Vehicle-to-Vehicle
VAT	Value added tax
VMS	Variable-message sign
VRU	Vulnerable Road User
WLD	Wireless Local Danger Warning
WP	Work Package
WSP	Warning system for pedestrian

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Terminology

Term	Definition
Annual cost	The cost per year of owning and operating an asset over its entire lifespan.
Annuity rate	The annual rate charged for borrowing or earned through an investment.
BCR	An indicator, used in CBA, which attempts to summarize the overall value for money of a project or proposal.
IRR	A method of calculating rate of return. The term "internal" refers to the fact that its calculation does not involve external factors, such as inflation or the cost of capital.
NPV	A measurement of profit calculated by subtracting the present values (PV) of cash outflows (including initial cost) from the present values of cash inflows over a period of time.
PV	The value of an expected income stream determined as of the date of valuation.

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Executive Summary

In the past years, there has been tremendous progress in the field of intelligent transport systems (ITS); several successful cooperative mobility projects have proven potential benefits of cooperative systems in increasing both energy efficiency and safety for specific transport modes. However, the large variety of cooperative applications have been designed for different goals, stakeholders or specific settings/ environments and have been developed on a silo-based approach and deployed independently from each other, serving however, at a higher level, similar goals and functionalities for the end-user. Scalability, IT-security, decentralization and operator openness are some of the most important properties that a technical and commercial successful solution must provide.

C-MobILE aims to stimulate/ push existing and new pilot sites towards large-scale, real-life C-ITS deployments interoperable across Europe. Well-defined operational procedures will lead to decentralized and dynamic coupling of systems, services and stakeholders across national and organizational borders in an open, but secure C-ITS ecosystem, based on different access technologies, the usage of which is transparent for service providers and seamless and continuous for the end-users across different transport modes, environments and countries.

The main scope of this document is to report the results of the ex-ante Cost-Benefit Analysis (CBA), executed at the beginning of the project. Within the context of Deliverable 2.1: Ex-ante CBA, the C-ITS services are evaluated prior to their deployment, to assist in prioritization and implementation support. Ex-ante CBA based on literature review, and past projects, uses estimated values to rank the C-ITS services based on their expected impacts and obtain economic appraisal results. The appraisal results obtained are considered as immediately comparable with the ex-post CBA, to be executed at the end of the project. The delivery of ex-ante and ex-post demonstration CBAs, in combination with the design of business models and the understanding of end-user needs related to service availability and uptake, constitute vital steps for large-scale deployments and real market roll-out. This comprehensive dual approach aims to increase the effectiveness and use of the CBA results, in order to ensure that bundled C-ITS applications deployed within the project are financially viable and that they can be sustained also after the end of the project from a business perspective.

The execution of an ex-ante CBA comprises an evaluation procedure which intends to provide insights into the pros-benefits and cons-costs of a project/ policy. According to literature review, CBA is considered as one of the most approved approaches to ex-ante evaluate a specific transport policy, since it allows effectiveness and efficiency in terms of prioritization, use of resources, financial viability and time optimization. Such analyses require though a significant number of assumptions, as the estimation of costs and benefits is most difficult since they have not yet occurred. A tendency for inaccuracies and overestimations, due to various causes of errors, is common among this type of studies and has to be taken into consideration. Nevertheless, an ex-ante CBA assists in both technical and practical aspects of the decision-making process, contributing overall in the planning process, where an "in advance" quantification and expression of costs and benefits in monetary terms is considered of significant importance.

The ex-ante CBA procedure involved a desk research and a data collection exercise, in order to define the methodology to be followed, as well as to obtain literature review data, necessary for estimations. The review of previous studies and projects provided valuable inputs, enabling both the definition of the methodological framework and the collection of data associated to costs and benefits of C-ITS services deployed in Europe and USA. The approach followed for the performance of the ex-ante CBA, is the snapshot one, which suggests the preselection of one or several target years and the calculation of the benefit cost ratios (BCRs) for these target years. In terms of data inputs, data concerning the impacts of C-ITS services on individual vehicles and data related to costs associated to the deployment of the C-ITS services were derived from the literature review, while each deployment site provided data on the current status, the C-MobILE extensions and traffic characteristics.

Considering the impact data extracted from the literature review, which refer to percent values of the impacts of Day 1 and Day 1.5. C-ITS services at EU level and for the timeframe of 2015-2030, the impact areas defined for the scope of the ex-ante CBA comprise of road safety, traffic efficiency and the environment. More specifically: a) benefits resulting from road safety increase were attributed to reductions in road fatalities, severe and slight injuries, b) benefits resulting from traffic efficiency increase were attributed to reductions in travel time and increase in average speeds, and c) benefits associated to environmental aspects were attributed to reductions in fuel consumption and pollutant emissions. Regarding costs data, prices derived from previous studies and projects are associated to the following elements: Traffic Management Centre (TMC), Roadside Units (RSUs) – Dedicated Short-Range Communications (DSRC), in-vehicle devices – On-Board Units (OBUs), personal devices (e.g. mobile phones) and data collection. Overall, it should be taken into consideration that the quality of these inputs constitutes a questionable issue, since benefits and cost estimates are much less accurate than that of traditional traffic management measures, yielding possibly in less precise results. More specifically, benefits of C-ITS services vary by location, due to e.g. the presence of traditional roadside systems. Nevertheless, since the approach concerning the performance of the ex-ante CBA is based on literature review and past projects, using such inputs comprised the best available option for the time being.

The measurement of benefits and costs against a counterfactual was based on the comparison of a scenario with-the-project with a counterfactual baseline scenario without-the-project. The baseline scenario was

defined as the one describing the deployment sites' current situation as of today, 2017, whilst the with-the-project scenario describes a reference situation depicting the C-ITS services deployment (including the C-MobILE extensions and updates) in the deployment sites by 2020 (target year). Hence benefits and costs were measured as the change compared with what would have been the case without the C-MobILE project. In order to prevent pitfalls, resulting from existing diversities between the deployment sites' characteristics, a set of common general assumptions was defined, enabling the assessment and comparison of the outputs of the ex-ante CBA for each deployment site. The list of general assumptions relates to issues concerning additional investments, the economic lifetime of the C-ITS infrastructure, installations of in-vehicle devices, end-user equipment, business models, prices and impact rates.

The ex-ante CBA was performed for each deployment site. The first step of the economic analysis was the calculation of costs. Costs data originating from the various sources inflated to 2017 levels, according to indices of consumer prices of the countries represented by the deployment sites. A discount rate of 4% was used, while the lifetime of the various systems was defined for each deployment site, resulting in deployment-site specific annuity rates. Total costs per each system and per year were calculated, then aligned to the attributes of the C-ITS services deployment of each deployment site. The second step of the analysis comprised of the benefits' calculation. For this scope, the C-ITS services impacts were scaled down, according to an extrapolation/ scaling down methodology, from national, i.e. EU, to local level, i.e. deployment site. The physical impacts for each deployment site by 2020 were defined, enabling the expression of benefits in monetary terms, based on estimates of 2020 inflated market prices. As a last step, separate BCRs for the 2020 C-ITS services deployment were set as indicative values for defining whether the C-ITS services implementation is favourable from a socio-economic point of view for each deployment site.

The outputs of the ex-ante CBA demonstrated specific categories of costs and benefits, dominating the overall cost-effectiveness of the C-ITS services. More specifically, for the majority of the deployment sites, costs associated to TMC integration, as well as to data collection, constituted the greatest portion of 2020 total costs. In terms of benefits, the biggest contributions proved to result from reductions in road accidents and travel time, showing the potential for significant improvements in the fields of road safety and traffic efficiency. Overall, BCRs were estimated to range between 2 and 5, for the majority of the deployment sites, reassuring a significant socio-economic return for every monetary unit invested in the implementation.

1. Introduction

1.1. C-MobILE at a glance

The C-MobILE (Accelerating C-ITS Mobility Innovation and depLoyment in Europe) vision is a fully safe and efficient road transport without casualties and serious injuries on European roads, in particular in complex urban areas and for Vulnerable Road Users (VRU). We envision a congestion-free, sustainable and economically viable mobility, minimizing the environmental impact of road transport. C-MobILE will set the basis for large scale deployment in Europe, elevating research pilot sites to deployment locations of sustainable services that are supported by local authorities, using a common approach that ensures interoperability and seamless availability of services towards acceptable end user cost and positive business case for parties in the supply chain.

1.2. Objective

C-MobILE aims to stimulate/ push existing and new pilot sites towards large-scale, real-life C-ITS deployments interoperable across Europe. Well-defined operational procedures will lead to decentralized and dynamic coupling of systems, services and stakeholders across national and organizational borders in an open, but secure C-ITS ecosystem, based on different access technologies, the usage of which is transparent for service providers and seamless and continuous for the end-users across different transport modes, environments and countries.

The main scope of this document is to present the ex-ante CBA performed for the C-MobILE project. The methodology is based on literature review, and past projects utilised to rank C-ITS applications based on their expected impacts, and obtain economic appraisal results immediately comparable with the ex-post CBA that is going to be performed in WP6.

1.3. Intended audience

The audience of this deliverable are Deployment Site Leaders, Service Providers and Public Authorities involved in the deployment of the C-MobILE services in each of the Deployment sites. Besides, the deliverable is written for project-external stakeholders, including all the relevant EC agencies and units, expert groups and associations interested in the potential cost and benefits of C-ITS services deployment.

1.4. Approach

Deliverable 2.1: Ex-ante Cost Benefit Analysis, included in WP2 (Needs and requirements for implementation), addresses the C-MobILE objective 8 listed below. WP2's successful achievement will be measured by different means, i.e. the publication of corresponding deliverables.

/ Objective 8: Demonstrate the added value and economic viability by means of a comprehensive Cost-Benefit Analysis and impact assessment.

> Define an impact assessment methodology via the automation of the testing cycle for evaluation while testing that will quickly provide answers and early adaptations of C-ITS services. An ex-ante CBA will analyse the impact of each application and the bundling of applications. The appraisal results obtained will be compared with an ex-post CBA. The CBA findings will be used for the development of business plans for the large-scale deployment.

Deliverable 2.1 contains the results of the ex-ante CBA, executed at the beginning of the project, in order to evaluate the C-ITS services and service bundles prior to their deployment, and to assist in prioritization and implementation support.

1.5. Document structure

This deliverable presents the C-MobILE ex-ante Cost-Benefit Analysis methodology and in order to facilitate the use of this deliverable by the project partners, as well as to be sure that its content is taken into account by the related project activities, the concrete chapters and content that should be taken into account by each activity and deployment site leader is listed below:

/ Chapter 1 "Introduction" provides the rationale and context of the C-MobILE project.

/ Chapter 2 "Ex-ante Cost-Benefit Analysis Framework" describes the general context and the objectives addressed by an ex-ante CBA.

/ Chapter 3 "C-MobILE Ex-ante Cost-Benefit Analysis Methodology" describes thoroughly the methodology used for the analysis.

/ Chapter 4 "Results" presents the findings regarding the costs and benefits of each Deployment Site.

/ Chapter 5 "Main Conclusions and Recommendations" provides the major outcomes of the ex-ante CBA.

2. Ex-ante Cost-Benefit Analysis Framework

2.1. General notions of an ex-ante Cost-Benefit Analysis

The main purpose of a Cost-Benefit Analysis (CBA) is to contribute in decision-making and particularly in investment decisions, based on objective and verifiable methods, as a result of an evidence-based and successful policy. This particular contribution varies according to the time that the CBA is performed, as a CBA can be performed ex-ante, ex-post or in the interim of a project. The term ex-ante refers to any prediction that is made prior to a project, in order to estimate the future impact of a newly implemented policy [2]. The term is typically associated with the evaluation procedure, as any form of ex-ante evaluation (e.g. appraisal, policy analysis, impact assessment, feasibility study, Cost-Benefit Analysis) constitutes a fundamental tool for improving the quality, relevance and comprehensiveness of project design. According to EC rules, it is important to start ex-ante evaluation work early on in the process when options for project formulation are still open [3].

CBA is considered to be one of the most approved methodologies to ex-ante evaluate transport policy options, as it scores high for effectiveness and efficiency [3], [4]. Research into the use of ex-ante evaluation frameworks shows that CBA is used at least in some stage of the whole evaluation procedure [5]. Basically an ex-ante CBA is a preliminary overview of all the pros (benefits) and cons (costs) of a project or policy option. These costs and benefits are as much as possible quantified and expressed in monetary terms. Costs and benefits that occur in different years are discounted and presented as so called net present values. Final results are often presented in summarizing indicators, such as the difference between costs and benefits, the return on investment, and the benefit-cost ratio [6]. There are several explanations for the popularity of CBA in the ex-ante evaluation of transport projects and its role in decision-making [7]:

/ First, most of the costs and benefits are relatively well known, at least theoretically. Investment, maintenance and operation costs can be derived from data from projects constructed in the past, or from tenders.

/ The second reason for the popularity of CBA is its often-assumed "neutral" characteristic compared to its main competitor: multi-criteria analysis (MCA). In MCA effects are presented and weighed using weights per effect. Setting the weights is not at all value-free. On the other hand there is a broad consensus that CBA is much more value-free than MCA.

Different steps are defined in the ex-ante CBA, and at each step should correspond to a specific analysis to be adapted to the level of maturity of the project [8]:

/ Preliminary analyses with global exploration of the impact of the project.

/ More detailed analyses when the project is more mature and the spatial location more precise. At this stage, a concerted process with stakeholders must take place.

/ Detailed ex-ante appraisal including official documents required by legislation or regulation in order to satisfy legal aspects of evaluation (e.g. reference to planning documents, agreed reference values for unit costs).

As pointed out by many studies there are possible common mistakes and pitfalls in an ex-ante CBA. In an ex-ante CBA, the estimation of costs and benefits is most difficult because they have not yet occurred. In this case the analysis will require a significant number of assumptions and may yield less accurate results [9]. An ex-ante CBA can show a large variation in terms of quality and assumptions, as many of them suffer from methodological fallacies, such as not covering essential information or including errors. Heterogeneous assessment approaches, can occur when appraising a project, resulting this way to inaccuracies in the estimate of future demand (and particularly demand overestimation) and investment cost (and particularly cost overruns). Studies demonstrate that there are many reasons behind this tendency. In terms of demand overestimation, the estimation of passenger and freight flows at an aggregated level prohibits an accurate network assignment. Regarding cost overruns, the causes typically differ, as it is not possible to find one single reason for the deviations. What exactly causes costs overrun is difficult to predict, but for sure the decision making process plays a significant role. The main causes of errors in costs estimation for an ex-ante CBA can be defined as follows [10]:

/ Delays in implementation.

/ Changes in project specifications and design.

/ Changes in rates between currencies.

/ Changes in quantity and prices.

/ Changes in safety requirements.

/ Changes in environmental requirements.

/ Technological risks.

The quality of an ex-ante CBA is of crucial importance for an adequate planning process. During recent decades, methodologies, as described in the literature, as well as in practice with respect to CBA, have

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developed considerably, though many challenges for further improvements remain. The main recommendations for the improvement of the methodology for any type of ex-ante evaluation of large scale deployment projects in the transport sector are summarized in the two following points [8]:

/ Consider the whole project cycle, having different stages, from preliminary appraisal to ex-post evaluation. In the appraisal stage, a comprehensive and adapted to the level of debates and analyses taking place at different stages approach is recommended. A more global assessment should be conducted in the beginning, while a more complete and detailed one at the end. In this comprehensive approach, the ex-post evaluation should enable the ex-ante evaluation procedure to be fine-tuned through an ongoing feedback process between the operating results of existing infrastructures and the assumptions used to evaluate new capital expenditure decisions.

/ Adopt a dynamic approach to ex-ante appraisal. The time dimension of the decision process must be integrated, managed and controlled. Consequently, appraisal cannot be made once and for all, but must adapt to such different stages, with more detailed analysis when the project is defined.

Regarding the overall contribution of an ex-ante CBA to the decision-making process, the pros and cons, affecting various aspects of the process, can be summarized as follows [7]:

Aspects of the decision-making process	Pros	Cons
Technical	/ Prioritisation. / Efficient use of resources. / Financial viability. / Choice between alternatives/ options. / Optimise timing.	
Political	Ensures transparency.	/ Lack of alignment with policy objectives. / Too much transparency.
Practical	Focuses on "easy" to measure direct impacts.	/ A lack of understanding of CBA by officials and politicians. / Partial analysis. / Modal comparisons difficult.

Table 1: Pros and cons of using ex-ante CBA

2.2. Differences between an ex-ante and an ex-post Cost-Benefit Analysis

The ex-ante CBA and the ex-post CBA typically exhibit differences. The first differentiation relies on the purpose served from each type of CBA. The ex-ante CBA can be characterised as project-specific and decision-oriented, by means of contributing to decide whether to proceed with a project or not. Ex-ante analysis is best for this purpose, as its contribution to public policy decision-making is direct and immediate. The ex-post CBA can be characterised as project-specific and evaluative, by means of proving whether the decision to proceed with the project has been justified. Ex-post analysis is conducted after a project. At such time it is obviously too late to reverse the resource allocation decision for this particular project. The important ways in which the two different types of CBA serve different purposes are presented bellow [1]:

Value	Class of Cost-Benefit Analysis	
	Ex-ante	Ex-post
Resource allocation decision for the project.	Yes – helps to select best project or make "go" versus "no go" decisions, if accurate.	Too late – the project is over.
Learning about actual value of specific projects.	Poor estimate – high uncertainty about future benefits and costs	Excellent – although some errors may remain. May have to wait long for study.
Contributing to learning about actual value of similar projects.	Unlikely to add much.	Very useful – although may be some errors and need to adjust for uniqueness. May have to wait long for project completion.
Learning about omission, forecasting, measurement and evaluation errors in CBA.	No.	No.

Table 2: Value of different classes of CBA

The second differentiation is associated with the content of each type of CBA, concerning especially the difference in the results between an ex-ante CBA and an ex-post CBA. Such deviations may result from methodological errors, but also from false assumptions or changes in the external environment. Studies have shown that an ex-ante CBA per se is weakened as a sole decision making tool. Methodological weaknesses may require adjustments in the ex-ante analysis and for a sensible comparison of project appraisal ex-post and ex-ante, it may be necessary to correct the ex-ante analysis for methodological errors to create a basis for comparison. More specifically, evidence about the most common mistakes and pitfalls in an ex-ante CBA suggests that systematic ex-post evaluation (e.g. CBA) is important in decision making and in particular if it is linked to ex-ante incentives to reveal true information about the projects characteristics [10].

The ex-ante CBA is mainly informative and useful for understanding whether the conceptual forecasting model adopted before project implementation was adequate to support the investment decision. It allows understanding where the efforts in improving the quality of project appraisals should be addressed, identifying those areas where the actual ex-ante methodology and decision tools are effective and those where they are weaker. The ex-post CBA can be defined as an activity based on the reassessment of the ex-ante CBA. Scope of the ex-post CBA is not discovering deviations from forecasts per se, but understanding the causes behind the deviations. The key point is whether the deviation should be attributable to endogenous or exogenous factors. While the latter are hardly predictable and outside the control of the project management, the former might be included in the ex-ante analysis to reduce the related risks. Basically, endogenous forecasting error is a matter of cost, effort, or incentives of the ex-ante analysis [11], [12].

The main differences between the ex-ante and the ex-post CBA can be summarized in the following points [9]:

/ The ex-ante CBA, undertaken when a project is being considered, is useful in considering whether a project should be undertaken or in comparing alternative prospective projects aimed at common policy objectives. The ex-post CBA provides decision makers with total project costs and benefits upon the project's completion, to assist them in evaluating a project's overall success.

/ In the ex-ante CBA, the estimation of costs and benefits is most difficult because they have not yet occurred. In this case the analysis will require a significant number of assumptions and may yield less accurate results. In contrast, in an ex-post analysis costs and outcomes are largely known and can often be estimated accurately. Nonetheless, it can be difficult to determine which costs and benefits to attribute to the project because the observed outcomes may have been the result of projects or events other than the ones being analysed.

/ For the ex-ante CBA, it is necessary to predict the impacts over the life of the project, concerning the possibility of each cost or benefit to remain the same each year or to increase, decrease, or disappear in each subsequent year. Especially in the case of changes over time, it should be taken into account the possibility of a smooth increase in the costs or benefits or of a change at irregular intervals. For an ex-post CBA, much of this information may be known, particularly if actual costs and outcomes have been reported annually. It may help to consider whether costs and benefits are upfront, accruing only in the first year, or whether they are recurring costs or benefits that occur every year.

A comparison between an ex-ante and an ex-post CBA is most useful for learning about the value of CBA per se. Such a comparison helps to estimate the level of confidence of the estimated net benefits of a possible subsequent relevant ex-ante CBA, hence providing a measure of ex-ante precision, as well as to explain the divergence between expected and realised benefits and costs [1].

2.3. Review of previous Projects and Studies

The literature review conducted within the framework of the ex-ante CBA for C-ITS showed that there are no relative studies or past project deliverables demonstrating results for ex-ante CBAs. Although there is a significant number of studies and past project deliverables, related to ITS and C-ITS, demonstrating CBA methodologies, data and results. Since the C-MobILE ex-ante CBA methodology is based on literature review and past projects, and since an ex-ante CBA methodology differs in no way to an ex-post CBA methodology, it is crucial to present a review of these particular previous activities.

The eIMPACT project (2006-2008), "Socio-economic Impact Assessment of Stand-alone and Co-operative Intelligent Vehicle Safety Systems (IVSS) in Europe", addressed the need to quantify the effects of the systems, in order to support decision making. During 2008 the project carried out impact assessments of twelve stand-alone and cooperative systems at the EU level, for 2010 and 2020. For each of these years, a scenario with a low penetration rate, reflecting no incentives to accelerate deployment, and a high penetration rate, including policy incentives for system deployment, was analysed. One of the outputs was the CBA for the twelve systems, which was extended by a stakeholder analysis, examining the costs and benefits incurred by users, industry and public authorities. The deliverable D6 "Cost-Benefit Analyses for stand-alone and co-operative Intelligent Vehicle Safety Systems" provided concrete, unified results for the socio-economic impact of IVSS, confronting the benefits and costs of the systems. Among the considered IVSS, four systems, were considered to communicate with other vehicles (Wireless Local Danger Warning) or with the infrastructure (eCall, Intersection Safety, and SpeedAlert), while all the other systems had no communication [13], [14].

Acronym	Name	Communication Type
WLD	Wireless Local Danger Warning	V2V
ECA	eCall	I2V
INS	Intersection Safety	I2V
SPE	SpeedAlert	I2V

Table 3: The considered eIPMACT V2V and I2V IVSS

System costs contained the costs for vehicle and infrastructure equipment, as well as operating and maintenance costs. Costs for vehicle equipment were relevant for each IVSS and reflected the consumption in resources which were necessary to build the IVSS. Costs for infrastructure equipment were only applicable for eCall and Intersection Safety. Operating and maintenance costs on vehicle side were not considered in the project, due to not available reliable information, in contrast to operating and maintenance costs on infrastructure side, which were estimated. The system costs per system were based on expert guesses and the approach used contained the following steps [14]:

/ An analysis of the technical architecture of the IVSS, in order to identify the various technical solutions.

/ The selection of one possible technical solution, depending on which one was the most likely for the considered years.

/ A list of the system components for each IVSS.

/ An estimation of each system component's consumption in resource.

/ For each IVSS all costs for the used system components were summed up for the year 2010 and for the year 2020.

Each estimation was based on the knowledge of the year 2008, while possible economies of scale and learning curves effects were not considered, resulting in system costs to be the same for one year – independent of the considered scenario. The specific approach showed a big advantage for the concept of system bundles, proving that if certain IVSS were bundled, the costs would not go up linearly. If the IVSS could share common components, the common components would only be built in once. Thus, the costs of system bundles with common components would be less than the sum of the system costs of each IVSS, representing in economic terms the sub-additivity of costs. The estimated system costs per vehicle, relevant for determining the denominator of the BCR, were multiplied with the number of equipped vehicles in the considered years. This value was determined by multiplying the fleet penetration rate with the vehicle fleet. For referring this product on only one year, the value had to be annualised. This was done by multiplying the value with the annuity rate. The IVSS was considered to be in use over the complete lifetime of the vehicle, which average economic lifetime was estimated in 12 years for EU25, while the discount rate was estimated as 3%. The equations used for system costs calculation were [14]:

$$(1)\ System\ cost\ per\ year\ for\ IVSS_{year\ x} = System\ costs\ total_{year\ x} \times AR,\ \text{with}$$

$$(2)\ AR = \frac{d \times (1+d)^n}{(1+d)^n - 1},\ \text{with}$$

AR: annuity rate,

d: discount rate (3%), and

n: economic lifetime of a vehicle (12 years).

The costs for infrastructure investments, required for eCall and Intersection Safety were taken from literature or, if no relevant information was available, extrapolated, and then annualised. The operating and maintenance costs for infrastructure were considered especially for eCall, where the PSAP had to be filled with employees, as well as for SpeedAlert, where costs for updating the digital maps were attributed to the navigation system software provider [14].

The benefit-cost appraisal of IVSS was based on a comprehensive safety impact assessment. The benefits considered were related to safety effects, as well as direct and indirect traffic effects. For the appraisal or the safety effects, the collected accident data had to be adjusted by the IVSS effects, resulting in the safety impact. The cost-unit rates for the safety impact, based on the year 2003, contained the costs per fatality and injury, respectively, and the costs per property damage. These values were scaled up to year 2010 and 2020 conditions considering the development of the real Gross Domestic Product (GDP) in the European Union, while an inflation rate of 2% was used for the expression of all the 2008 year prices. The indirect traffic effects were calculated per system, based on the safety impact and on the time of day each IVSS was considered effective. A daily distribution of the cost-unit rates for congestion was determined by using the cost-unit rate for congestion on average and the daily load curve of the traffic, resulting in cost-unit rates for congestion per fatality and per injury. Some IVSS, among them Wireless Local Danger Warning, SpeedAlert and Intersection Safety, considered to have a direct impact on the traffic, in terms of traffic flow harmonization, accelerations and decelerations mitigation, as well as fuel consumption and accordingly CO emissions reduction. However, the traffic simulations showed that only SpeedAlert had a traffic impact significantly different from zero [14].

The step followed after the definition of the with- and without-case, the quantification of safety and traffic impacts and their monetisation, was the economic evaluation, in means of comparing the economic benefits with costs through the calculation of the benefit-cost-ratio (BCR) [14]:

$$(3)\ BCR_{t,S} = \frac{B_{t,S}}{C_{t,S}},\ \text{with}$$

BCR: Benefit-cost-ratio,

t: Time horizon defined,

S: Low Scenario or high scenario,

B: Estimated value of benefits for t, and

C: Estimated value of costs for the year t.

The calculation of the sum up of all the benefits (safety benefits, indirect traffic benefits and direct traffic benefits) measured in Euro, is described by the following formulation [14]:

$$(4)\ B_{t,S} = F_{t,S} \times (CU_F + IT_{t,S,F}) + I_{t,S} \times (CU_I + IT_{t,S,I}) + A_{t,S} \times CU_A + 1_{IVSS\_DT} \times DT_{t,S},\ \text{with}$$

B: Benefit,

t: Considered year t (2010 or 2020),

S: Low scenario or high scenario,

F: Avoided fatalities,

CU: Cost-unit rate,

IT: Indirect traffic impact per fatality / injury,

I: Avoided injuries,

A: Avoided accidents,

IVSS_DT: Function is 1 if the considered cooperative system has traffic impacts, otherwise 0

DT: Direct traffic impact.

The costs were determined by multiplying the vehicle stock with the fleet penetration rates and with the annualised costs per system, done for both scenarios and for both years [14]:

$$(5)\ C_{t,S} = VS_t \times FP_{t,S} \times CS_t,\ \text{with}$$

C: Costs,

t: Considered year (2010 or 2020),

S: Considered scenario (low or high),

VS: Vehicle stock,

FP: Fleet penetration rate, and

CS: Annualised costs per system (discount rate: 3%, lifetime: 12 years).

CODIA (Co-Operative Systems Deployment Impact Assessment) (2007-2008) aimed to provide an independent assessment of direct and indirect impacts, costs and benefits of five co-operative systems: Speed adaptation due to weather conditions, obstacles or congestion (V2I and I2Vcommunication), Reversible lanes due to traffic flow (V2I and I2V), Local danger/ hazard warning (V2V), Post-crash warning (V2V), and Cooperative intersection collision warning (V2V and V2I). The report "Co-Operative systems Deployment Impact Assessment (CODIA) – Deliverable 5, Final Study Report" provides a description of the methods used in the assessment of costs, impacts and benefits of the five cooperative systems, as well as the results concerning those impacts. Most of the cost estimates were based in the costs available from the eIMPACT project, while the costs for the infrastructure elements were largely obtained from the cost database maintained by the U.S. Department of Transportation as well as from "The handbook of road safety measures". The estimation of penetration rates of selected systems for the years 2015, 2020 and 2030 was conducted in several phases resembling the procedures applied in the eIMPACT project, while the calculations were based on European data originally describing the status of the European transport and vehicle system in 2005 [15].

The benefit and cost assessment methodology relied on standard discounted flow and CBA techniques. Regarding the series of assumptions and decisions adopted, the items of costs and benefits included in the calculus consisted of the following categories [15]:

Actor	Costs	Benefits	Non-monetised costs	Non-monetised benefits
System users	*Purchase cost of the system.	*Time cost savings.	In some cases the maintenance and	-

			upgrading costs.	
	*In some cases the maintenance & operating costs.	*Accident cost savings.		
Infrastructure managers	Required ITS infrastructure investments and maintenance.	-	-	Increased road safety and enhanced traffic management.
External (society)	-	*Time cost savings. *Accident cost savings. *Environmental cost savings.	-	Increased tax revenues due to corporate income and VAT.

Table 4: CODIA Cost and benefit items

The formula used for the calculation of the net present value of the deployment of each system was [15]:

$$(6)\ NPV = \sum_{t=2005}^{n} \left[\frac{ACC_t + Tim_t + Env_t - Sinv_t - Sope_t - Iinv_t - Iope_t}{(1+r)^{t-2005}} \right], \text{ with}$$

ACC: Accident cost savings in year t

Tim: Time cost savings in year t

Env: Environmental cost savings in year t

Sinv: System investment cost in year t, i.e. the purchasing cost of users

Sope: System operating and maintenance costs for the users in year t

Iinv: Required ITS infrastructure or other infrastructure investment in year t

Iope: ITS infrastructure operating and maintenance cost in year t

r: the rate of return, discounting rate

t: time starting from base year 2005 until n, selected to extend maximum to 2030.

All systems proved to have safety benefits, resulting in reductions in accident related congestion, while Dynamic speed adaptation showed most potential (-7%) to decrease fatalities and Cooperative intersection collision warning had highest potential (-7%) to reduce injuries. Concerning the direct systems' benefits to traffic, the speed adaptation and local danger warning caused the highest increases in journey time. Benefits concerning emissions were very small for all systems, with benefits associated to indirect emissions effects due to reduced accident related congestion, to be somewhat larger, indicating lower emissions. With regard to benefit cost ratios, the systems to indicate socio-economic profitability were Speed adaptation and Local danger warning indicate, in contrast to Cooperative post-crash warning and Reversible lane control who were proved not socio-economically profitable [15].

The "Report on socio-economic, market and financial assessment" conducted within the framework of the SAFESPOT project (2006-2010) had the objective to provide a socio-economic assessment for two cooperative system bundles, based on technically specified safety applications addressing road intersection safety, hazard and incident warning regarding road condition and low visibility, and keeping speed limit and safe distance. The core of the assessment methodology was a CBA estimating possible safety and traffic effects of the SAFESPOT bundle to prove the profitability of the system from a socio-economic point of view [16].

The estimation of the penetrations rates of the SAFESPOT cooperative system was based on an experts' survey about the market potential of the systems in new vehicles, with respect to different business and service models concerning the financing of the systems and services provided. Regarding the estimations of benefits related to safety, the cost-unit rates included personal damage, property damage and congestion related to accidents, based on a proposal of the EC for personal damage costs [17]. The cost unit rates reflected an average productivity growth of 2,4 % in the EU until the target year 2020, while the values proposed by the EC were scaled up to prices of the year 2009 using an inflation rate of 2 % which was considered as price stability by the European Central Bank. As traffic benefits were considered savings in travel time, fuel consumption, CO_2 emissions and NOx-equivalent emissions. The cost-unit rates were derived from eIMPACT, based on 2005, except for the ones regarding CO_2 emissions, which were updated according to the suggestion of the German Federal Environment Agency [18]. The system costs generally consisted of two elements: 1) investment costs, which appear only once in a lifetime of a system, 2) operating and maintenance costs, which appear several times during the lifetime (e. g. every year). The investment costs had to be annualized, hence the system costs per cooperative system and per year were determined by multiplying the investment costs by the annuity rate, and adding the operating and maintenance costs. The results of the CBA were presented through the BCR, where the benefits and costs in formal terms were given as follows [16]:

$$(7)\ B_t = F_t \times c_F + I_t \times c_I + 1_{IVS\_DT} \times DT, \text{ with}$$

B: Benefits (EUR)

t: Considered year t (2020)

$c_{,}$ c: Cost-unit rate for fatalities / injured (EUR)

F: Avoided fatalities

I: Avoided injured

1IVS_DT: Function is 1 if the considered cooperative system has traffic impacts, otherwise 0

DT: Direct traffic impact.

$$(8)\ C_t = VS_t \times FP_t \times CS_t,\ \text{with}$$

C: Total costs (EUR)

t: Considered year (2020)

VS: Vehicle stock

FP: Fleet penetration rate (%)

CS: Annualised costs per system (discount rate: 3%, lifetime: 12 years).

The report "Final Report and Recommendations of the Intelligent Infrastructure Working Group" (2010) conducted by the e-Safety and the Intelligent Infrastructure Working Group, aimed to define intelligent infrastructure by analysing the services expected to be delivered, as well as the minimum levels of equipment/ systems required to supply various cooperative systems. The five key questions to be addressed included: the definition of intelligent infrastructure, the specific services contributing to the implementation, the necessary technological resources and the respective business areas, actions to be done to assist the implementation, and the relation between intelligent infrastructure and intelligent vehicles. The report elaborates the potential added value and assesses the impacts of a variety of services focusing on travel information provision, traffic management, freight transport and logistics. The impacts of the services were estimated in terms of negative percent values depicting the expected improvement of traffic safety and the reduction of congestion and greenhouse gases. Estimates were made as well for the services' benefit-cost ratios [19].

The estimates of the added value of the services proved to be very positive with regard to the policy objectives of safety, environment and throughput. The estimates presented in the report were, however, largely based on the impacts assessed for autonomous versions of the services and for individual services. It was considered that the cooperative systems would be capable of providing substantial impacts, when deployed in an integrated manner. In other words, an individual service would rarely be economically viable, but bundling of services would likely make it possible to reach positive business cases. Concluding, it was stated that the need of collecting robust and statistically reliable data on the socio- and private economy impacts of the cooperative systems, both for individual services and especially for bundles of services complementing each other in terms of functionalities and impacts, is rather urgent [19].

The euroFOT project (2008-2011) "European Field Operational Test on Active Safety Functions in vehicles", by testing and assessing the performance of eight key functions on European roads, aimed to contribute to the market introduction of and wider uptake for intelligent vehicle systems. The deliverable "Deliverable D6.7 Overall Cost-Benefit Study" informs about the socio-economic dimension of the impacts derived from euroFOT and the costs associated with such technologies. The methodological choices of the CBA comprised the following elements [20]:

/ The scenarios assumed for the systems included a full penetration and a 10% penetration rate, each of them combined with medium economies of scale (10% reduction of unit cost when output volume is doubled). In addition different levels of economies of scale as well as various equipment rates were considered with respect to their impact on the benefit-cost results.

/ The boundary conditions (road safety performance, traffic performance) reflected 2010 year conditions, wherever possible. This approach had the advantage that no projections for fleet, performance and price development had to be integrated in the model.

/ Although the calculation model was ready to perform a full set of CBA for each tested function, the CBA feasibility was narrowed down due to non-applicable and/ or insignificant impacts found in the FOT, as well as performance restrictions in up-scaling to EU-27 level.

/ The cost-unit rates regarding accidents had been chosen according to the best good practice at European level. Key values included Mill. € 1,6 per avoided fatality, € 70.000 per avoided injury, efficiency benefits of avoided casualties (add on to road safety): € 15.500 per avoided fatality accident, € 5.000 per avoided injury accident, Time cost-unit rates (per vehicle hour): € 20 per vehicle hour for cars and € 30 for Heavy Goods Vehicles, Net fuel costs (i.e. without taxes, per l): € 0,75 for gasoline as well as Diesel, Environmental costs: € 70 per ton CO_2.

/ The unit costs per system were derived top-down from market prices of ACC+FCW. Using the FESTA/ eIMPACT approach the resource costs of such systems were calculated by applying factor 1/3.

The main results of the cost-benefit assessment can be summarized as follows [20]:

/ The costs of equipping the entire fleet of passenger cars and heavy trucks with the combined system ACC+FCW led to annually approx. Bn € 1,6 (passenger cars) and approx. Mn € 28 for heavy trucks (because of the smaller fleet).

/ Annual benefits for cars added up to Bn € 0,8 to Bn € 1,2 (full penetration) respectively Mn € 126 to Mn € 175 (10% penetration rate), depending on the magnitude of safety impact.

/ Annual benefits for trucks amounted to approximately Mn € 108 and Mn €146.

/ For trucks, the ACC+FCW bundle was clearly profitable from society point of view. The benefit-cost ratio was between 3.9 and 5.2.

/ For cars, the attainable benefits (based on the assumptions introduced to the assessment) were not sufficient to outweigh the costs. The benefit-cost ratio ranged between 0,5 and 0,7.

/ Sensitivity of the results was tested for the cars scenario. The overall result was that modifying input parameters (such as higher cost-unit rates for impact appraisal, considering potential underreporting of injury accidents) would bring the benefit-cost ratio close to or even above 1.

/ Former ex-ante impact assessment studies had indicated more favourable benefit cost results (e.g. eIMPACT).

/ For passing the profitability threshold it would require to widen the scope of the assessment by including also benefits from avoiding property damages.

The Deliverable D.FL.6.4 "Cost-Benefit Analysis" contains the cost-benefit analysis results for the deployed systems within the FREILOT project (2009-2012). The FREILOT consortium developed an approach to deal with the issue of fuel consumption for goods vehicles in urban areas, by deploying the following systems: Delivery space booking, Energy efficient intersection control and In-vehicle systems. Considering the fact that each technology had different settings and was associated to specific assumptions and hypotheses, the FREILOT consortium defined a set of common assumptions to all the CBA scenarios, in order to compare and assess them. The general hypotheses were associated to investment types and the responsible stakeholders. The main assumptions included a hypothetic city (a virtual 2.000.000 inhabitants urban area created from real data, where the investor would be a public authority, having the money available to invest gradually in systems introduction). The time horizon for the CBA was considered to be of ten years, assuming that the level of operating costs and revenues would remain constant over that period. The discount rate and the target IRR were assumed to be the French public one, i.e. 4%. The final result of the analysis was the estimation of costs and benefits for two main stakeholders, the city (or the collective community) and the transport carriers (or individuals), by using evaluation tools, such as generalising local effects to a city point of view [21].

The COBRA project "Cooperative Benefits for Road Authorities" (2011-2013) aimed to help road authorities to position themselves to realise the potential offered by developments in cooperative systems. It did so by providing insights into the costs and benefits of investments, both from a societal perspective and a business case perspective. The insights were provided on the basis of a decision support tool which enabled the costs and (monetised) benefits of cooperative services to be compared in various contexts. The document "Deliverable 4.1 Example Results of Cost Benefit Analysis" presents a series of examples of the results of analysis of costs and benefits and the business case for national road authorities to invest in cooperative systems in different situations. The tool enabled road authorities to consider investment in cooperative systems to deliver services in three bundles of functions based on communications between vehicles and infrastructure [22]:

1. Local Dynamic Event Warnings: Hazardous location notification, road works warning, traffic jam ahead warning and post-crash warning (eCall).

2. In-vehicle Speed and Signage: In-vehicle signage, dynamic speed limits and Intelligent Speed Adaptation (ISA).

3. Travel Information and Dynamic Route Guidance: Traffic information and recommended itinerary, multi-modal travel information and truck parking information and guidance.

The method used in the tool was based on recommended techniques for benefit cost analysis developed in European projects. The user guide which accompanies the tool describes the cooperative systems and scenarios which are available for assessment, the parameters which can be set by users, and the technical aspects of using the tool. The tool itemises the main benefits in monetary terms for each bundle of services. Monetised benefits can be identified as arising from two sources: 1) societal benefits, where the cooperative services provide a monetisable benefit to society as a whole, 2) direct monetary benefits, where the implementation of (a bundle of) cooperative services leads to direct savings to the road authority. The benefits included in the tool are: reduced fatalities and injuries, reduced accidents, less incident-induced congestion, more reliable journey times, reduced travel times, reduced fuel consumption, reduced emissions (CO, NOx, PM) from smoother traffic flow and reduced infrastructure requirements [22].

The tool relies on making conservative estimates, in order to reduce the likelihood of overoptimistic assessments. The tool enables a certain degree of flexibility in terms of which costs to be included, depending on policies on the scope of the business case (e.g. include direct road authority costs, and exclude owners costs). Cost categories are comprised of: in-vehicle costs (one-off capital costs, e.g.

equipment and installation; annual operational costs, e.g. subscriptions and cellular communication costs) and societal problem costs (road safety, e.g. fatalities, injuries, damage and other associated costs; travel time; fuel consumption, e.g. money spent petrol and diesel, excluding tax; and emissions, e.g. CO, NO, particulate matter). Other input data categories are associated to the forecast of number of vehicles to be equipped, impact values, deployed units (number of RSUs, number of back offices, road length), deployment of existing roadside infrastructure, discount rate [22].

The analyses presented in the report covered a range of different situations, in order to indicate where the main costs and benefits arise and how these change over time, as well as to demonstrate the sensitivity of the results to certain key parameters. The analyses represented three different scenarios: 1) all in-vehicle costs were set to zero and the bundles were considered at medium and high penetration rates (with penetration in the vehicle fleet at 75% and 100% by 2035), 2) in-vehicle annual communication and subscription costs, as well as one-off in-vehicle equipment costs were included, 3) the choice of the Cellular or Wireless Beacons platforms and of different business models, affecting the national road authorities, was considered. All of the analyses presented results for deployment over the entire assessment period, 2012 – 2030, covered by the model [22].

The objective of the DRIVE C2X project (2011-2014) was to assess comprehensively cooperative systems by means of extensive FOTs in different European countries. The functions tested included [23]:

/ Obstacle warning/ Road works warning (OW/ RWW).

/ Traffic jam ahead warning (TJAW).

/ Car breakdown warning (CBW).

/ Weather warning (WW).

/ Approaching emergency vehicle warning (AEVW).

/ In-vehicle signage (IVS).

/ Green-light optimal speed advisory (GLOSA).

/ Emergency Electric Brake Light (EEBL).

The evaluation procedure focused on determining the impacts of the DRIVE C2X functions on safety, mobility, efficiency, and environment. The DRIVE C2X project collected empirical data from FOTs, which was used in the impacts assessments. A CBA was not carried out. The deliverable D11.4 "Impact Assessment and User Perception of Cooperative Systems" reported on the impact assessment and user acceptance of the DRIVE C2X functions, based on measuring subjective and objective driver behaviour. Outcomes of the deliverable are reliable numerical impact estimates of DRIVE C2X functions on traffic safety, mobility, efficiency and environment, based on real use of the functions on the test sites. All results made use of measurements carried out before, during and after the driver testing in the DRIVE C2X FOTs [23].

The SEE-ITS (2012-2014) project aimed to stimulate cooperation, harmonization and interoperability between isolated ITS in South East Europe, by focusing on setting the framework for ITS deployment in the field of road transport and for interfaces with other modes of transport based on the guidelines of the European Union's Directive (2010/40/EU) dealing with ITS deployment. One of the project's tasks was the performance of CBAs for the nine countries constituting the consortium (Greece, Austria, Italy, Romania, Hungary, Bulgaria, Slovenia, Croatia and Albania). The delivered reports included detailed CBAs of the integrated traffic & mobility management and traveller information systems that were developed in the framework of the project, while the overall benefits and costs from a future implementation of the aforementioned systems were computed. The adequate techniques for the transformation of qualitative criteria (environmental, social) were identified and applied for the computation of the external effects. The computation of costs and benefits followed the analytical CBA procedure, namely the analysis was composed by three different perspectives: the user perspective, the operator's perspective and the government's perspective. The overall welfare of the society for the countries was calculated as the sum of the three separate perspectives [24].

The Compass4D (2013-2015) pilot project deployed C-ITS services in seven European cities (Bordeaux, Copenhagen, Helmond, Newcastle, Thessaloniki, Verona, Vigo) in order to improve road safety, increase energy efficiency and reduce congestion for road transport. The project aimed also at identifying deployment opportunities and barriers, and finding solutions for those. Therefore, an important part of the work focused on CBA, deliverable D6.4 "Cost benefit Analysis", as a sound validation method of business models and prospective analysis. As a first step, the deployment and operation costs associated with the piloted services were analysed, including all investments as well as all tactical and operational costs, year after year, for a time horizon of 10 years. These costs were weighed against the measured benefits based on input from deliverable D4.2. "Final Results Report". Based on the results, the CBA provided feedback on how to optimize benefits and minimize costs [25].

The impact of the deployed Compass4D services was assessed for each individual pilot and over the entire network of a virtual model city, therefore all external costs were accounted for. In an effort to analyse the deployment on the same comparative basis, the same general assumptions were followed in all pilots. In particular it was assumed that the investment in infrastructure was done by a public authority, mainly a city, and the money to invest was available. In the case of the virtual model city CBA, investments were

made gradually during various years. The CBA was made with a 10-year horizon, with the operating cost levels and revenues remaining constant over this period. The target internal rate of return was set to 4%, assuming that no private investors were involved [25].

The initial analysis was performed on a pilot site basis rather than on a provided service basis, in an effort to evaluate the efficiency of the combined services provided in any pilot. In this sense, the outcome of the analysis aimed only to demonstrate the viability of the current pilot sites over a horizon of 10 years and identify which functionalities and services and modes of transport had the potential to generate the larger financial benefits. All relevant initial investment and annual maintenance and operation costs for each pilot site were collected. Then, in order to estimate the socio-economic benefits, the achieved time and fuel consumption reduction attributable to the relevant C-ITS services deployed in each pilot were identified. The estimations of the socio- economic benefits considered a number of important parameters for each transport mode, like the engine capacity, type of fuel, average fuel consumption, fleet composition, total number of passengers per transport mode, total distance travelled etc. In addition a number of common constants for all pilot sites had to be identified, like the societal cost of CO_2 emissions, CO_2 emissions per litre diesel and petrol, the cost of goods hours for heavy goods vehicles, the societal cost of travel time by taxi and the societal cost for travel time per passenger in public transport. In order to perform the CBA on a pilot site basis, all sites provided information about their assets per relevant stakeholder. Then the annual operation and maintenance costs associated with the listed assets per pilot were assembled. Costs included [25]:

/ The annual regular maintenance costs related to technical support, warranty extension, and stock per stakeholder and asset.

/ The costs related to unforeseen damages and potential accidents.

/ The annual insurance costs.

/ The LTE communication costs.

/ The necessary staff costs.

The costs of disruption during installation and maintenance were not considered.

Calculations were repeated assuming a gradually increasing annual fee for the use of the deployed services of the main users who benefit from the offered C-ITS services. This was done to identify the impact of the annual return of the deployed services on a pilot site basis on the viability of the system. In all pilots considered, with the exception of Verona for which no relevant data were available, the annual balance for Year 1 was estimated based on the assembled initial investment, the operational and maintenance costs and the total annual benefit. The estimated values for the total annual benefit and the total balance were then used to estimate the evolution of the PV of the deployed services assuming that there is no expansion of the system and an average discount rate of 4 %, over a 10 years period. Furthermore, the estimations were then repeated by considering a total of four scenarios of imposed fee to the users of the deployed services. It should be mentioned that the CBA, which was performed for each individual pilot, considered only a small number of equipped vehicles and intersections and it did not address safety impacts. Hence the main objective was to identify which functionalities and services and modes of transport had the potential to generate the larger financial benefits and to assess whether the deployment of C-ITS services could bring net benefits [25].

A complete CBA was performed on a virtual model city, which had the characteristics of several medium European areas assuming optimum penetration of the deployed Compass4D services for all modes of transport (heavy goods vehicles, buses and light vehicles). Considering the need to also address safety impacts the penetration rate over the network of the model city was assumed to be 100 %. The annual balance for the initial investment and O&M (operation and maintenance) costs were firstly estimated. Then the annual and total return, over a 10 years horizon were calculated, assuming that all investment costs were realized during the first 5 years of the project. In this first step, safety impacts were not considered. The results of the calculations made for the case of the virtual model city confirmed the significant net benefits that the deployment of the C-ITS services could bring to cities. Calculations proved that even under the assumption that no travel time and fuel consumption reductions can be achieved, the benefits that arise due to the improvements in road safety outweigh considerably the relevant costs [25].

The main conclusions were that [25]:

/ Significant benefits can be achieved providing an implementing city integrates all functionalities and services related to C-ITS in their infrastructure.

/ The final benefits mostly depend on the network geometry, the initial traffic status and driving behaviour.

/ When considering safety impacts, the benefits that arise from the deployment of the C-ITS services are far greater compared to the associated costs.

/ In case the services are deployed over the entire city network, which implies a penetration rate of 100 %, the generated annual return is so high that the investment would be compensated from the first year of the operation of the system.

The VRUITS (2013-2016) project assessed the safety and mobility impacts of ITS applications for VRUs and the impacts of current and upcoming ITS applications on the safety and mobility of VRUs. The project

identified as well how the usability and efficiency of ITS applications can be improved, and recommended which actions has to be taken at a policy level to accelerate deployment of such ITS. The deliverable D3.1 "Assessment of the selected ITS applications on safety, comfort, mobility and socio-economic impact" provides the framework for the CBA of VRUITS, which is based on the comparison of the situation where the examined ITS service is deployed, to the business-as-usual case where no such service would be available. The time horizon for the CBA was from the year 2015 up until 2030. The CBA was carried out from an EU-27 perspective, meaning that the costs and benefits of the systems were calculated on an EU level and no specifications were given on a country or city level. After defining the costs involved for the installation and operation of the different versions of the examined ITS services, the CBA method considered the impacts these services would have in the fields of safety, mobility (travel time and travel costs), comfort and environment (indirect effects of the systems were not included in the scope of the CBA, e.g. health effects and increased social inclusion of vulnerable road users). The most likely penetration rates of the systems up until 2030 were taken into account and were processed in a low, medium and high scenario. The potential costs and benefits in these fields were then quantified and monetised before they weigh against the systems' deployment and operation costs [26].

The monetisation of the impact categories was performed according to the following methods [26]:

/ Safety impacts were monetised following the guidelines for definition of the costs of accidents as developed by the project HEATCO.

/ Direct mobility impacts took into consideration the value of the change in the number, duration, mode and length of trips conducted by different road user groups as a consequence of the introduction of the examined ITS.

/ Comfort was monetised based on the existing practice in the field of public transport where the Value of Time is connected to the comfort level of passengers.

/ Potential environmental benefits were estimated in a simplistic way, focusing on the impacts on emissions due to a change in the overall modal shift and passenger-km carried out per mode.

The systems' impacts were expressed in indicators such as the net NPV, the IRR and the payback period. The use of these indicators intended to identify the systems which could yield the greatest benefits in the most efficient way. In the calculations a discount rate of 5,5% was used, while in the sensitivity analysis the effect of a higher and lower rate was calculated. The sensitivity analysis was performed to establish the robustness of the estimated impacts of the examined ITS, involving testing the impact on the results of the CBA for each ITS, in terms of NPV, in the case where basic assumptions regarding project implementation and the size of the estimated impacts were systematically reviewed [26].

The deliverable D6.4 "Cost Benefit Analysis" of the CO-GISITICS project (2014-2017) presents the results of the CBA performed for 5 services (Intelligent Truck Parking and Delivery Areas Management, Cargo Transport Optimisation, CO_2 Footprint Monitoring and Estimation, Priority and Speed Advice and Eco-drive Support), for each type of stakeholder and for each of the 7 pilot sites – logistics hubs (Arad, Bilbao, Bordeaux, Frankfurt, Thessaloniki, Trieste and Vigo). The analysis of costs was based on data provided by the pilot site leaders, which were collected after the services were tested, in order to depict better the real costs needed to run the services. The measurement of benefits was based on a selection of KPIs, such as the number of km travelled, the average fuel consumption, CO_2 emissions and average waiting time, which were measured before and after the CO-GISITICS services were put into operation [27].

The CBA consisted of four phases, aiming to present the results of the analysis from four different perspectives. In Phase I, the main stakeholders of the services were identified along with the main indicators of the costs and benefits, which were collected from pilot sites leaders in Phase II. The collected data referred to three different scenarios: 1) the "AS-IS" scenario, 2) the investments needed to deploy the services, and 3) the costs and benefits identified to execute and maintain the services. In Phase III the CBA was carried out from the point of view of the different stakeholders (e.g. private, public) and for each service. Finally, in Phase IV, data were aggregated with the main objective of presenting different business solutions, proving the advantages, in terms of costs and benefits, of the multiple deployment of services. The evaluation of the costs and benefits was based on the NPV over 5 years to assess the time needed for payback of the investment [27].
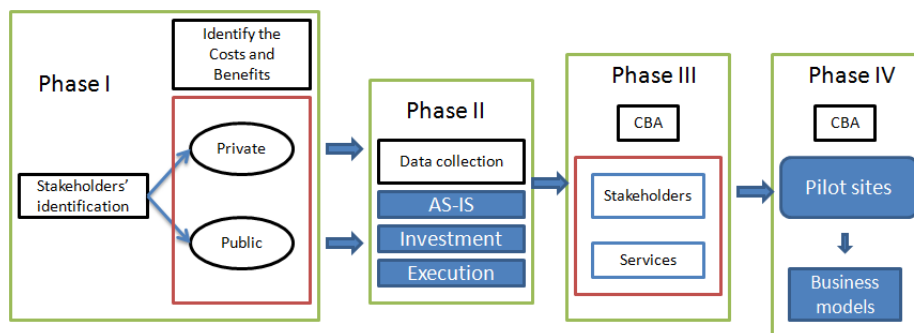

Figure 1: CO-GISTICS cost-benefit analysis methodology

EC defined the risks of uncoordinated C-ITS deployment and mapped them on a "C-ITS Problem Tree", depicted in the document "Final Report" (2016) [28] of the C-ITS Platform. In an attempt to support the deployment of C-ITS in Europe, the Working Group on Cost Benefit Analysis (WG1) proposed the Day 1 and Day 1.5 services. The EC commissioned Ricardo Energy and Environment to carry out a study on the Deployment of C-ITS in Europe. WG1 functioned as an expert group to provide feedback on the work of Ricardo and its sub-contractor. The study proposed a selected number of scenarios that would lead to the widespread and coordinated deployment of interoperable C-ITS services throughout Europe. The analysis studied the costs and benefits of deploying C-ITS enabled services for road transport in the Member States of the European Union in the period between 2015 and 2030.

Ricardo Energy and Environment together with subcontractors Trasporti e Territorio (TRT), were commissioned to deliver a study titled "Study on the Deployment of C-ITS in Europe" (2016), which aimed to assess the benefits and costs that could be achieved through a series of potential European C-ITS deployment scenarios, described in the study. The study presents a full CBA modelling phase, as a result of desk research, consultation and data collection exercise, as well as a series of international case studies, in order to identify best practice and lessons learned elsewhere, which may be relevant to the EU. A series of steps were required to produce the outputs from the CBA, involving an extensive data collection exercise (literature review, expert input), the definition of a series of deployment scenarios (one baseline scenario and five independent & additional scenarios) and a series of modelling steps centred around the ASTRA and TRUST models [29].

As a first step the main problems to be addressed were defined, contributing in the establishment of a foundation layer, which would constitute the base for the CBA. The core requirements included EU-wide interoperability and continuity of services, environmental and safety issues, technological neutrality and achieving sufficient uptake rates. Considering also the aspects of multimodality and technological readiness of already existing demonstration projects, WG1 established a list of C-ITS services that were likely to be deployed first. The following step was the establishment of a baseline scenario, describing the likely deployment roadmap of C-ITS services, without additional EU action, but including existing Member State and industry initiatives. The deployment scenarios were identified based on estimations of the most promising rapid and widespread uptake, over and above the baseline scenario. Each deployment scenario was built on the previous one and together covering the whole list of Day 1 and Day 1.5 services, as well as all relevant vehicle and road types. The scenarios needed to be translated into their environmental, social and economic impacts, hence requiring [28]:

/ The definition of uptake rates of the C-ITS technology.

/ Modelling the effects of the introduction of the C-ITS technology.

/ The quantification of the benefits.

/ The quantified benefits' translation into costs and their comparison to required investment.

/ The assessment of secondary effects (e.g. reduced fuel tax revenues, job creation, and modal shift).

The final step included the formation of the input data to be used in the analysis. In order to reach the best possible quality of data, the combined experience and knowledge of the WG1 was complemented with discussions and live feedback during meetings to make intelligent estimations, while data gaps were filled by the literature review. The first overall conclusion of the CBA was that the benefits of the C-ITS services deployment are expected to be very large, appearing though not in the short-term. The second overall conclusion was that benefits concentrated in reduced travel times, reduced accident rates and reduced fuel consumption, whilst costs were largely dominated by vehicle equipment. Concerning the estimated overall BCR, it resulted to be very high, up to 3 to 1, as total annual benefits estimated at 15Bn € and total annual costs estimated at Bn € 2,5 by 2030 [28].

Three main data inputs were required to carry out the modelling required for the CBA of the various C-ITS deployment scenarios developed, namely: 1) C-ITS service and infrastructure uptake and penetration rates, 2) C-ITS service impact data, 3) C-ITS supporting technology and service costs. For the purposes of modelling, C-ITS services were grouped into a series of service bundles, based on a number of metrics, including: whether they are V2V or V2I; whether they are Day 1 or Day 1.5 services; their primary targeted geographic deployment areas (Trans-European Transport Networks (TEN-T) corridors, core TEN-T, TEN-T comprehensive, urban); the communications technology they employ; their primary targeted vehicle type(s); and their primary purpose [29].

The baseline scenario was defined as the one in which "no additional EU action" is taken beyond on-going activities (expected developments already initiated by national or regional public authorities were included, as well as their continuation for the duration of the modelling period, to 2030). The definition of the uptake and penetration rates in the baseline relied on two key elements: 1) all EU Member States were ranked into three "country groupings" ("Front Runner", "Planned Adopter", or "Follower") corresponding to different levels of ambition in existing and planned deployments, so that average infrastructure penetration rates, for each country grouping, and an overall average EU-level penetration rate for infrastructure to be estimated; 2) the uptake rate for hardware required to support C-ITS services in vehicles and in the aftermarket was based primarily on expectations that a bundle of safety-based C-ITS services would be mandated in the US from 2018. The five independent and additional scenarios were based on the assumption that each one of them would be building on the previous through the deployment of additional bundles and thereby representing an increased level of ambition. For the full definition of hardware uptake rates, the hardware/

devices and associated software and services used to facilitate the C-ITS services were divided into four main categories [29]:

1. In-vehicle ITS sub-system (V2V and V2I).
2. Personal ITS sub-systems (V2I and possibly in the future V2V).
3. Roadside ITS sub-systems (V2I).
4. Central ITS sub-systems (part of a centralised traffic management system).

For each one of these categories various deployment assumptions were made, relevant to the scenario-combined bundles and the equipped vehicles [29].

Three key categories of impact-related outputs were produced by the CBA [29]:

1. Environmental impacts.

   / Fuel consumption and CO_2 emissions.

   / Air quality.

2. Social impacts.

   / Health and safety (road fatalities, severe and slight injuries).

   / Jobs and employment market.

   / Privacy and personal data.

3. Economic impacts.

   / Direct economic impacts.

   / Secondary impacts, such as changes in competitiveness, congestion, reliability and distributional impacts.

   / Impacts on GDP.

Regarding the modelling outputs, all costs and benefits were quoted in 2015 prices, using a 4% social discount rate for future costs/ benefits. The majority of the systems deployed to support the rollout of C-ITS services were considered at a relatively early stage of maturity, since costs are likely to improve through time. To account for this, an initial learning rate of 10% was applied to all up-front costs for personal, in-vehicle and roadside ITS sub-systems. A wide range of input data and assumptions fed into the modelling for each scenario, with penetration/ uptake assumptions being the inputs with the largest uncertainties. In order to minimize the impact of variations in these assumptions, three sensitivities ("low", "medium" and "high") were developed for each of the five scenarios, with each showing a varying degree of ambition with respect to deployment levels [29].

The main conclusions and recommendations from the study are summarized in the following points [29]:

   / A small number of cost and benefit categories dominate overall cost-effectiveness of C-ITS.

   / There is a significant benefit from spreading initial investment costs across more services.

   / More rapid deployment results in faster break-event due to "network" effects.

   / Using cellular networks to provide V2I services can have immediate benefits.

   / C-ITS deployment is highly beneficial at an EU level, but coordinate action is required.

   / Additional evidence is required in a number of fields to support the deployment of C-ITS.

The ANACONDA (Assessment of user needs for adapting COBRA including online database) project, building on the results of the Cobra project, aimed to position COBRA+ as a major tool for decision-making support for deployment of C-ITS for National Road Authorities (NRAs). The new COBRA+ tool is enhanced with new functionalities, greater geographic coverage and more flexibility, and therefore updated to meet the users' requirements. ANACONDA enabled the analysis of 7 C-ITS services, as well as their combinations [30]:

   / Hazard Location Warning.

   / Road Works Warning (short distance).

   / Traffic Jam Ahead Warning.

   / Shockwave damping.

   / In-Vehicle Signage (excluding speed limits).

   / In-Vehicle Signage Speed Limits.

   / Traffic information and Road Works (long distance) Information.

The deliverable D4.1 "Report on data collection and processing" presents the approach for collecting and processing the data required for the cost-benefit calculations in the tool. Data can be divided into: 1) country-specific data about the road network and infrastructure costs, 2) expected (societal) impacts of the C-ITS services and 3) assumptions for the underlying cost benefit models, such as penetration curves for different technologies. The collection of country-specific data was divided into two phases, which were conducted subsequently: the NRAs of the countries were first asked to provide general data about the network to be analysed in ANACONDA, and then asked to provide additional NRA specific details. The data figures included network size, societal problem size (e.g. accidents, emissions), forecasts of societal problem size data, driven distances per year, as well as more specific data on the costs of existing and future ITS infrastructure (e.g. variable message signs and ITS-G5 beacons). To cope with missing data, the project team conducted a literature review to fill the gaps, while in the case of still data missing, default values were provided to complete the sheets for each country. The percentage change of impacts on safety, traffic efficiency, fuel consumption and emissions due to the introduction of C-ITS, was synthesized from various impact assessment studies (e.g. CODIA, EasyWay, eIMPACT) and literature sources, setting the basis for the societal cost-benefit calculations [30].

The "DOT ITS Knowledge Resources" is a website, developed by the Intelligent Transportation Systems Joint Program Office (ITS JPO) of the U.S. Department of Transportation (U.S. DOT), which presents summaries on the benefits, costs, deployment levels, and lessons learned for ITS deployment and operations from over 20 years of ITS evaluation studies, research syntheses, handbooks, journal articles, and conference papers tracking the effectiveness of deployed ITS. The CV Benefits Database [31] provides findings from C-ITS evaluations, presented in a concise summary format. Each CV benefit summary includes items such as a title in the form of a short statement of the evaluation finding, context narrative, and identifying information such as date, location, and source, as well as the evaluation details that describe how the identified C-ITS benefit was determined. C-ITS benefits presented on the website are organized by three benefit categories: 1) safety, 2) mobility, and 3) energy and environment. The CV Costs Database [32] constitutes a national resource for transportation professionals to go to in order to obtain cost estimates for C-ITS deployments. The CV Costs Database contains estimates of C-ITS costs that can be used for developing project cost estimates during the planning process or preliminary design phase, and for policy studies and CBAs. Both non-recurring (capital) and recurring (operating and maintenance) costs are provided where possible. Two types of cost data are available: unit costs and system cost summaries. The primary difference in the two types is the level of aggregation. The costs database only offered unit costs data when it was first brought on line in September 1999, system cost summaries were added in September 2003.

The Vehicle-Infrastructure Integration (VII) initiative (2008) was a federal initiative, with research and planning sponsored by the Department of Transportation's (DOT) Intelligent Transportation Systems Joint Program Office (ITS JPO), which sought to bring about substantial improvements in highway safety and trip times via a nationwide, coordinated network of communications between vehicles and the roads they are traveling on, as well as among vehicles themselves. The report titled "Vehicle-Infrastructure Integration (VII) Initiative Benefit-Cost Analysis; Version 2.3" aimed to provide as comprehensive an accounting as possible of the expected future costs and benefits of VII and its applications. The presented CBA methodology involves a systematic quantification of costs and benefits of the VII program over its life-cycle by using a well-accepted procedure for discounting values in future time periods to present values. The approach is simple as the CBA compares the expected benefits of the applications that VII would enable against the expected costs of VII installation, operations, and maintenance, over a defined project time horizon. The main intermediate steps of the process were as follows [33]:

/ Estimate the impacts of VII-enabled applications (e.g. number of hours of traffic delay that would be prevented by a particular traffic signal timing application).

/ Convert these impacts into monetary terms using economic variables.

/ Estimate the life-cycle costs of VII, including upfront capital costs for equipment installation, ongoing operations and maintenance costs, as well as any incremental costs of specific applications (net of any cost savings that may be produced).

/ Forecast the benefit and cost figures into the future across the expected time horizon of the project, with adjustments based on the VII implementation schedule and other factors.

/ Translate benefit and cost figures for all future years into present-value terms using a selected base year and discount rate.

The three deployment scenarios described in the report were [33]:

1. The On-Board Equipment Deployment Schedule: VII on-board equipment (OBE) would be installed on all new light-duty vehicles produced for the US market, with a four-year phase-in period starting in 2012.

2. The Roadside Equipment Deployment Schedule: assumptions for RSE deployment reflected a five-year build-out period from 2011 to 2015.

3. The Application Deployment Schedule: the applications reviewed in the report were assumed to be ready for deployment in 2011, with the exception of winter maintenance and traveller information (2012) and signal timing and adjustment (2013).

For the purposes of the CBA, the set of potential applications, which was analysed, included the following [33]:

/ Signal Violation Warning.

/ Stop Sign Violation Warning.

/ Curve Speed Warning.

/ Electronic Brake Lights.

/ Advance Warning Information.

/ Localized Weather/ Road Condition Warning.

/ Winter Maintenance.

/ In-vehicle Signing.

/ Ramp Metering.

/ Signal Timing and Adjustment.

/ Corridor Management.

/ Traveller Information.

/ Electronic Payment.

/ Private Applications.

Using a set of assumptions regarding unit costs, program organization, and deployment scenarios and timelines, a comprehensive model of the total costs to society for developing, implementing and operating the VII program was constructed. All costs were assigned to one of five major cost areas [33]:

1. Roadside Infrastructure costs.

2. On-board Equipment costs.

3. Network Backhaul costs.

4. Application-specific costs.

5. Governance and VII Program costs.

In each of these areas, three cost types represented different stages of the program: development, deployment or installation, and operations & maintenance. The sum of the discounted stream of these cost estimates was the present value of the cost of the VII program. Regarding the benefit estimation for the applications, it should be mentioned that at that period of time most of the applications were defined as general use cases but do not yet had a detailed "concept of operations" document, delineating their precise functions and impacts. The calculations were based on available information derived from testing documents, as well as a set of assumptions developed and documented through a Task Force process. For safety applications, benefits were calculated based on the reductions in motor vehicle crashes that the application was expected to bring about. Applications focused on mobility varied a bit more in the calculation of benefits, but in general the approach was to combine statistical information about travel delays with reasonable assumptions about the impacts of the application on traffic flows. A similar approach was taken for estimating and monetizing the fuel savings, emissions reductions and other environmental benefits to be obtained through the applications [33].

The National Highway Traffic Safety Administration (NHTSA) – Department of Transportation (DOT) proposed a document in order to establish a new Federal Motor Vehicle Safety Standard (FMVSS), No. 150, to mandate V2V communications for new light vehicles and to standardize the message and format of V2V transmissions. Through the document "FMVSS No. 150 Vehicle-To-Vehicle Communication Technology For Light Vehicles" (2016) NHTSA aimed to create an information environment in which vehicle and device manufacturers could create and implement applications to improve safety, mobility, and the environment. The document includes chapters referring to benefits and costs associated to V2V applications deployment, as well as a Cost-Effectiveness analysis (CEA) [34].

The benefit analysis calculated the benefits for a scenario in which two safety applications, Intersection Movement Assist (IMA) and Left Turn Assist (LTA), were implemented. Although there was no concrete market data to allow definitive predictions about how or when these two applications would be implemented, the adopted scenario was based on several sources including an interviewed survey conducted on the future V2V market, NCAP (New Car Assessment Programme) data related to deployment of vehicle-resident advanced technologies, and other information obtained by the agency. Potential benefits for other apps, such as Forward Collision Warning (FCW) and Blind Spot Warning/ Land Change Warning (BSW/ LCW), were not considered because the effectiveness of these apps could be achieved by vehicle-resident system [34].

Benefits were presented in two measures: annual benefits and the lifetime benefits for a model year vehicles (MY benefits). The annual benefits represented the collective benefits that would be accrued from all V2V-equipped vehicles for a specific calendar year. These benefits were discounted in the breakeven

analysis to determine the year that the total costs of the proposed rule would be paid back through the total realized benefits of the proposed rule. The MY benefits represented the total benefits that would be realized through the life of a MY vehicles, thus required to be discounted by 3 and 7 percent to reflect their present value. These benefits were used in the cost-effectiveness and net-benefit analyses respectively to determine the MY vehicles that would become cost-effective and achieve positive net benefits. Benefits included crashes, fatalities, injuries, and PDOVs (vehicles that only incur property damage and none of their occupants incur an injury) that could be reduced by the proposed rule. Three major factors were considered to influence the benefits: 1) the size of the crash population, 2) application effectiveness, and 3) vehicle communication rates. The undiscounted annual benefits thus were the product of these three factors, expressed mathematically by the following generic formula [34]:

$$(9)\ B_i = P \times E \times C_i, \text{ where}$$

B: Annual benefits (or MY benefits) of the proposed rule at year i,

P: Target population (crashes, fatalities, injuries, or PDOVs),

E: Effectiveness of apps (i.e., IMA or LTA), and

C: communication rate at year i.

The chapter referring to costs quantifies the costs of the proposed rule and discusses non-quantified costs. The costs of the proposed rule were based on the primary proposals for message authentication and misbehaviour reporting based on SCMS and included the cost for [34]:

/ Vehicle equipment.

> DSRC radios and relevant in-vehicle components and hardware security module (HSM) for enabling a secure communication among vehicles (vehicle equipment cost).

> Two apps, IMA and LTA (vehicle equipment cost).

/ Communication.

> Other in-vehicle components primarily for supporting the communication between vehicles and SCMS.

> The communication network (e.g., cellular, Wi-Fi, and satellite) for the communication between vehicles and SCMS.

> Non in-vehicle equipment also for vehicle-to-SCMS communication.

/ SCMS.

/ Fuel economy impact.

> The fuel economy impact due to the added weight from the in-vehicle equipment from DSRC radios, relevant in-vehicle components, HSM and the in-vehicle components for supporting the communication between vehicles and SCMS.

To correspond to benefit estimates, the costs were presented in two measures: annual costs and costs by MY vehicles (MY costs). The annual costs represented the yearly financial commitment on vehicle equipment, communication, and SCMS plus the annual fuel economy impact. The MY costs represented the total investment born by MY vehicles plus the lifetime fuel economy impact from those MY vehicles. It was assumed that vehicle equipment, communication, and SCMS costs were paid by new vehicle owners when their vehicles were purchased. Therefore, these three costs were identical for both cost measures. The only difference between the two cost measures was fuel economy impact. Two technology implementation approaches were considered, which could meet the safety, security, and privacy requirements of the proposed rule: 1) one DSRC radio pairing with a hybrid of communication protocol that included cellular, Wi-Fi, and Satellite (one-radio approach), and 2) two DSRC radios pairing with a DSRC-exclusive communication protocol (two-radio approach). Both the annual and MY costs were presented as a range covering the costs from the two approaches [34].

In order to determine when the proposed rule would recoup all the investment up to that year through the benefits, a breakeven analysis was performed. The breakeven analysis determined the year that the total investment of the proposed rule would be paid back through the total realized benefits of the proposed rule. The total investment of the proposed rule for a year was the cumulative annual costs from the first year of implementation up to that year. Similarly, the total realized benefits were the cumulative monetized annual benefits from the first year of implementation up to that year. All annual costs and monetized benefits used in the analysis were discounted back to 2021, the first year of implementation of the proposed rule [34].

Conducting an overview of the literature review, several conclusions, regarding the methodologies and approaches followed in the various projects and studies, can be drawn:

/ Each project/ study examined different C-ITS services, implemented to address various mobility challenges.

/ The geographical coverage of each project/ study varies, as some case studies refer to a single pilot site, others refer to cities in different countries, while others refer to the EU level.

/ Each study set a different base year (baseline scenario), as well as a different time horizon of the CBA, corresponding mostly to the years 2020, 2030 and 2035.

/ Regarding the C-ITS services implementation, different penetrations rates, based on various scenarios, were used in the projects/ studies. Low, medium or high penetration rates were developed in line with experts' surveys' results.

/ Differences among discount rates, cost-unit rates and inflation rates exist.

/ Economies of scale and learning effects were not considered in most of the studies/ projects.

/ Various assumptions, hypotheses and business models were used for the scope of the CBAs.

/ The bundling concept (varying form the C-MobILE perspective) appears in previous projects as well: eIMPACT, SAFESPOT, e-Safety and Intelligent Infrastructure Working Group, and COBRA.

/ In the framework of each project/ study, the execution of the CBA was done either by tools generated from the projects/ studies, or by existing models, or based on classical calculation methods.

/ Calculations were conducted to determine the costs and benefits of the C-ITS services for various stakeholders' categories, i.e. end-users, industry, and public authorities.

/ Costs estimations were conducted based mainly in literature review data, extrapolation methodologies, as well as experts' guesses and estimations. Differences among the various technical solutions and the equipment used in the implementation procedures exist. In some cases projects/ studies avoided to include certain costs' types, due to lack of sufficient data.

/ Benefits of the C-ITS services were defined in accordance to the respective socio-economic impacts, which were examined in the context of the projects/ studies. The impacts resulted from impact assessment methodologies, defined in the framework of each project/ study, and based on modeling simulation results, on the literature review or on data derived from FOTs. Variations among the impact rates and the respective benefits of the C-ITS services exist.

/ Different indicators were used in order to assess the results of the CBAs: NPV, IRR, BCR.

3. C-MobILE Ex-ante Cost-Benefit Analysis Methodology

3.1. Scope of the ex-ante Cost-Benefit Analysis

This section presents the basic steps of the methodological approach followed to perform the ex-ante CBA for the C-MobILE project.

In terms of producing summary measures of performance, a CBA can provide results from two different perspectives. The lifecycle approach suggests the calculation of the NPV by summing up all discounted values of benefits (plus sign) and costs (minus sign) over the lifecycle of the project. The snapshot approach suggests the preselection of one or several target years and the calculation of the BCRs for these target years. In this case the costs are transformed to annual values (using a discount rate) and then compared to the target year benefits. Both approaches are considered feasible and present good practice, while the choice between the two depends on information needs [15]. Since the goal of the ex-ante CBA within the C-MobILE project is to assess the profitability of the C-ITS services and service bundles, the snapshot CBA is considered appropriate, in terms of projecting the costs and benefits associated to the deployment of the C-ITS services in 2020, the year indicating the final stage of the project. The target year 2020 comprises the time horizon of the analysis, considering that the time period of 2017-2020 is the timeframe for the large-scale demonstration of the C-MobILE C-ITS services.

The geographical scope of the analysis is the eight deployment sites, Barcelona, Bilbao, Bordeaux, Copenhagen, Newcastle, North Brabant, Thessaloniki and Vigo, all differing from each other in terms of number of inhabitants, topography, demographic characteristics, cultural elements, etc., as well as in terms of transport network geometry and functional characteristics. The targeted population includes all the types of users of the C-ITS services, i.e. drivers and VRUs, within the deployment sites' limits. The C-ITS services to be deployed are clustered in thematic application bundles, identified according to their relevance to deployment sites, feasibility and potential for market uptake. The bundling concept ensures a seamless service to end-users and enables integration of existing applications through a multi-variant optimisation of properties of the individual applications. The service bundles will be developed and provided in the form of open, modular and extendable wrap applications, which (by having the ability to interface with all single services) will bring together the complete suite of C-ITS services under one common user environment, with rich user experience features [35]. Through this approach, users of this bundling dimension will only need to have and use a single C-ITS application, which will provide them with context-, location-, and temporal-aware information and services, utilizing individual C-ITS services in the background. Bundling becomes thus part of the C-ITS technology, i.e. the previously mentioned "wrap" application will "orchestrate" the provision of individual C-ITS applications/services.

3.2. Inputs for the analysis

The main data inputs required to carry out the ex-ante CBA can be summarized in three categories:
1. C-ITS services' impact data: the impacts of C-ITS services on individual vehicles when installed across different vehicles and road types. These impacts are expressed in percent values depicting the contribution of the C-ITS services in road accidents' reduction, travel time reduction, average speed increase, fuel consumption reduction as well as CO_2 and polluting emissions reduction.
2. C-ITS systems costs data: costs associated to the deployment of the C-ITS services, i.e. costs regarding the investments (installation/ commissioning) and the operation/ maintenance of the equipment and infrastructure necessary to facilitate the services.
3. Deployment Sites data: data concerning the current situation of the deployment sites, i.e. existing C-ITS infrastructure and C-ITS services' end-users, data describing the C-MobILE C-ITS services' demonstration, i.e. additional infrastructure and end-users, and statistical data referring to traffic characteristics (e.g. modal split) as well as to impact areas (e.g. safety, environment, etc.), which are expected to be affected by the C-ITS services deployment.

3.2.1. Data collection

The data collection of costs and impacts comprises of an extensive literature review of about 100 documents covering a variety of aspects of C-ITS services and related technologies in Europe and USA. Among the main contributing sources, described explicitly in Chapter 2.3., the following constitute the key sources, which provided the data needed for the analysis:
- **/** "Impact assessment of Intelligent Vehicle Safety Systems" – eIMPACT.
- **/** "Co-Operative systems Deployment Impact Assessment" – CODIA.
- **/** "SP6-BLADE-Business Models, Legal Aspects, and Deployment" – SAFESPOT.
- **/** "CVIS costs, benefits and business models" – CVIS.
- **/** "Methodology Framework, Update" – COBRA.
- **/** "Cost Benefits Analysis & Business Model Elements for Deployment" – COMeSafety.

/ "Business case and benefit-cost assessment of EasyWay priority cooperative services" – EasyWay.

/ "Cost Benefit Analysis" – Compass4D.

/ WG1: European Commission DG MOVE C-ITS Platform Working Group 1 – Cost/ Benefit Analysis.

/ "Study on the Deployment of C-ITS in Europe: Final Report" – DG MOVE.

/ "Report on data collection and processing" – ANACONDA.

/ "Impact Assessment and User Perception of Cooperative Systems" – DRIVE C2X.

/ "Final Report and Recommendations of the Intelligent Infrastructure Working Group" – eSafetyForum.

/ Connected Vehicles Benefits and Costs Database – USDOT-ITS JPO.

Regarding data gaps emerging from data not directly available from the literature review, a number of assumptions were used in order to proceed with the analysis. These assumptions are explicitly elaborated in Chapter 3.3. "Deployment Scenarios and General Assumptions".

3.2.1.1. C-ITS services impact data

The impact areas of the C-ITS services' deployment are directly related to their anticipated benefits. C-ITS deployment can provide wide benefits for users and society, justifying the need for their identification and monetization in the context of a CBA. Considering the available data derived from the literature review, the impact areas defined for the scope of the analysis are:

/ Road safety.

/ Traffic efficiency.

/ Environment.

The impact area of comfort, i.e. increase of comfort of individual road users, is not in the scope of this analysis, since impact data associated to this aspect is unavailable. Nevertheless, it should be taken into account that C-ITS services are capable of increasing individual road users' comfort in various ways, e.g. by providing up-to-date information on traffic or route (as in navigation), or by providing priority to certain parties in the traffic [36].

One of the most anticipated societal benefits of C-ITS services is the improvement of roadway safety conditions. C-ITS technology is considered to be capable of exhibiting profound effects on drivers' and VRUs' safety. The provision of warnings for various situations to all types of road users, allowing time for reaction and avoidance, is expected to offer some of the most promising opportunities for avoiding road accidents, hence contributing to fatalities', severe and slight injuries' reduction in motorways, inter-urban and urban roads [15], [37].

C-ITS services have the potential to increase traffic efficiency and achieve optimization of traffic flows at and between intersections and roundabouts of a suitably equipped road network. By enabling traffic data collection and mobility information provision, congestion can be addressed in real-time, ensuring travel time savings, as well as reduction of vehicle-hours. C-ITS services provide also the opportunity to promote selected modes of mobility with respect to the size of cities (e.g. public transport and emergency vehicles can be fostered using C-ITS services in all vehicles and related traffic lights) [38], [38].

Regarding the environmental benefits of the C-ITS services, their contribution in the reduction of the negative environmental externalities of transport is considered to be significant. C-ITS services offer a high potential for avoiding high traffic density by improving the processes, safety and efficiency of all modes of transportation. Such services allow foresighted driving, passing traffic lights in adaptive "green waves", smoothing traffic flows and reducing efforts for finding a parking place. Cooperative feedback to drivers provides smoothest circulation, lesser delays and stops, diversion of traffic flows in response to automatically detected incidents and timely notifications to drivers (both on V2V and V2I communications capabilities), contributing this way to energy and fuel savings, as well as to emissions and noise reduction. Fuel consumption reductions constitute a major environmental benefit and they can be directly estimated as limiting GHG emissions. GHG emissions reduction includes also direct air-quality improvement in highly dense city centres, by proportionally reducing most toxic concentrations of NOx, SOx, CO, VOC and PM concentrations [37], [38].

The data collected from the literature review refer to percent values of the impacts of Day 1 and Day 1.5 C-ITS services [39] at EU level and for the timeframe of 2015-2030. The following table presents the C-ITS services' contribution to each of the impact areas. For certain C-ITS services, with no impact data available, there is an indication of "N.A." in the respective sections of the table. Since data did not distinguish between direct and indirect impacts, some concerns regarding specific C-ITS services arise. More specifically, safety impacts of the Probe Vehicle Data service could be considered as indirect, while the Cooperative (Adaptive) cruise control (Urban ACC) service may possibly affect environmental impacts positively.

C-MobILE Bundles	C-ITS Services	Impact area							
		Road Safety				Traffic efficiency		Environment	
		Fatalities reduction	Severe injuries reduction	Slight injuries reduction	Material damages reduction	Average speed increase	Travel time reduction	Fuel consumption and CO$_2$ emissions reduction	Air pollutant emissions reduction (CO, NOx, VOC, PM)
1	Rest time management	N.A.							
	Motorway parking availability					+	+	+	+
	Urban Parking availability					+	+	+	+
2	Road works warning	+	+	+	N.A.				
	Road hazard warning (incl. traffic jams)	+	+	+	+	+			
	Emergency Vehicle Warning	+	+	+	N.A.				
	Signal Violation Warning	+	+	+	N.A.				
	Warning system for pedestrian (not limited to crossings)	+	+	+	N.A.				
3	Green priority	+	+	+		+	+	+	+
	Green light optimal speed advisory (GLOSA)/ "Dynamic eco-driving"	+	+	+				+	+
	Cooperative traffic light for pedestrian	N.A.							
	Flexible infrastructure (HOV, peak-hour lanes)	N.A.							
	In-vehicle signage (e.g. Dynamic speed limit)	+	+	+	+			+	+
	Mode & trip time advice (e.g. by incentives)					+		+	+
	Probe Vehicle Data	+	+	+	N.A.				
4	Emergency Brake Light	+	+	+	+				
	Cooperative (Adaptive) cruise control (Urban ACC)	N.A.							
	Slow or Stationary Vehicle Warning	+	+	+	+				
	Motorcycle approaching indication (including other VRUs)	+	+	+	+				
	Blind spot detection/ warning (VRUs)	N.A.							

Table 5: Impacts of the C-ITS services

The following table presents the precise average values of the percentages of the C-ITS services impacts on the aforementioned impact areas.

C-ITS Services	Fatalities reduction (%)	Severe and slight injuries reduction (%)	Material damages reduction (%)	Travel time reduction (%)	Average speed increase (%)	Fuel consumption reduction (%)	CO_2 emissions reduction (%)	CO emissions reduction (%)	NOx emissions reduction (%)	VOC emissions reduction (%)	PM emissions reduction (%)
GLOSA	0,10	0,13	-	-	8,00	0,40	0,40	0,60	0,20	0,60	0,10
SVW	2,30	7,15	-	-	0,85	-	-	-	-	-	-
IVS	6,00	6,00	0,60	-	-	2,90	2,90	0,20	0,50	0,30	2,30
MAI	3,80	3,80	3,80	-	-	-	-	-	-	-	-
PVD	2,40	2,80	-	-	-	0,01	0,01	-	-	-	-
EBL	2,70	2,50	2,50	-	-	-	-	-	-	-	-
WSP	1,80	1,90	-	0,61	-	-	-	-	-	-	-
SSVW	2,80	1,75	0,70	0,61	-	-	-	-	-	-	-
RWW	9,00	1,50	-	9,20	-	-	-	-	-	-	-
EVW	0,80	0,80	-	-	2,00	-	-	-	-	-	-
RHW	9,00	0,70	3,60	-	-	0,01	0,01	-	-	-	-
MTTA	-	-	-	-	-	5,98	5,98	2,20	0,90	2,80	0,60
MPA	-	-	-	-	-	0,79	0,79	0,80	0,30	0,80	0,10
UPA	-	-	-	-	-	0,79	0,79	0,01	0,30	0,80	0,10
GP	-	-	-	-	-	17,07	4,64	8,30	-	8,30	8,20

Table 6: Average percentages of the impacts of the C-ITS services

3.2.1.2. C-ITS systems costs data

The extensive literature review provided a significant number of data associated to the costs of the C-ITS systems deployment. In order to use this data as inputs for the ex-ante CBA, it was necessary to proceed with a categorization of the various C-ITS systems' components described in the literature review. Taking into consideration the ERTICO document "Communication Technologies for future C-ITS service scenarios" [40] and for the purposes of the analysis, the C-ITS systems' components were categorized into five types:

1. Traffic Management Centre (TMC) Integration.

2. Roadside Units (RSUs) – Dedicated Short-Range communications (DSRCs).

3. In-vehicle devices.

4. Personal devices.

5. Data Collection.

TMC integration is considered as the procedure of integrating the C-ITS supporting technology, responsible for managing the C-ITS services for an entire city, or a road operator, or a national highway system, into an existing TMC. This array of technologies constitutes the central sub-systems, enabling the connection of the roadside sub-systems (RSUs) to a central system, where data are analysed and used for traffic management optimization purposes. Costs associated to TMC integration include costs arising from the additional equipment or services required to: integrate the RSUs into the TMC, update or develop new interfaces from RSUs to local traffic controllers, operate and maintain the TMC back office and the local controller interfaces, update or develop and maintain software applications [29].

Roadside Units (RSUs) – Dedicated Short-Range communications (DSRCs) are the components of the C-ITS services' deployment, such as beacons on gantries or poles, which enable the communications along specific stretches of the road network. In case of aiming to deploy ITS-G5 communication, the delivery of the C-ITS systems may occur through the upgrade of the existing RSUs or the installation of new ones. Upgrades are more likely to take place in urban areas, where the upgrade of existing traffic light systems is considered to be more common. The installation of new RSUs is considered to be more relevant to inter-urban areas, where the required infrastructure is possibly not already in place and the installations must be done from scratch, in order to achieve additional ITS-G5 coverage. The upfront cost for upgrading an existing RSU to be capable of delivering C-ITS functionality comprises of equipment and hardware costs, as well as of installation and mounting costs, depending on the complexity of the installation. The annual ongoing costs for the operation and maintenance of a RSU include costs for activities like realigning the antennas, rebooting hardware, checking system operational status and other routine checks. Costs for power consumption, data and secure communications (i.e. development and implementation of a security credentials management system) should also be taken into account. In the case of installing a new RSU, costs are considered to be higher than costs for upgrading an existing one, as additional activities, such as radio surveys, map/ GID generation, planning, design, system integration and license, and traffic control, lead to increased costs [29], [33], [34].

In-vehicle devices (OBUs) are devices attached to the vehicles' communication buses, enabling both V2V and V2I communications along C-ITS equipped roads. These devices can either by fitted by the vehicle manufacturer to a new vehicle or retrofitted to an old one. Regarding in-vehicle devices to be fitted in new vehicles, two categories can be defined: 1) those capable of delivering only ITS-G5 based services, and 2) those capable of delivering both ITS-G5 based services and cellular based services. These devices can be of two types: 1) Self-contained, which are not connected to the vehicle's data bus and only use a wire to get power from the vehicle, capable of sending and receiving Basic Safety Messages (BSM) and providing advisories/ warnings, and 2) Vehicle Awareness Devices, which use a wire to get power from the vehicle, they send out but do not receive BSM nor do they provide advisories/ warnings. As far as retrofit devices are concerned, they typically connect to the vehicle's data bus, sending and receiving BSM, as well as providing advisories/ warnings. The elements of the upfront costs are the same both for new and old vehicles, including a number of in-vehicle components such as two DSRC transmitter/ receivers, two DSRC antennas, an electronic control unit and additional wiring. Costs associated to C-ITS technologies' integration, development and testing, and to vehicles' software development constitute also parts of the upfront costs. Ongoing costs are composed of maintenance, secure communications and OEM maintenance of in-vehicle software (updates), with cellular data costs to be added for the case of vehicles with ITS-G5 and cellular technology [28], [34].

Mobile phones, tablets, PNDs and other handheld devices, not attached to the vehicle's information bus are characterized as personal devices. Based on literature review findings, for the timeframe of 2015-2030, C-ITS services are expected to be provided by two major types of devices, mobile phones and PNDs. C-ITS services can be offered by mobile phones through various types of business models, depending on the interactions between the involved stakeholders (i.e. technology/ software providers, road operators, public authorities). According to the "Study on the Deployment of C-ITS in Europe" [29], costs associated to smartphones' end-users' charges could be expressed within three types of business models: 1) subscription based model, where charges would be incurred by an annual subscription fee for using the C-ITS services, 2) app store/ online marketplace based model, where charges would come from downloading the applications, and 3) free model, where the applications could be provided for free by a public transport authority or a road operator. Hence upfront, as well as ongoing costs, for mobile phones depend on the business model to be chosen. The same logic applies to PNDs, where end-users could either purchase the

device and pay an annual subscription fee or bear a one-off cost for access to the C-ITS services. Elements comprising the upfront costs of PNDs include the equipment, the applications and the software development, while operation and maintenance costs typically arise from data usage, subscription fees and applications' updates.

Data collection refers mainly to traffic data collection along a suitably equipped road network to support C-ITS services' applications. The process of data collection can be achieved either traditionally through the infrastructure or through third parties. Probe based data collection offered by third parties, refers to purchasing data from service providers, which own data collection equipment and monitor mobile-based traffic data sources, covering large portions of the road network. Access to these data sources provides rich speed and travel time data, as well as incident, construction, road closure and weather information. The cost of these commercially available systems varies by types of data desired (speed, volume, travel time, etc.), desired accuracy and timeliness of the data (e.g., 90% accurate within five minutes), types of roads for which data is desired (freeways, major arterials, minor arterials, etc.) and geographic boundaries (e.g. city, region, state). Both types of data collection, traditional and third-party, are aligned to initial capital costs and annual recurring costs [33].

The following table describes the cost category, the responsible stakeholders, the communication technologies and the units aligned to each C-ITS services component. A range of 2016 cost prices (minimum to maximum) for all the possible types of the main C-ITS services components are presented thoroughly in Annex 1: "C-ITS Services Components' Costs Breakdown", depicting the results of the literature review data processing in line with the methodology described in Chapter 3.4. "Economic Analysis".

C-ITS Services components	Cost category	Stakeholder	Communication technology	Units
TMC Integration	/ Installation / Operation & Maintenance	/ Road operator	/ V2V / V2I	/ Per deployment area per year
RSUs– DSRCs	/ Installation / Operation & Maintenance	/ Road operator / OEMs / End-user	/ V2V / V2I	/ Per intersection / Per RSU per year / Per km of road per year / Per license per year
In-vehicle devices	/ Installation / Operation & Maintenance	/ OEMs / End-user	/ V2V / V2I	/ Per vehicle per year
Personal devices	/ Installation / Operation & Maintenance	/ End-user / Equipment provider	/ V2V / V2I	/ Per user per year
Data Collection	/ Installation / Operation & Maintenance	/ Data provider / End-user	/ V2V / V2I	/ Per centerline km per year

Table 7: Costs breakdown of C-ITS services deployment

3.3. Deployment Scenarios and General Assumptions

Measurement of benefits and costs against a counterfactual constitutes the main objective of a CBA. CBA typically compares a scenario with-the-project with a counterfactual baseline scenario without-the-project, hence benefits and costs have to be measured as the change compared with what would have been the case without the project. Building a baseline scenario comprises of two cases: either the case of a completely new asset (e.g. there is no pre-existing service or infrastructure), where the without-the-project scenario is one with no operations, or the case of already existing facilities (e.g. investments aiming in their improvement), where the baseline scenario includes the costs and benefits to operate and maintain the services at a level that it is still operable (Business As Usual (BAU)) or even small adaptation investments that were programmed to take place anyway (do-minimum) [41].

Within the C-MobILE framework the most appropriate baseline scenario would be the one describing the deployment sites' current situation as of today, 2017, since the extent of the already existing C-ITS services' deployment differs in each one of them. The with-the-project scenario describes a reference situation depicting the C-ITS services deployment in the deployment sites by 2020, i.e. the C-MobILE extensions and updates in each deployment site. The following table presents the data describing the two scenarios for each deployment site. This data was collected from questionnaires distributed to the Deployment Sites Leaders.

Deployment Site	Bundles	Baseline Scenario: Current Situation 2017	Reference Scenario: C-MobILE Extensions 2020
Barcelona	2 & 3	/ No C-ITS services	/ 45 km (inter-)urban roads > 6 km motorways > 6 km inter-urban roads > 39 km urban roads / 200 cars / 1 emergency vehicle / 100 motorcycles / 175 pedestrians / 6.000 cyclists
Bilbao	1 & 2	/ 275-300 intersections equipped with RSUs / 400-450 bus drivers / 3.000-3.500 truck drivers / 20.000-25.000 cyclists / 15.000-20.000 shared bicycles	/ 35 km urban roads / RSUs updates / 3.000 car drivers / 34.675 end-users totally
Bordeaux	1, 2, 3 & 4	/ 14 intersections equipped with RSUs / 12 OBUs / 850 cars / 20 taxis / 6 emergency vehicles	/ 50 RSUs / 20 vehicles equipped with new OBUs / 60 km inter-urban roads / 2.590 km urban roads / 3.000 cars / 413 taxis / 20 or more emergency vehicles / 40 buses (public transport) / 50 trucks / 40 cyclists / 80 pedestrians / 500 users of public transport
Copenhagen	2 & 3	/ 50 intersections equipped with RSUs (44 ITS G5 based intersections, 6 cellular based intersections) / 8 km inter urban roads / 9,3 km urban roads / 87 buses equipped with OBUs / 2 private vehicles equipped with OBUs	/ RSUs and OBUs update / 317 end-users (VRUs and vehicle drivers)
Newcastle	2, 3 & 4	/ 39 intersections equipped with RSUs / 7 km of C-ITS equipped road network / 13 emergency vehicles equipped with OBUS / 2 private cars equipped with OBUs / 50 cyclists	/ RSUs and OBUs upgrade / Up to 10 taxis / 200 cyclists and pedestrians
North Brabant	1, 2, 3 & 4	/ 49 RSUs / 21 km of road network	/ 54 RSUs totally

C-MOBILE

Thessaloniki	2 & 3	/ 12 intersections / 6 RSUs / 10 km (inter-)urban roads / 10 km motorway / 600 taxis	/ Additional signal controlled intersections / 6.500 cars / 300 pedestrians
Vigo	2, 3 & 4	/ 100 km of motorways (30 RSUs ITS-G5) / 49 intersections (49 RSUs) covered with ITS-G5 / 30 vehicles equipped with OBUs / 20 trucks / 10 buses	/ 30 cars / 5-10 emergency vehicles / 10 motorcycles / Pedestrians TBD / ITS G5 and Cellular communication technology

Table 8: Overview of the current status and C-MobILE extensions on the Deployment Sites

The diversity between the deployment sites attributes', depicting the different technology settings, necessary for the C-ITS services deployment, indicates the need to define a set of common assumptions, in order to proceed with the analysis. The context of these assumptions focuses on establishing a common path for the C-ITS services deployment, enabling this way the assessment and the comparison of the outputs for each deployment site. The list of assumptions comprises of the following presumptions:

/ The deployment of the C-ITS services asks for no additional TMCs to be built, as the existing ones will act as the base for integrating just the additional equipment. Hence costs referring to TMC integration apply to the connection of new RSUs to TMCs and to the updates necessary for the back offices' operation and maintenance, in order to support the management of the C-ITS services. Costs attributed to depreciations on previous investments are not taken into account, since it was rather difficult to distinguish.

/ The economic lifetime of the C-ITS infrastructure is considered to be 15 years for all deployment sites.

/ In-vehicle devices providing the C-ITS services are available only to certain vehicle types, i.e. urban buses, emergency vehicles and a small number of other vehicle types (e.g. cars, taxis, and trucks). The new in-vehicle devices considered for the C-ITS services' deployment are of two types, regarding the communication technology used: in-vehicle devices capable of delivering only ITS-G5 based services, and in-vehicle devices capable of delivering both ITS-G5 based services and cellular based services. The types of the in-vehicle devices aligned to the vehicles of each deployment site, depend on the communication technology to be used within the framework of the C-MobILE extensions.

/ The C-ITS services will be provided to certain types of end-users, i.e. passenger car drivers, truck drivers, taxi drivers and VRUs, by mobile phones. Costs regarding mobile phones exclude up-front purchase costs, since the devices are considered to be already owned by the end-users. Costs data related to other types of personal devices supporting C-ITS services, i.e. PNDs, are presented here for informative purposes only, and will not be modelled in the analysis.

/ Costs in general are assumed to be consistent across all vehicle categories and to depict market prices.

/ In an attempt to eliminate costs, the C-ITS services are considered to be provided for free to mobile phone users, for example by road operators or urban transport authorities. The applications required to enable the C-ITS services on the relevant road network are assumed to be developed and maintained by an independent app developer, who is paid by the road operator or the urban transport authority. Cellular data usage will be covered by the end-user, while no upfront fee will be charged for downloading the app and no subscription fees will be charged for accessing the service.

/ Given the assumption that the C-ITS services applications are offered free to the end-users and that mobile phones are already owned by them, lifetimes are not relevant to mobile phones for the ex-ante CBA [29].

/ The values of all pre-2017 costs, which have been inflated to 2016 levels, apply for 2017 as well.

/ The percentages of the C-ITS services impacts by 2030, derived from the literature review, are assumed to apply for 2020 as well, as they represent a modelling timeframe of 2015-2030.

3.4. Economic Analysis

The ex-ante CBA is performed in deployment site basis, i.e. the methodology to be followed is applied to each deployment site, resulting in individual results. This approach is considered to be efficient in terms of

providing for each deployment site a clear picture of the costs and the benefits to arise from the C-ITS services deployment, assisting this way in prioritization and implementation support.

As a first step, costs related to investments and to the operation and maintenance of the C-ITS systems were collected from the literature review. In order to convert this data to inputs useful to the analysis, a categorization of the various C-ITS systems' components, aligned to the respective costs, was formed (see Chapter 3.2.1.2. "C-ITS systems costs data"). Given the fact that there was a diversity between the base years for the costs data originating from the various sources, all pre-2017 costs had to inflate to 2017 levels (C-MobILE baseline), using the Eurostat Harmonised indices of consumer prices (HICPs) for each of the countries represented by the deployment sites (Denmark, France, Greece, Netherlands, Spain and UK) [42]. Due to lack of data for the year 2017, all pre-2017 costs inflated to 2016, since the latest annual average indexes' available data for the respective EU countries refer to 2016. The pre-2017 costs were inflated for each deployment site to 2016 levels using the following equation:

$$(9) \ Cost_{2016} = \frac{HICP_{2016} \times Cost_{pre-2016}}{HICP_{pre-2016}}$$

In order to calculate total annual costs, i.e. investment costs and operation and maintenance costs, for each component of the C-ITS systems, investment costs, which appear only once in the lifetime of the system, had to be annualized. In other words investment costs had to be distributed over the lifetime of the system. For annualizing the investment costs, information about the discount rate and the lifetime of the systems is necessary. Given this data, an annuity rate can be calculated (see Equation (2), Chapter "2.3. Review of Past Projects and Studies"). For the scope of the analysis a discount rate of 4% was used, according to the methodology proposed by the "Guide to Cost-Benefit Analysis of Investment Projects – Economic appraisal tool for Cohesion Policy 2014-2020" of the EC.

Regarding the lifetime of the systems (an important factor affecting the formation of the annuity rate), there are differences in life expectancies of the various elements of the systems, like infrastructure, vehicles and OBUs. According to the literature review, life expectancy for physical infrastructure components is higher than that of vehicles, while communication infrastructure has a lifetime which is suggested even shorter than the lifetime of vehicles [16]. In the framework of this ex-ante CBA, the lifetime of the infrastructure was estimated as of 15 years, while the lifetime of the different vehicle types (passenger cars, light commercial vehicles, e.g. emergency vehicles, heavy commercial vehicles, e.g. trucks and urban buses, and TWs, e.g. motorcycles and bicycles) were derived from ACEA data referring to the average age of the EU car fleet by country in 2015 (latest available data) [43].

Having determined the annuity rate, the total costs per C-ITS systems' component and per year were calculated by multiplying their investment costs by the respective annuity rate, and adding the operating and maintenance costs (see Equation (1), Chapter "2.3. Review of Past Projects and Studies"). Regarding the wide range of data costs prices, a range of minimum and maximum annualized total costs was defined for each component. These values were then aligned to the specific C-ITS services deployment characteristics of each deployment site (e.g. number of RSUs, number of OBUs, number of mobile phone users, etc.), in order to determine the respective range of the total annual costs for 2020 (minimum and maximum annual costs). The 2017 total annual costs were derived from data, extracted from the filled in questionnaires, which were distributed to the Deployment Site leaders. The following table presents an overview of the estimated range of annualized total costs.

C-ITS services components	Annualised total costs (€)	
	Minimum	Maximum
TMC Integration	713.802,51	852.633,63
Existing RSU	547,13	917,03
New RSU	1.237,61	2.497,33
Retrofit in-vehicle device	26,19	37,97
Self-Contained in-vehicle device	22,14	32,10
Vehicle Awareness device	7,29	10,57
ITS-G5 in-vehicle device	29,25	54,97
ITS-G5 & Cellular in-vehicle device	31,64	57,41
Mobile Phone	2,49	-
PND	11,12	-
Traditional Data Collection	1.573,25	-
Probe Data Collection	785,42	-

Table 9: Overview of annualized C-ITS services components' costs range

The second step of the analysis comprised of the benefits' calculation. Regarding the fact that benefits constitute the monetary value of the physical impacts of the C-ITS services, data concerning the impacts of

the C-ITS services had to be extracted from the literature review. As mentioned above (see Chapter 3.2.1.1. "C-ITS services impact data"), the available data refer to the impacts of the C-ITS services at EU level by 2030. In order to convert this data to inputs useful to the analysis, it had to be modified, so as to express impacts at deployment site level. The procedure, followed to produce the most accurate estimates of such impacts, includes the scaling down of the impacts of the C-ITS services from EU level to deployment site level.

The proposed statistical extrapolation/ scaling down methodology constitutes the opposite one of the methodology used to scale up impacts from local to regional/ national level, i.e. statistical extrapolation/ scaling up methodology. The process of scalability from local level to regional/ national territorial dimension is based on statistical methods, which couple measurements of real world impacts/ benefits with transport-related statistics, in order to weight them and generate scaled up ones to regional and national levels [24]. This approach was used in several previous related studies [44], [45], [46], [47] and projects [24], [48]. The methodology requires as a first step, desktop research of statistical data at city, regional and national level related to the tested scenarios. These general data are the multipliers that allow assessing impacts on different levels as to transfer impacts of demo activities in all the other countries [24].

For the scope of the current analysis, the statistical data, which was derived from the filled in questionnaires and then modified appropriately to be used as multipliers, was the total annual number of vehicle kilometres (Vkm) driven in a year per road type, i.e. motorways, inter-urban roads and urban roads, in each deployment site. This data was considered as the most appropriate ones among others, since the impacts of the C-ITS services at EU level by 2030 were modelled per road and vehicle type. The correlation of the number of the total annual vehicle kilometres driven in each road type with the respective modal split, resulted in the formation of the multipliers, used in the scaling down methodology. For deployment sites with such data unavailable, average values of the estimated scaled down impact rates were used in the analysis.

More specifically, with scaling down we mean the extrapolation or translation of effects from a large (geographic) scale to a smaller (local) scale. The literature review distinguishes two methods for scaling up [48], hence the respective reverse ones could be used for scaling down:

1. Scaling down using statistics (direct method), with data made available through a source.

2. Scaling down using a (macroscopic) multimodal traffic simulation model on small scale level (e.g. deployment site level).

For the scope of this analysis, the first method was used. The method used as a starting point the effects on road safety, traffic efficiency and the environment on a large scale level (EU), distinguished for different situations (surroundings such as traffic state, vehicle type, etc.). The impacts at EU level were derived from literature. Generally, the definition of situations that are distinguished depends on the system characteristics, the situational variables that are expected to have the largest impact, and the possibility of measuring the different situations. Data for the same situations are needed on the local level that is targeted [48]. For the purpose of this analysis, it was assumed that the situations on the local level, i.e. deployment site, and on the national level, i.e. EU, are the same. Differences for cities with and without C-ITS services are not addressed from this perspective, yielding possibly to less accurate estimations. Inserting though differentiations into the scaling down method was considered rather hard, since it would require the development of various deployment site-specific scenarios, in order to come up with different C-ITS services penetration rates. Assumptions on such an issue are risky. Previous studies used experts' surveys to define penetration rates, something not conducted in the scope of this analysis. The impacts on the various areas on the national scale were scaled down using statistical data (for example on kilometres driven for the relevant modes) under the specific situations. To make it more clear, an example of the scaling down of the impacts of the Road Hazard Warning service from EU level to deployment site level is given.

The literature review provided the following data on the impacts of RHW on road fatalities reduction on EU level:

Situation – EU	Change in road fatalities
Cars (private cars and taxis) – motorways	-5,2%
Cars (private cars and taxis) – inter-urban roads	-5,3%
Cars (private cars and taxis) – urban roads	-1,7%

Table 10: Effects of RHW on road fatalities on EU level

The aim was to scale down to deployment site level. The available traffic statistics for e.g. the Thessaloniki deployment site were the number of total annual Vkm driven in motorways, inter-urban roads and urban roads, and the model spit. At this it has to be clear that traffic statistics were available only on regional level, i.e. Region of Central Macedonia (RCM), hence an assumption that the same values apply also to the deployment site was done. The correlation of the number of total annual Vkm driven in each road type with the percentage of the modal split attributed to cars (i.e. private cars and taxis) (data explicitly presented in Chapter 4.1.7. "Thessaloniki"), led to the calculation of the number of annual Vkm driven by cars (i.e. private cars and taxis) on each road type.

Situation – Thessaloniki Deployment Site	Vehicle kilometers driven in a year (2014)

Cars (private cars and taxis) – motorways	1064,0873 Million
Cars (private cars and taxis) – inter-urban roads	767,887 Million
Cars (private cars and taxis) – urban roads	1997,9735 Million
Total	3829,9478 Million

Table 11: Vehicle kilometres driven by cars in the Thessaloniki Deployment Site

Then the results were scaled down to deployment site level by doing a direct, simple calculation. When all cars are equipped with the RHW service, there is a reduction of 5,2% on 28% (1064,0873/ 3829,9478) of the total kilometres driven, a reduction of 5,3% on 20% (767,887/ 3829,9478) of the total kilometres driven, and a reduction of 1,7% on 52% (1997,9735/ 3829,9478) of the total kilometres driven. The weighted average is then a 3,4% reduction of road fatalities on the Thessaloniki deployment site level (5,2% x 0,28 + 5,3% x 0,20 + 1,7% x 0,52). The same logic applies to the other C-ITS services and modes of transport. The impacts were scaled down only for the deployment sites of Thessaloniki and Vigo, since statistical data were unavailable for the rest of the deployment sites. Therefore, average values of the impacts of the deployment sites of Thessaloniki and Vigo were used. For example, a reduction of 621,77 litres in fuel consumption for the deployment sites of Barcelona, Bilbao, Bordeaux, Copenhagen, Newcastle and North Brabant, resulted as the average value of the total reduction in fuel consumption, achieved by the relative C-ITS services, in the Thessaloniki deployment site, i.e. 1016,363 litres, and in the Vigo deployment site, i.e. 227,168 litres. The same logic applies to the other impact areas as well.

The scaling down methodology led to the identification of individual impact rates, concerning safety, traffic efficiency and the environment, per C-ITS service and per deployment site. Having determined the percentage change in the factors aligned to each impact area and by applying them to the respective statistical data (e.g. annual road fatalities, annual fuel consumption), extracted from the filled in questionnaires, it was possible to calculate the physical impacts for each deployment site by 2020. These values were then converted into euros (€), by attributing to them estimates of 2020 inflated market prices, expressing the total benefits of the C-ITS services for each deployment site. The 2020 cost-unit rates for each deployment site, in accordance to the respective EU countries' cost-unit rates, as well as the initial cost-unit rates, derived from the Report for the EC, "Update of the Handbook on External Costs of Transport" [49] and from the Compass4D project [25], are thoroughly presented in Annex 2 "Deployment Sites' 2020 Cost-unit rates".

The last step of the analysis is comprised of the comparison between the estimated 2020 total costs and total benefits of each deployment site. For this comparison, the measure of the Benefit-Cost Ratio (BCR) was calculated, according to the following equation:

$$(10)\ BCR = \frac{Total\ Benefits_{2020}}{Total\ Costs_{2020}}$$

The results concerning the BCRs constitute the indicative values for defining whether the C-ITS services implementation is favourable from a socio-economic point of view for each deployment site. The BCR of each deployment site expresses the absolute profitability of the respective C-ITS services, interpreted as the socio-economic return for every monetary unit invested in the implementation. Hence the BCR is the indicator of efficient resource allocation. The evaluation of the deployment sites' BCRs was conducted in line with the following classes [16]:

- **/** 0 < BCR < 1: The BCR is rated "poor" showing the socio-economic inefficiency of the C-ITS services deployment.

- **/** 1 ≤ BCR < 3: The BCR is rated "acceptable" meaning that the social benefits, associated with the implementation of the C-ITS services, exceed the costs up to almost three-times, which can be labelled as an acceptable absolute efficiency.

- **/** BCR ≥ 3: The BCR is at least as high as "3" indicating an "excellent" result of the CBA. The C-ITS services should be in first line for market deployment.

4. Results

4.1. Outputs per Deployment Site

In this section the results of the ex-ante CBA are presented per deployment site. For each deployment site the outputs of the analysis are considered to represent costs associated to the deployment of the respective C-ITS services as a comprehensive system. More specifically, for the bundled C-ITS services, if a component is needed by two or more services, the services can share access to this component, so that the component is needed only once. This results in bundle costs which are expected to be lower than the sum of costs needed for systems with accordant stand-alone services. The synergies help the bundle to achieve a higher profitability [50]. Outputs representing the benefits per deployment site result from the total monetary equivalent, comprised of the separate ones which each C-ITS service can attribute to the deployment site per impact area. This way a clear identification of the direct savings of the bundled C-ITS services is achieved, depicting the financial gains of the bundling concept.

The main constraint encountered during the analysis, was the lack of significant data referring to the deployment sites. The collection of statistical data associated to traffic parameters, safety and emissions proved to be a challenging task, since the majority of such data is unavailable on deployment site level. Consequently, apart from the generic assumptions, described in Chapter 3.3. "Deployment Scenarios and General Assumptions", individual ones had to be made for each deployment site, based on their specific needs. These assumptions are explicitly described in the following chapters.

At this point, it should be mentioned that within the frame of this ex-ante CBA, which is based mainly in estimations and assumptions, a deviation from the real costs and benefits of the future C-ITS services deployment is possible. This is mainly due to the fact that typically during such demonstrations/ pilot programs the technology or the product of interest are prototypes that have not been standardized to a large extent. At the same time, only a limited number of infrastructure and end-users are equipped, depicting a lower efficiency of the deployed services compared to the expected ones in even a larger future scale deployment. Moreover, the analysis showed that for some deployment sites, costs associated to specific components resulted to be lower than the respective minimum ones that the literature review provided. This deviation is due to the fact that costs estimations were also based on data provided from the deployment sites, hence some costs can be characterised as deployment site-specific, varying from the values derived from the literature review. Costs and benefits estimated in the context of this analysis express the marginal C-MobILE annual costs and new infrastructure investment, and the benefits generated by the additional deployment of C-MobILE C-ITS services. The process followed for the estimation of costs and benefits was adapted as best as possible to the distinctive characteristics of each deployment site, in order to achieve the most accurate results.

4.1.1. Barcelona

Barcelona currently does not offer C-ITS services. The total annual operational cost, including maintenance costs as well, of the existing Barcelona TMC (traffic control centre) rises to € 1.000.000, while operation and maintenance costs regarding data collection in an annual basis are of € 300.000. Since the C-ITS services deployment is in a preliminary stage, no relative infrastructure neither technology equipment is present in the deployment site. Total annual costs associated to the current situation, 2017, were estimated as of € 1.300.000, depicting costs at the Barcelona city level rather at the deployment site level.

The C-ITS services to be demonstrated in the framework of C-MobILE cover the aspects of infrastructure-to-vehicle (I2V) safety and traffic efficiency, hence specific updates and extensions must occur. In this content, Barcelona municipality will work with the existing infrastructure for traffic control and connectivity, as deployment of new infrastructure is not foreseen. The traffic control centre will be adapted following the C-MobILE architecture so it can seamlessly support the deployment of the applications and services. End-users will make use of the C-ITS services through mobile phones or embedded applications, using cellular technology. The integration of the Barcelona traffic control centre and of the Barcelona smart city infrastructure, in line with the C-MobILE architecture, will comprise the source of traffic and road user information [35].
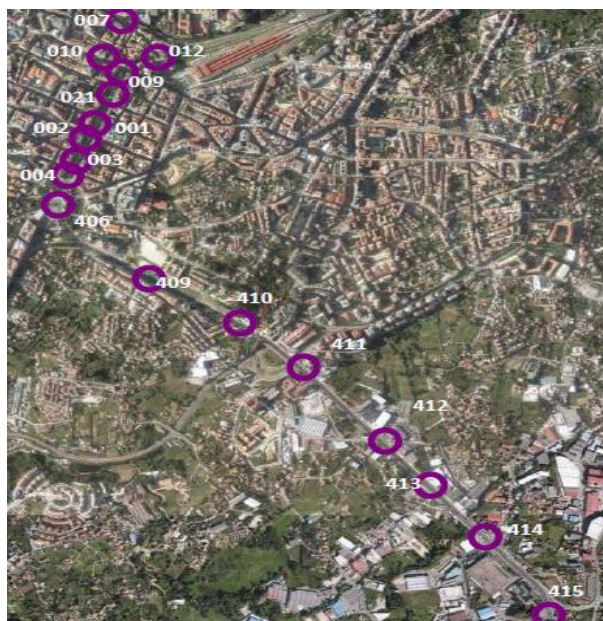
Figure 2: Example of a GLOSA corridor in the Barcelona Deployment Site

Estimations of the total annual costs (operation and maintenance) of the integrated TMC (2020 deployment scenario) were not available from the side of the deployment site, hence calculations were based on the data extracted from the literature review. For the C-ITS services demonstrations, in terms of infrastructure extensions, neither RSUs nor OBUs are foreseen. The total length of the road network, to be used for the C-ITS services' implementation and support, is estimated as of 45 km within the deployment site area. In terms of end-users, Barcelona will provide 200 private cars drivers, 1 emergency vehicle, 100 motorcyclists, 6.000 cyclists and 175 pedestrians. The number of taxi drivers and users of public transport is still to be determined.

Total annual costs referring to the future C-ITS services deployment, 2020, were estimated to range from € 800.724,19 (minimum costs) to € 939.555,31 (maximum costs). These costs are lower than the 2017 total annual costs, since they are attributed to the specific deployment site area, where the C-ITS services will be demonstrated, and not to the whole city of Barcelona (2017 total annual costs). The following table presents an overview of the current and future C-ITS services implementation in Barcelona. Costs breakdown for 2020 and total annual costs for the years 2017 and 2020 are depicted in the figures below.

C-ITS services implementation in Barcelona	
Existing	None
To be implemented	/ Road Works Warning
	/ Road Hazard Warning
	/ Emergency Vehicle Warning
	/ Signal Violation Warning
	/ Warning System for VRUs
	/ Green Priority
	/ Green Light Optimal Speed Advice
	/ Time To Green/ Red
	/ Cooperative Traffic Light for VRUs
	/ Flexible Infrastructure
	/ In-vehicle Signage (Speed)
	/ Mode and Trip Time Advice
	/ Probe Vehicle Data

Table 12: C-ITS services current (2017) and future (2020) status in the Barcelona Deployment Site
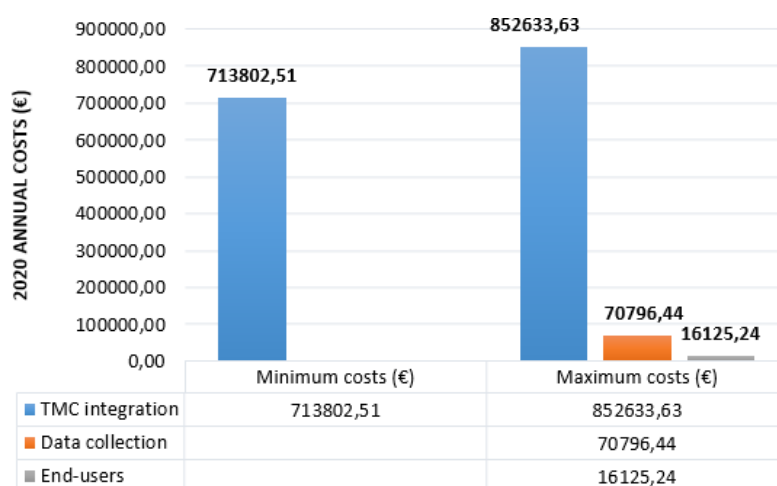
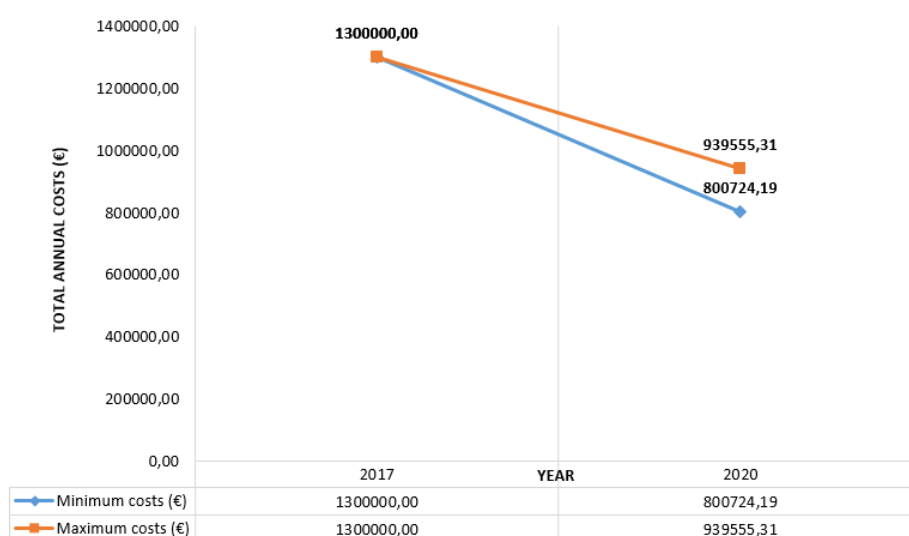Figure 3: 2020 costs breakdown for the Barcelona Deployment Site

Figure 4: 2017 and 2020 total annual costs for the Barcelona Deployment Site

The anticipated benefits from the C-ITS services deployment in the Barcelona deployment site comprise of reductions in road incidents, fuel consumption and emissions, as well as of traffic efficiency increase. Data on the total annual number of vehicle kilometres (Vkm) driven in a year per road type (i.e. motorways, inter-urban roads and urban roads) was unavailable, impeding the calculation of the impacts of each C-ITS service according to the extrapolation/ scaling down methodology (Chapter 3.4. "Economic Analysis"). In order to proceed with the estimation of the C-ITS services' impacts for the Barcelona deployment site, it was assumed that the respective percent values could be represented sufficiently by the average values of the impacts of the deployment sites, which total annual numbers of vehicle kilometres driven in a year per road type were available, i.e. Thessaloniki and Vigo.

Since Barcelona has not deployed any C-ITS services in the past, there is no existing "study are", e.g. a previous pilot site, in order to extract the necessary data for the benefits' estimation. All data provided from the Barcelona deployment site refer either to the Barcelona Metropolitan Area (BMA) or to the whole city of Barcelona. Hence estimating a monetary equivalent of reductions associated to such data would lead to benefits' overestimation. On account of this, it was assumed that reductions in road accidents, CO_2 emissions and fuel consumption could be represented by the average values of the reductions estimated for the rest of the deployment sites. In terms of traffic efficiency, it was assumed that average speeds for vehicles driving within the BMA apply as well to the ones of the vehicles to be driving within the Barcelona deployment site. The 2020 total annual benefits for the Barcelona deployment site were estimated as of € 2.018.992,50. The following table presents the data collected from the deployment site, while benefits estimates and the respective monetary equivalent are explicitly presented below.

Barcelona Statistical Data		Area of reference
Total annual vehicle kilometres (Vkm)	46.579.763	Barcelona city
Total annual hours travelled (hours)	3.742.000	Barcelona city

Modal split in urban roads (%)	Private cars	23%	BMA (Barcelona Metropolitan Area)
	Taxis	0,9%	
	Buses – public transport	5%	
	Light commercial vehicles – e.g. emergency vehicles	8%	
	Heavy commercial vehicles – e.g. trucks	0,7%	
	Motorcycles	17%	
	Non-motorized modes (e.g. bicycles)	46,8%	
Average speed in motorways (km/h)	Passenger vehicles – private cars and taxis	114	BMA
	Buses – public transport	89	
	Light commercial vehicles – e.g. emergency vehicles	113	
	Heavy commercial vehicles – e.g. trucks	85,3	
Average speed in inter-urban roads (km/h)	Passenger vehicles – private cars and taxis	92	BMA
	Buses – public transport	20,8	
	Light commercial vehicles – e.g. emergency vehicles	88	
	Heavy commercial vehicles – e.g. trucks	76,2	
Average speed urban roads (km/h)	Passenger vehicles – private cars and taxis	19,1	BMA
	Buses – public transport	14,4	
	Light commercial vehicles – e.g. emergency vehicles	17,8	
Annual Fuel consumption (tons)	2.800.698		Barcelona city
Annual CO_2 emissions (tons)	85.946,25		Barcelona city
Annual CO emissions (tons)	31,9		N.A.
Annual NOx emissions (tons)	2.873,3		Barcelona city
Annual VOC emissions (tons)	183,9		N.A.
Annual PM emissions (tons)	28.918		N.A.
Annual fatalities in urban roads	Passenger vehicles – private cars and taxis	5	Barcelona city
	Buses – public transport	1	
	Light Commercial vehicles – e.g. emergency vehicles	0	
	Heavy vehicles – e.g. trucks	2	
Annual severe injuries in urban roads	Passenger vehicles – private cars and taxis	24	Barcelona city
	Buses – public transport	8	
	Heavy vehicles – e.g. trucks	1	
Annual slight injuries (number)	Passenger vehicles – private cars and taxis:	2.740	Barcelona city
	Buses – public transport:	516	

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	Light Commercial vehicles – e.g. emergency vehicles:	24	
Annual material damages (€)	43.048.000		N.A.

Table 13: Statistical data from the Barcelona Deployment Site

Benefits per impact area – Barcelona	2017 scenario	2020 scenario	Reduction
Vehicles' average speed increase in motorways (km/h)			
Passenger vehicles	114	114,1	0,1 (increase)
Buses	89	89,5	0,5 (increase)
Light commercial vehicles	113	113,1	0,1 (increase)
Heavy commercial vehicles	85,3	87,2	1,9 (increase)
Vehicles' average speed increase in inter-urban roads (km/h)			
Passenger vehicles	92	92,1	0,1 (increase)
Buses	20,8	21,3	0,5 (increase)
Light commercial vehicles	88	88,1	0,1 (increase)
Heavy commercial vehicles	76,2	78,1	1,9 (increase)
Vehicles' average speed increase in urban roads (km/h)			
Passenger vehicles	19,1	19,2	0,1 (increase)
Buses	14,4	14,9	0,5 (increase)
Light commercial vehicles	17,8	17,9	0,1 (increase)
Environment – Energy			
CO_2 emissions (tons)			
Equivalent diesel consumption (l)	-		621,77

Table 14: Benefits estimates for the Barcelona Deployment Site

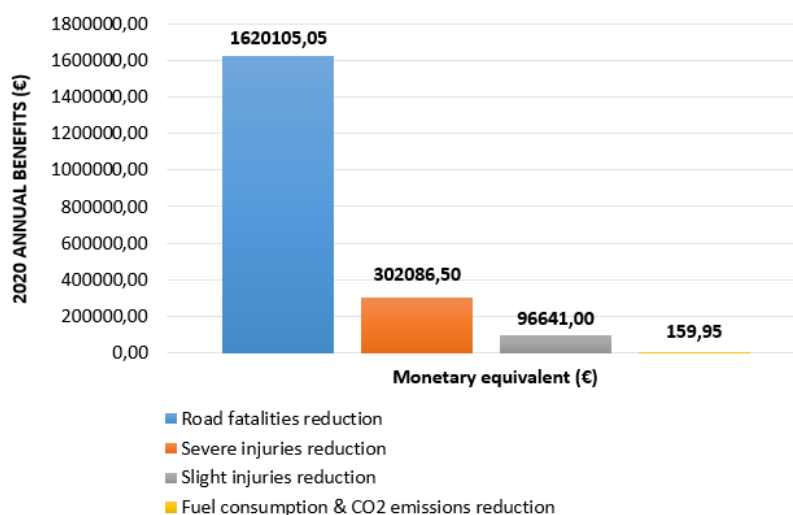Figure 5: Monetary equivalent of the 2020 annual benefits for the Barcelona Deployment Site

In line with the outputs of the analysis, the estimated BCR for the year 2020 for the Barcelona deployment site ranges between 2,15 and 2,52. A BCR within this range, i.e. 1-3, is considered as an acceptable one, proving that the C-ITS services deployment is capable of offering significant social benefits to the Barcelona deployment site.

4.1.2. Bilbao

The city of Bilbao, facing common urban challenges, such as congestion, noise and pollution, aims to improve mobility and accessibility through the implementation of the C-MobILE C-ITS services. The data collected from the Bilbao deployment site provided an insight on the status of the current C-ITS infrastructure, consisting of approximately 275-300 intersections equipped with RSUs, as well as on the existing end-users. More specifically, as of today 400-450 car drivers, 3.000-3.500 truck drivers and about 25.000 cyclists have access to the already implemented C-ITS services, provided to them through cellular commination technology. Costs associated to end-users issues are estimated as of € 50.000 -150.000, according to data derived from the Bilbao deployment site.

Data concerning the total annual costs of the existing TMC were not available, hence it was assumed that such costs could correspond to the respective costs of the Thessaloniki deployment site, i.e. € 88.600,00, since both TMCs currently support the same number of C-ITS services (two existing C-ITS services in each deployment site). Data on the annual operational and maintenance costs of the existing RSUs were also unavailable, thus such costs were estimated based on the data collected from the literature review. Total annual costs aligned to the current (2017) C-ITS services' infrastructure and end-users in the Bilbao deployment site were estimated to range between € 401.237,99 and € 507.768,40.

Within the C-MobILE context, Bilbao intends to successfully operate and implement four additional C-ITS services. For this scope infrastructure updates are foreseen, such as operating processing units for parking availability detection, cloud server set up, RSUs' update and online and real-time access to end-users. The services will be provided via cellular communication technology within a range of 35 km of urban roads [35], while according to the Bilbao deployment site data, the final number of end-users will rise to 34.675. Estimations on the annual total costs of the TMC, supporting the integrated C-ITS services, were not provided from the Bilbao deployment site. In order to avoid overestimations, such costs were not calculated based on the literature review data, since prices were considered rather high and not representative of the Bilbao C-ITS deployment. Therefore, 2020 total annual TMC costs were assumed to follow a growth ratio equal to the one of the Thessaloniki deployment site, since both of them were assumed to have equal 2017 total annual TMC costs.

According to the outputs of the analysis, costs expressing the 2020 C-ITS services deployment in Bilbao, were estimated to range from a minimum amount of € 401.994,32 to a maximum one of € 512.963,50. Increase in costs is slight and it is attributed mainly to the RSUs' updates. The following table presents an overview of the current and future C-ITS services implementation in Bilbao. Costs breakdown for 2020 and total annual costs for the years 2017 and 2020 are depicted in the figures below.

C-ITS services implementation in Bilbao	
Existing	/ Urban Parking Availability
	/ Road Works Warning
To be implemented	/ Rest Time Management
	/ Motorway Parking Availability
	/ Road Hazard Warning
	/ Blind Spot Detection

Table 15: C-ITS services current (2017) and future (2020) status in the Bilbao Deployment Site
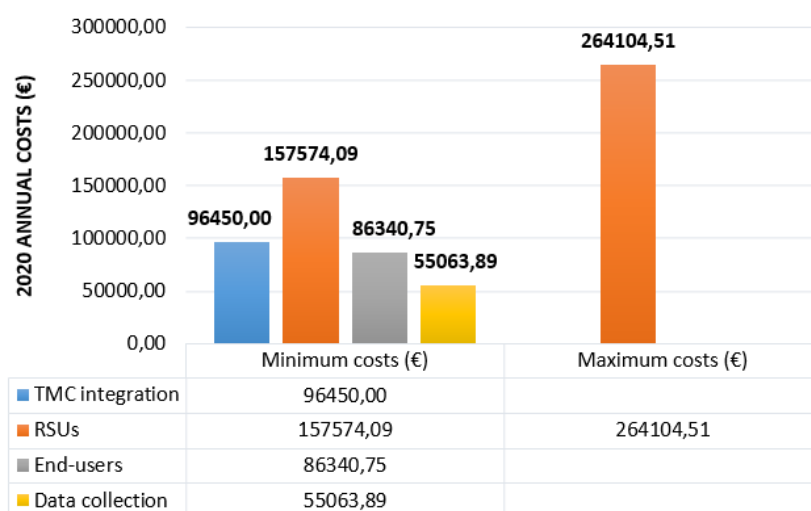
Figure 6: 2020 costs breakdown for the Bilbao Deployment Site
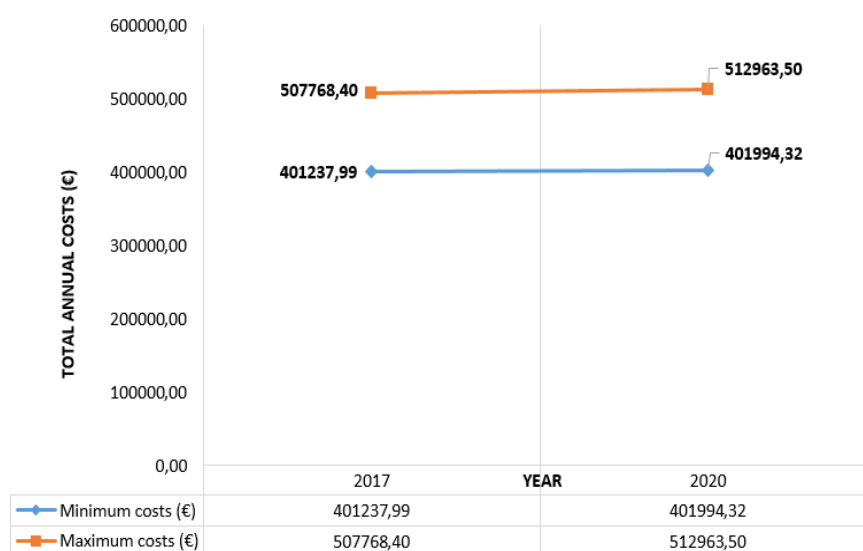
Figure 7: Total annual costs for the Bilbao Deployment Site

Statistical data depicting the current situation in the Bilbao deployment site was unavailable. Due to the lack of data, a precise estimation of the individual impacts of the C-ITS services at deployment site level could not be conducted, hence average values were used, as described before for the Barcelona deployment site (Chapter "4.1.1. Barcelona"). The 2020 total annual benefits for the Bilbao deployment site were estimated to be € 2.018.992,50. The following tables present the benefits estimates and the respective monetary equivalent.

Benefits per impact area – Bilbao	Reduction - 2020
Safety	
Road fatalities	0,8
Severe injuries	1,2
Slight injuries	5,1
Traffic efficiency	
Vehicles' (all types) average speed increase (km/h)	1,2 (increase)
Environment – Energy	
CO_2 emissions (tons)	
Equivalent diesel consumption (l)	621,77

Table 16: Benefits estimates for the Bilbao Deployment Site
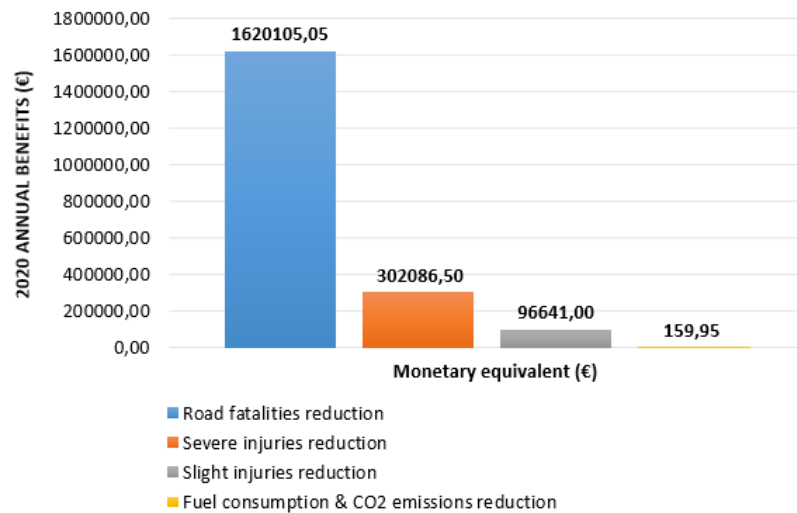
Figure 8: Monetary equivalent of the 2020 annual benefits for the Bilbao Deployment Site

The BCR for the year 2020, resulting from the C-ITS services deployment within the Bilbao deployment site, is estimated to range between 3,94 and 5,02. Such a BCR, which is greater than 3, indicates that the benefits expected from the C-ITS services implementation are about to significantly outweigh the costs. More specifically, the Bilbao deployment site could expect € 3,94 -€ 5,02 in benefits for each 1 euro of cost.

4.1.3. Bordeaux

Bordeaux has been engaged in a significant number of C-ITS deployment initiatives since 2014, such as the projects Compass4D, Scoop@F, CO-GISTICS and C-The Difference. The existing infrastructure, supporting six already implemented C-ITS services, covers the urban area of Bordeaux and the Ring Road. According to data derived from the Bordeaux deployment site, the total annual costs of the TMC, responsible for the existing C-ITS services' operation and maintenance in the urban area of Bordeaux, are estimated to be € 8.000. The 14 existing intersections, equipped with RSUs, are estimated to generate annual total costs of € 6.000, while annual costs attributed to the operation and maintenance of 12 vehicles, equipped with OBUs, come to € 4.000. The existing C-ITS services are provided via ITS G5 and cellular communication to a total number of 876 vehicle drivers (850 cars, 20 taxis and 6 emergency vehicles). Total annual costs associated to data collection are estimated as of € 50.000, while the ones referring to end-users' issues, e.g. mobile applications, data usage, come to € 100.000. Estimations on the total annual costs of the current (2017) C-ITS deployment in Bordeaux, in line with the data provided from the deployment site, indicated the amount of € 168.000.

Figure 9: C-The Difference Bordeaux Pilot Site

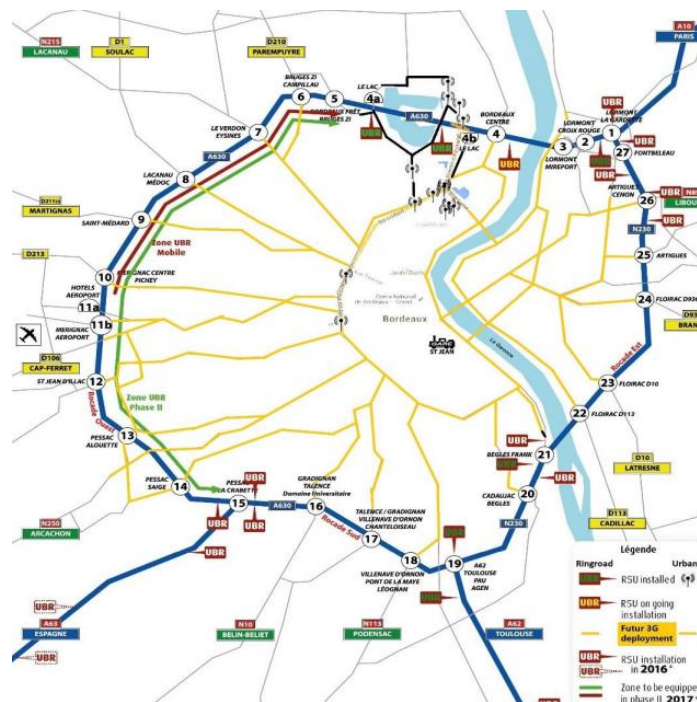The Bordeaux deployment site is involved in the implementation and operation of 22 C-ITS services (6 existing and 16 new) within the context of C-MobILE, covering all bundles. Infrastructure extensions include the installation of additional RSUs in the urban area of Bordeaux, as well as along the Ring Road, in order to accomplish interoperability with the existing Scoop@F RSUs [35]. According to data collected from the deployment site, 50 new RSUs (including replacements) will be integrated into the existing infrastructure, which will cover 60 km of inter-urban roads and 2.590 km of urban roads. Part of the C-MobILE updates constitute also the installation of approximately 20 OBUS in emergency vehicles. The communication type used for the C-ITS services' provision will remain as is, both ITS G5 and cellular. In terms of end-users, a significant extension is foreseen, adding to the current number 3.000 car drivers, 413 taxi drivers, 20 emergency vehicle drivers, 40 bus drivers (public transport), 50 truck drivers, 40 cyclists, 80 pedestrians and 500 users of public transport.

The Bordeaux deployment site estimates that total costs depicting the annual operation and maintenance of the integrated TMC, which will support all the C-ITS services, in the year 2020, will come to € 130.000. 2020 total annual costs referring to the rest of the equipment and end-users extensions, were estimated based on the data collected from the literature review. The respective calculations, conducted in accordance with the economic analysis methodology (Chapter 3.4. "Economic Analysis"), showed that total costs, indicative of the 2020 annual operational and maintenance needs of the C-ITS deployment in the Bordeaux deployment site, rise within the range of € 4.440.913,18 to € 4.466.107,61. This significant cost increase is mainly due to the costs associated to data collection and end-users (which are already the highest ones), as the total number of C-ITS equipped road km and the final number of end-users constitute the substantial part of the C-MobILE extensions. The following table presents an overview of the current and future C-ITS services implementation in Bordeaux. Costs breakdown for 2020 and total annual costs for the years 2017 and 2020 are depicted in the figures below.

C-ITS services implementation in Bordeaux	
Existing	/ Urban Parking Availability
	/ Road Works Warning
	/ Road Hazard Warning
	/ Emergency Vehicle Warning
	/ Signal Violation Warning
	/ Green Light Optimal Speed Advice
To be implemented	/ Rest Time Management
	/ Motorway Parking Availability
	/ Warning System for VRUs
	/ Green Priority
	/ Cooperative Traffic Light for VRUs
	/ Flexible Infrastructure
	/ In-vehicle Signage (speed, weather, others)
	/ Mode and Trip Time Advice
	/ Probe Vehicle Data
	/ Emergency Brake Light
	/ Urban CACC
	/ Slow/ Stationary Vehicle Warning
	/ Motorcycle Approaching Indication
	/ Blind Spot Detection

Table 17: C-ITS services current (2017) and future (2020) status in the Bordeaux Deployment Site
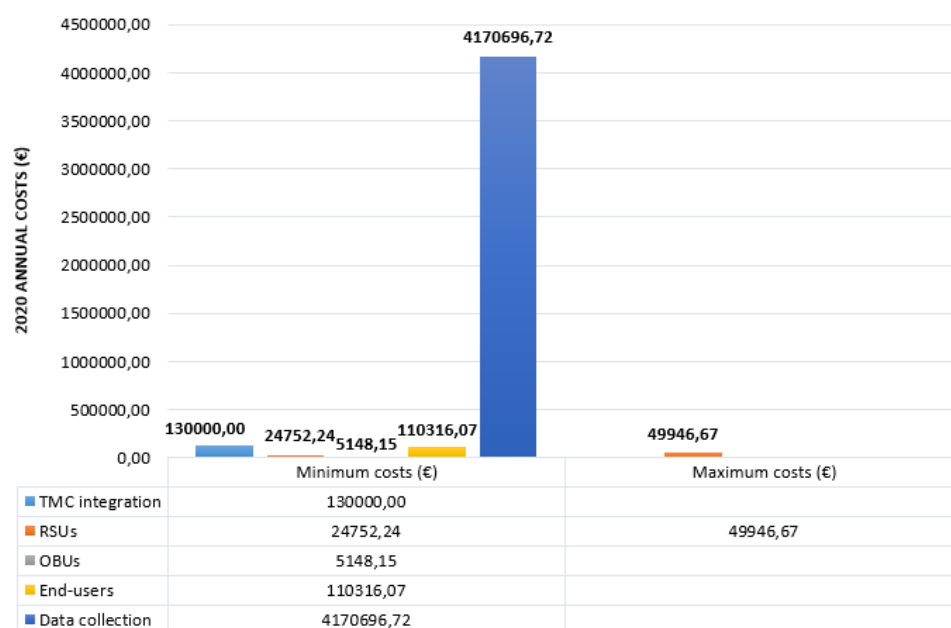
Figure 10: 2020 costs breakdown for the Bordeaux Deployment Site
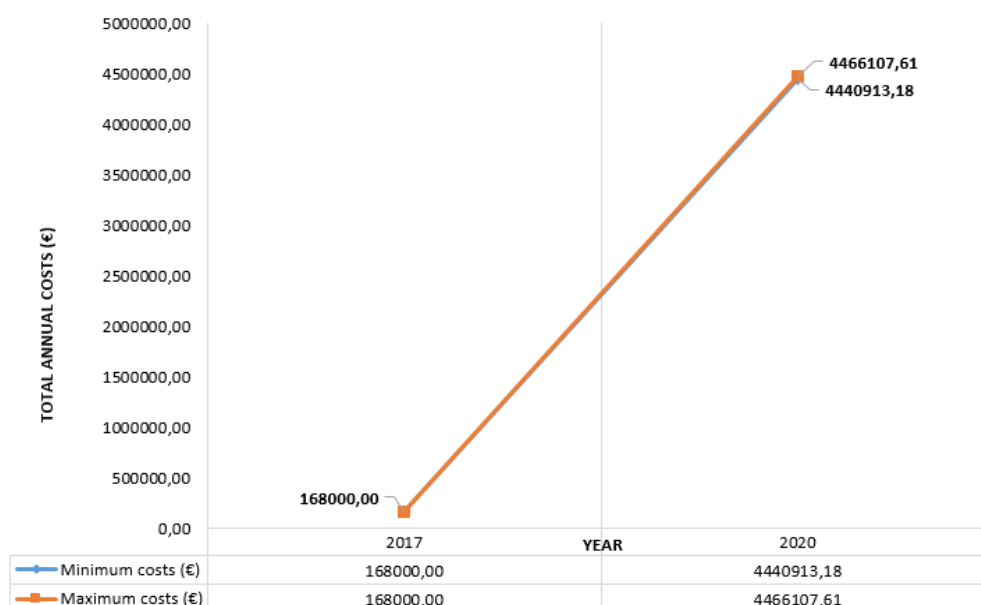
Figure 11: Total annual costs for the Bordeaux Deployment Site

Statistical data depicting the current situation in the Bordeaux deployment was not provided. Due to the lack of data, the impacts of the C-ITS services at deployment site level had to be expressed by average values. The most recent data, referring to CO_2 emissions, were the ones described in the Compass4D project, hence it was assumed that this value depicts the current situation in the Bordeaux deployment site. The rest of the benefits were estimated based on average values. The 2020 total annual benefits for the Bordeaux deployment site are estimated as of € 2.252.534,84. The following table presents the data from Compass4D project, while benefits estimates and the respective monetary equivalent are explicitly presented below.

Bordeaux – Compass4D data	
CO_2 emissions (tons)	167,36

Table 18: Bordeaux data from Compass4D

Benefits per impact area – Bordeaux	2017 scenario	2020 scenario	Reduction
Safety			
Road fatalities			0,8
Severe injuries			1,2

45

Slight injuries		5,1	
Traffic efficiency			
Vehicles' average speed increase (km/h)		1,2	
Environment – Energy			
CO$_2$ emissions (tons)	167,36		
Equivalent diesel consumption (l)	62.917,29	62.295,52	621,77

Table 19: Benefits estimates for the Bordeaux Deployment Site
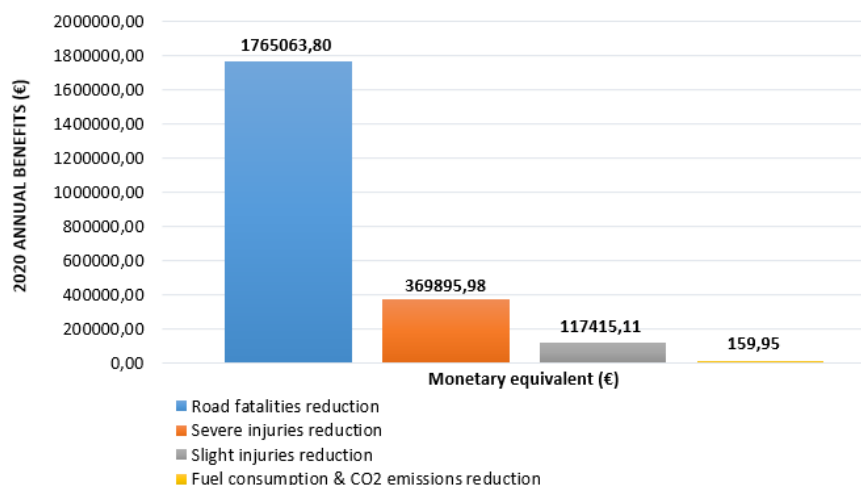
Figure 12: Monetary equivalent of the 2020 annual benefits for the Bordeaux Deployment Site

The BCR for the Bordeaux deployment site is estimated as of 0,51. This BCR is lower than 1, and it could be considered as "poor", as it claims that benefits do not overweigh costs. However, it should be taken into consideration that such a BCR is not a representative one, since it corresponds only to a certain amount of benefits. Benefits associated to traffic efficiency increase, which could add a significant monetary equivalent, were not estimated due to lack of data.

4.1.4. Copenhagen

The city of Copenhagen is already active in the field of the C-ITS services, as it was engaged to previous related projects, such as Compass4D. The current infrastructure covers one Compass4D corridor in the city of Copenhagen and the Folehaven corridor [35]. As of today it is estimated that the annual costs for the operation and the maintenance of the TMC, supporting the existing C-ITS services, is € 2.195.478. Costs related to data collection and end-users are included. Annual costs related to operation and maintenance of the current C-ITS services' infrastructure and technology equipment comprise of the cost of 50 equipped intersections (about 50 RSUs), € 134.268,64, and the cost of 87 equipped buses (public transport) and 2 equipped private vehicles (about 90 OBUs), € 8,056.01. The communication technology used for the existing C-ITS services is both ITS G5 and cellular, using 44 ITS G5 compatible intersections and 6 ITS G5 and cellular compatible intersections. At present, the C-ITS services are provided to 87 bus drivers. Total annual costs describing the current C-ITS services deployment, 2017, were calculated to € 2.337.560,45.

Figure 13: Equipped corridors in the Copenhagen Deployment Site

In the context of C-MobILE, the Copenhagen deployment site will implement specific C-ITS services focusing on infrastructure-to-vehicle safety and traffic efficiency. Updates of the existing infrastructure is foreseen, in order to enable compatibility of the existing C-ITS services with the C-MobILE architecture. The C-MobILE extensions include additional connections of technology components to the TMC, reconfi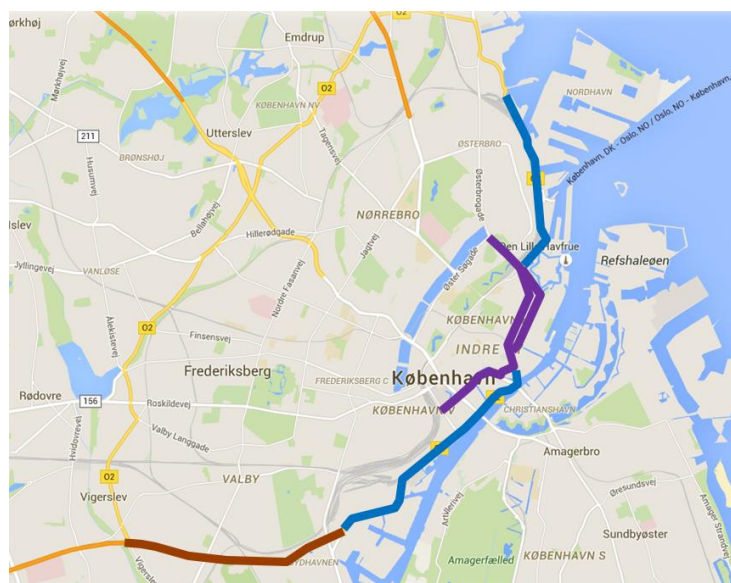guration of the TLCs, development of new interfaces for interoperability purposes and update of the HMI of the already developed C-ITS services applications [35]. According to the estimations of the Copenhagen deployment site, total annual costs regarding the TMC integration, operation and maintenance, for the year 2020, amount to € 2.195.158,90. The C-ITS services will be provided along a road network of totally 11 km of urban roads. As far as the technology equipment is concerned, the C-ITS services implementation will rely on the existing systems, which will be updated. Extension of end-users includes up to 30 truck drivers and 200 VRUs, i.e. cyclists and pedestrians. The number of VRUs is not validated, as it is not yet specified from the side of the deployment site, hence an assumption according to the data described on the GA document [35] is made.

Total annual costs expressing the 2020 C-ITS services demonstration in the Copenhagen deployment site were estimated as of € 2.355.578,68. According to the outputs of the analysis, only a slight increase in costs is about to occur, justified form the fact that Copenhagen has already implemented a significant number of C-ITS services, covering this way sufficiently the implementation of the new ones. The following table presents an overview of the current and future C-ITS services implementation in Copenhagen. Costs breakdown for 2020 and total annual costs for the years 2017 and 2020 are depicted in the figures below.

C-ITS services implementation in Copenhagen	
Existing	/ Green Priority
	/ Green Light Optimal Speed Advice
	/ Time To Green/ Red
	/ Cooperative Traffic Light for VRUs
	/ In-vehicle Signage (Speed)
To be implemented	/ Road Works Warning
	/ Road Hazard Warning
	/ Warning System for VRUs
	/ Mode and Trip Time Advice
	/ Probe Vehicle Data
	/ Emergency Brake Light
	/ Slow/ Stationary Vehicle Warning
	/ Blind Spot Detection

Table 20: C-ITS services current (2017) and future (2020) status in the Copenhagen Deployment Site
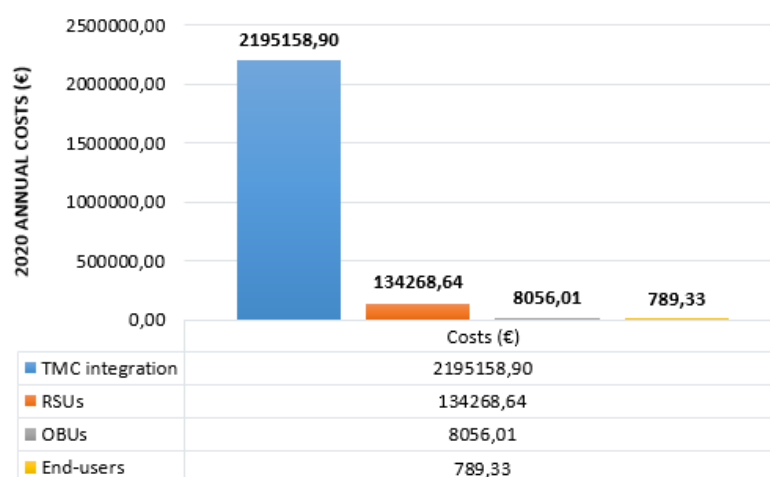
Figure 14: 2020 costs breakdown for the Copenhagen Deployment Site
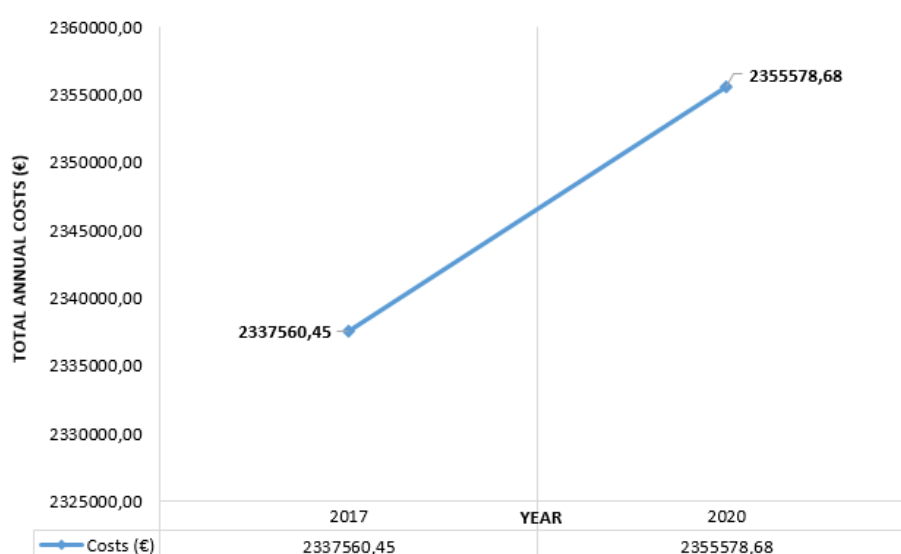
Figure 15: Total annual costs for the Copenhagen Deployment Site

The C-ITS services implementation and operation in the Copenhagen deployment site is expected to result in benefits attributed to road accidents' reduction, traffic efficiency increase, as well as CO_2 emissions' reductions. The statistical data provided by the Copenhagen deployment site provided insights into specific parameters, such as modal split, annual CO_2 emissions and annual fatalities in urban roads. Nevertheless, since the area of reference was not specified, it was considered more appropriate to use data from the Compass4D project, as the latter refer only to the "study area", i.e. the deployment site, and could prevent overestimations. Benefits regarding road safety and average speed increase were estimated based on average values. The 2020 total annual benefits for the Copenhagen deployment site were estimated as of € 7.981.903,67. The following tables present the data collected from the deployment site and data from the Compass4D project, while benefits estimates and the respective monetary equivalent are explicitly presented below.

Copenhagen Statistical Data			Area of reference
Modal split in urban roads (%)	Private cars:	24%	N.A.
	Buses – public transport	30%	
	Non-motorized modes (e.g. bicycles)	46%	
Annual CO$_2$ emissions in urban roads (tons)	Private cars and taxis	226,26	N.A.
	Buses – public transport	32,096	
	Light Commercial vehicles – e.g. emergency vehicles	60,35	
	Heavy vehicles – e.g. trucks	43,48	

Annual fatalities in urban roads	Private cars and taxis	169	N.A.
	Buses – public transport	1	

Table 21: Statistical data from the Copenhagen Deployment Site

Copenhagen – Compass4D data	
Passenger travel time public transport (hrs)	38.055.312
CO_2 emissions (tons)	1.037

Table 22: Copenhagen data from Compass4D

Benefits per impact area – Copenhagen	2017 scenario	2020 scenario	Reduction
Safety			
Road fatalities			0,8
Severe injuries			1,2
Slight injuries			5,1
Traffic efficiency			
Vehicles' (all types) average speed increase (km/h)			1,2 (increase)
Passenger travel time public transport (hrs)	38.055.312	36.228.657,02	1.826.66
Environment – Energy			
CO_2 emissions (tons)	1.037		
Equivalent diesel consumption (l)	389.849,62	389.227,85	621,77

Table 23: Benefits estimates for the Copenhagen Deployment Site
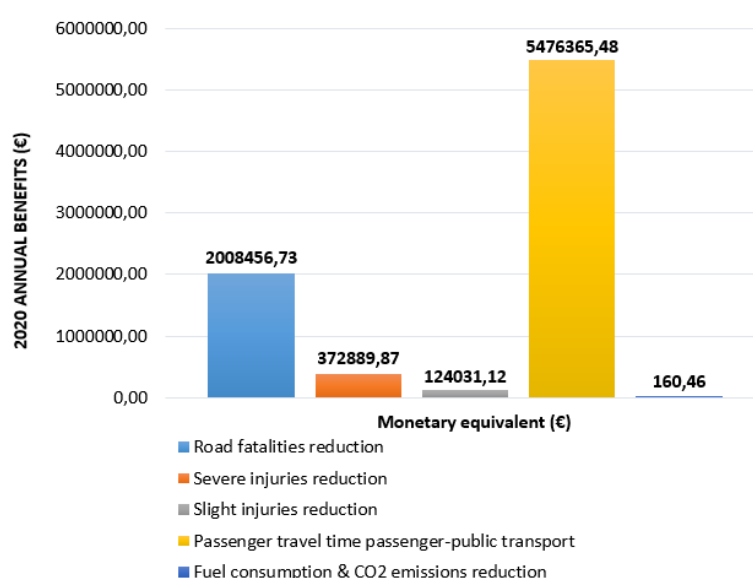
Figure 16: Monetary equivalent of the 2020 annual benefits for the Copenhagen Deployment Site

Based on the outputs of the economic analysis, the BCR for the Copenhagen deployment site in the year 2020 is estimated as of 3,39. This BRC, which is ranked higher than 3, points that the C-ITS services should be in first line for market deployment in the Copenhagen deployment site.

4.1.5. Newcastle

Newcastle has implemented C-ITS services in the past as well. The most recent C-ITS services' demonstrations, the ones aligned to the Compass4D project, employed a total of 11 emergency vehicles and 2 electric vehicles. Data collected from the Newcastle deployment site provided an estimation of € 569.872 regarding the annual operational and maintenance costs of the existing TMC. This data refer though to the entire region of Tyne and Wear, and not to the deployment site per se. As regards to the deployment site (2 corridors), 39 equipped intersections distributed along 7 km of the urban road network, constitute part of the current infrastructure. Each intersection is equipped with one RSU, resulting in total annual costs of approximately € 10.000. The communication technology used is both ITS G5 and cellular. The equipped vehicles comprise of 13 emergency vehicles and 2 private cars. The C-ITS services are

supported through 15 OBUs installed in the vehicles, with annual operational and maintenance costs rising to € 5.000. Costs associated to data collection are estimated to be € 5.000. Annual costs associated to the current (2017) operational and maintenance needs of all the aforementioned systems come to € 589.872,00.

The foreseen deployment includes the implementation and demonstration of C-ITS services addressing vehicle-to-vehicle safety issues. In order to achieve the integration of the C-MobILE architecture and to reassure interoperability, the Newcastle deployment side will proceed in a series of necessary steps including: cloud-based provision of services, configuration of the TLCs, open up of the collected data, upgrade of all the existing RSUs, extension and upgrade of the current OBU/ HMI technology, installation of sensors on vehicle blind spots (buses-public transport) and roll out of the C-ITS services to smartphone users [35]. Furthermore, new OBUs will be installed in 10 taxis, 10 trucks and 35 buses, while the number of VRUs estimated to use the C-ITS services is of 200.

Estimations provided from the Newcastle deployment site regarding the total annual costs of the TMC integration were of € 554.360. Costs associated to the additional extensions (mainly end-users) were calculated based on the data derived from the literature review, resulting in 2020 total annual costs of € 583.833,11. There is a minor difference between costs attributed to 2017 and 2020, as costs concerning the future C-ITS services deployment proved to be lower than the current ones. This difference could be justified from the fact that current costs include TMC costs referring to the entire region of Tyne and Wear, depicting prices relative to an area of a larger geographic coverage. The following table presents an overview of the current and future C-ITS services implementation in Newcastle. Costs breakdown for 2020 and total annual costs for the years 2017 and 2020 are depicted in the figures below.

C-ITS services implementation in Newcastle	
Existing	/ Road Works Warning
	/ Road Hazard Warning
	/ Warning System for VRUs
	/ Green Priority
	/ Green Light Optimal Speed Advice
	/ In-vehicle Signage (Speed)
To be implemented	/ Urban Parking Availability

Table 24: C-ITS services current (2017) and future (2020) status in the Newcastle Deployment Site
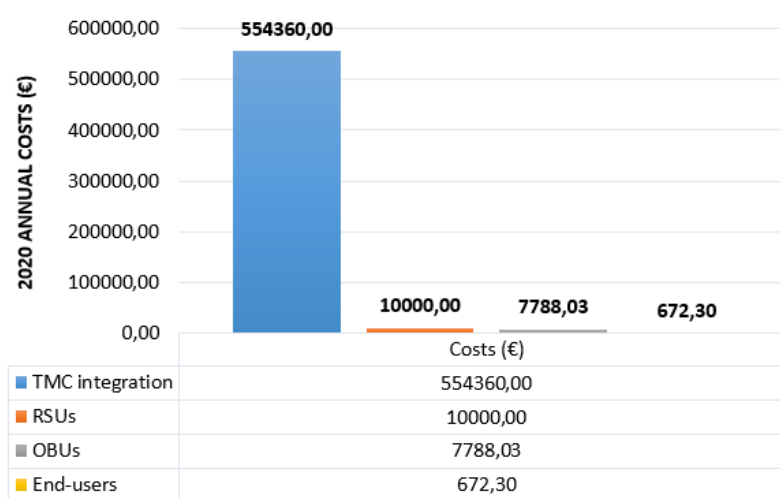
Figure 17: 2020 costs breakdown for the Newcastle Deployment Site
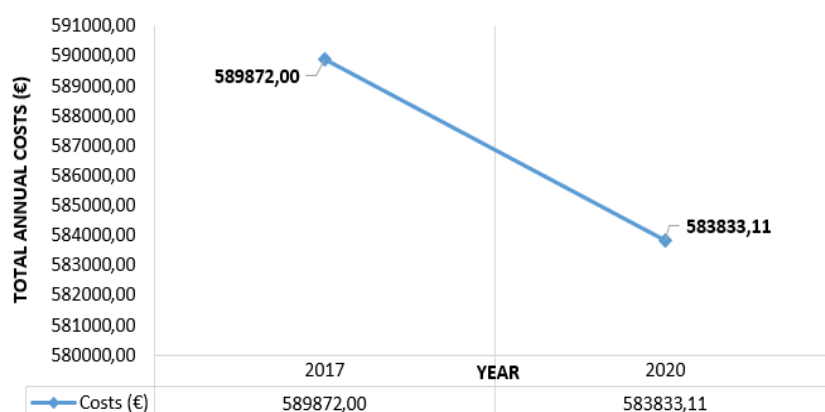
Figure 18: Total annual costs for the Newcastle Deployment Site

The impacts of the C-ITS services, to be implemented in the Newcastle deployment site, were estimated based on average values, as data on the total annual number of vehicle kilometers driven in a year per road type was unavailable. The Newcastle deployment site provided though data referring to the "study area", depicting average speeds and annual road accidents. These data enabled a partial estimation of benefits. The 2020 total annual benefits were estimated as of € 506.073,48. The following table presents the data collected from the deployment site and data extracted from the Compass4D project, while benefits estimates and the respective monetary equivalent are explicitly presented below.

Newcastle Statistical Data			Area of reference
Total annual vehicle kilometres (Vkm)	1.465.000.000		Entire district of Newcastle
Modal split in urban roads (%)	Private cars	83,8	Deployment corridor 2
	Taxis	N.A.	
	Buses – public transport	6	
	Light Commercial vehicles – e.g. emergency vehicles	8,7	
	Heavy vehicles – e.g. trucks	0,8	
	Motorcycles	0,6	
	Non-motorized modes (e.g. bicycles)	0,1	
Average speed in urban roads (km/h)	Passenger vehicles – private cars and taxis	32	A1058 (Corridor 1); Great North Road (Corridor 2)
	Buses – public transport	32	
	Light Commercial vehicles – e.g. emergency vehicles	32	
	Heavy vehicles – e.g. trucks	32	
Annual fatalities in motorways	Passenger vehicles – private cars and taxis:	0	Deployment corridor 1 & 2
	Buses – public transport:	0	
	Light Commercial vehicles – e.g. emergency vehicles:	0	
	Heavy vehicles – e.g. trucks:	0	
Annual fatalities in inter-urban roads	Passenger vehicles – private cars and taxis	0	Deployment corridor 1 & 2
	Buses – public transport	0	
	Light Commercial vehicles – e.g. emergency vehicles	0	
	Heavy vehicles – e.g. trucks	0	

Annual fatalities in urban roads	Passenger vehicles – private cars and taxis		Deployment corridor 1 & 2
	Buses – public transport	O	
	Light Commercial vehicles – e.g. emergency vehicles	O	
	Heavy vehicles – e.g. trucks	O	
Annual severe injuries in motorways	Passenger vehicles – private cars and taxis	O	Deployment site corridors 1 & 2
	Buses – public transport	O	
	Light Commercial vehicles – e.g. emergency vehicles	O	
	Heavy vehicles – e.g. trucks	O	
Annual severe injuries in inter-urban roads	Passenger vehicles – private cars and taxis	O	Deployment site corridors 1 & 2
	Buses – public transport	O	
	Light Commercial vehicles – e.g. emergency vehicles	O	
	Heavy vehicles – e.g. trucks	O	
Annual severe injuries in urban roads	Passenger vehicles – private cars and taxis	3	Deployment site corridors 1 & 2
	Buses – public transport	1	
	Light Commercial vehicles – e.g. emergency vehicles	O	
	Heavy vehicles – e.g. trucks	O	
Annual slight injuries in motorways	Passenger vehicles – private cars and taxis	O	Deployment site corridors 1 & 2
	Buses – public transport	O	
	Light Commercial vehicles – e.g. emergency vehicles	O	
	Heavy vehicles – e.g. trucks	O	
Annual slight injuries in inter-urban roads	Passenger vehicles – private cars and taxis	O	Deployment site corridors 1 & 2
	Buses – public transport	O	
	Light Commercial vehicles – e.g. emergency vehicles	O	
	Heavy vehicles – e.g. trucks	O	
Annual slight injuries in urban roads	Passenger vehicles – private cars and taxis	17	Deployment site corridors 1 & 2
	Buses – public transport	3	
	Light Commercial vehicles – e.g. emergency vehicles	O	
	Heavy vehicles – e.g. trucks	O	
	Bicycles	5	

Table 25: Statistical data from the Newcastle Deployment Site

Benefits per impact area – Newcastle	2017 scenario	2020 scenario	Reduction
Safety			
Road fatalities	O	O	O
Severe injuries in urban roads	4	2,8	1,2

Slight injuries in urban roads	25	19,9	5,1
Traffic efficiency			
Vehicles' (all types) average speed increase in urban roads (km/h)	32	33,2	1,2 (increase)

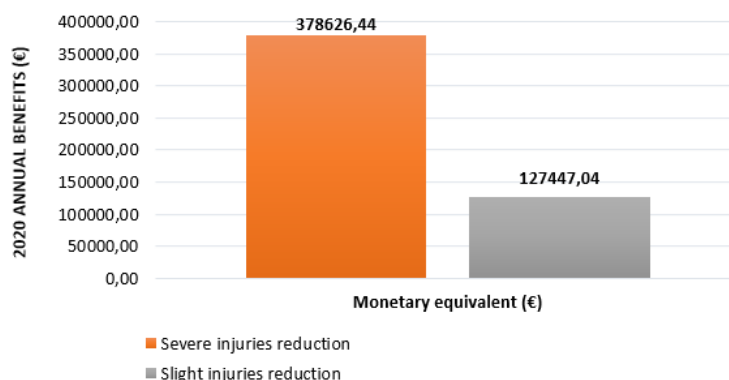Table 26: Benefits estimates for the Newcastle Deployment Site

Figure 19: Monetary equivalent of the 2020 annual benefits for the Newcastle Deployment Site

The outputs of the analysis, in terms of total annual costs and benefits for the year 2020, led to the calculation of a BCR of 0,87. The BCR for the Newcastle deployment site is slightly lower than 1, which could almost indicate the socio-economic inefficiency of the C-ITS services deployment. This BCR though should not be considered as representative of the real C-ITS services deployment, as it includes only a part of the expected benefits. Benefits attributed to traffic efficiency increase and to fuel consumption reduction, which would add a substantial monetary equivalent to the amount of the 2020 total benefits, were not taken into account, since data necessary for their estimation was not available.

4.1.6. North Brabant

The region of North Brabant, and especially the city of Helmond, has been engaged in previous projects related to the C-ITS services deployment, such as the Compass4D project. Within the Compass4D frame, a total of 20 heavy goods vehicles, 2 buses and 10 light vehicles (taxis) were having access to the C-ITS services. According to data provided from the North Brabant deployment site, costs associated to the annual operation and maintenance of the existing TMC rise to € 38.500. The existing C-ITS equipped road network consists of 21 kms, with 49 RSUs distributed along it. Total annual costs attributed to the existing RSUs were provided from the deployment site and estimated to the amount of € 655.000. Data on the annual costs of the data collection process indicated the amount of € 30.210,05. Total annual costs describing the current C-ITS services deployment (2017) in the North Brabant deployment site were estimated as of € 733.710,05.

In the context of C-MobILE, the North Brabant deployment site aims for the implementation of C-ITS services focusing on urban efficiency, infrastructure-to-vehicle safety, traffic efficiency and vehicle-to-vehicle safety. Regarding infrastructure extensions for the support of the future C-ITS services, the North Brabant deployment intends to operate a total number of 59 RSUs, which costs were estimated as of € 793.000. Further data concerning the costs of the TMC integration, extensions in the C-ITS equipped road network, updates or new installations of OBUs, and extensions in end-users, were not provided from the deployment site. Taking into consideration the available data, total annual costs depicting operational and maintenance needs in the year 2020 were estimated as of € 831.500. However, it should be taken into account that real-life deployment costs are expected to be higher, since estimations at this point remain partial, due to lack of substantial data.
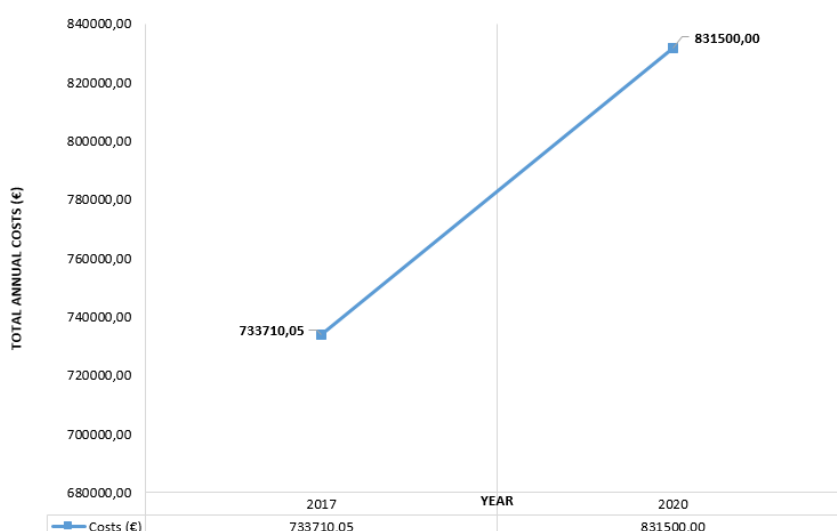
Figure 20: Total annual costs for the North Brabant Deployment Site

Statistical data describing aspects of road traffic, road accidents and emissions were not available from the North Brabant deployment site. Therefore, it was assumed that a rough estimation of the expected benefits could be provided based on average values. The 2020 total annual benefits for the North Brabant deployment site were estimated as of € 2.630.474,65. The following table presents the benefits estimates, while the respective monetary equivalent is explicitly presented in the figure below.

Benefits per impact area – North Brabant	Reduction – 2020
Safety	
Road fatalities	0,8
Severe injuries	1,2
Slight injuries	5,1
Traffic efficiency	
Vehicles' average speed increase	1,2
Environment – Energy	
CO$_2$ emissions (tons)	
Equivalent diesel consumption (l)	621,77

Table 27: Benefits estimates for the North Brabant Deployment Site
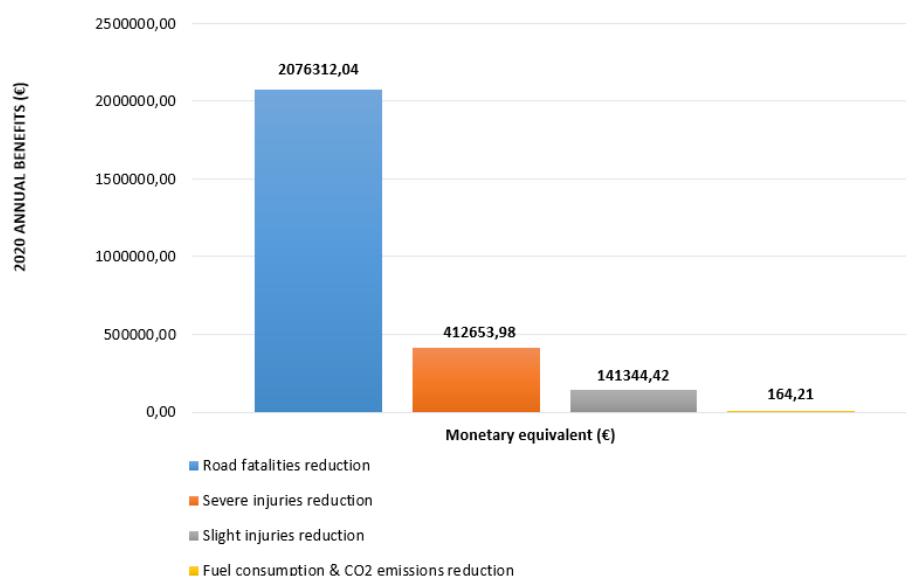
Figure 21: Monetary equivalent of the 2020 annual benefits for the North Brabant Deployment Site

The BCR for the year 2020, resulting from the outputs of the analysis, was estimated as of 3,16. Even though the total annual 2020 costs and benefits could be merely estimated, since there was a significant lack of data, the BCR (higher than 3) is ranked as "excellent", indicating that a more comprehensive estimation of the expected benefits could raise the ration even more.

4.1.7. Thessaloniki

Thessaloniki has been engaged and has invested early on in innovation initiatives and projects related to C-ITS services, such as the projects Compass4D and CO-GISTICS. Within the framework of Compass4D project, Thessaloniki implemented two C-ITS services, GLOSA and Road Hazard Warning, which were provided to 600 taxi drivers. The services were implemented with the use of the two existing TMCs of the Region of Central Macedonia (RCM), one responsible for Tsimiski St. (an urban street in the CBD) and one for the Peripheral Ring Road of Thessaloniki. During the Compass4D operational phase, the services were provided through ITS G5 and cellular communication technology along a road network of totally 20 km, 10 km motorways and 10 km (inter)-urban roads. The current infrastructure of the Thessaloniki deployment site comprises of 12 intersections (14 traffic lights) along Tsimiski Street, 6 RSUs and 5 VMSs along the Peripheral Ring Road, covering 13 km. Annual operational and maintenance costs associated to the TMCs, supporting the C-ITS services, rise to € 88.600,00. These costs include as well the annual total costs for the existing RSUs. Regarding in-vehicle equipment, Thessaloniki has employed 4 taxis equipped with OBUs, with total annual costs of € 240. In terms of end-users, the amount of € 60 is estimated to correspond to each end-user's needs. Based on these data, total annual costs depicting the current situation, 2017, in the Thessaloniki deployment site, were estimated as of € 124.840,00.
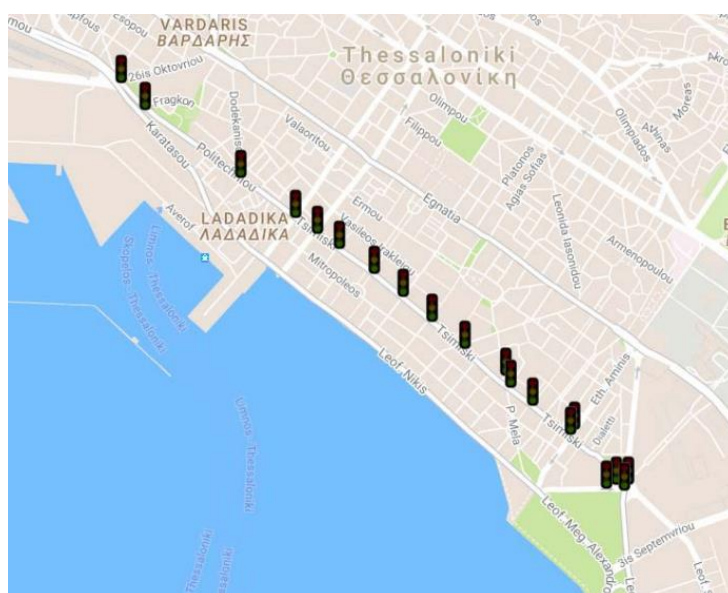
Figure 22: Equipped urban street (Tsimiski St.) in the Thessaloniki Deployment Site [51]

The commitment to the continuation of C-ITS services provision is aimed to be achieved within the C-Mobile C-ITS services deployment, since the Thessaloniki deployment site will implement and operate the C-ITS services related to infrastructure-to-vehicle safety and to traffic efficiency. Infrastructure upgrades necessary for integration and interoperability issues, include interfaces' development, as well as the integration of additional signal controlled intersections in the C-ITS enabled TMC. More specifically the geographically extended deployment site will cover urban and inter-urban gateways of the city, i.e. the city-airport route, adding approximately 10 km and 10 intersections to the total C-ITS equipped network [35]. No new RSUs neither additional OBUs are foreseen for the C-ITS services deployment, while the services demonstrations will be supported by the engagement of 6.800 additional end-users, 6.500 private cars and 300 pedestrians.

According to the outputs of the analysis, costs expressing the 2020 C-ITS services deployment in Thessaloniki, are estimated to rise in € 564.240,00. Increase in costs seems to be triggered mainly from the large number of end-users, which will have access to the C-ITS services through their mobile phones. The following table presents an overview of the current and future C-ITS services implementation in Thessaloniki. Costs breakdown for 2020 and total annual costs for the years 2017 and 2020 are depicted in the figures below.

C-ITS services implementation in Thessaloniki	
Existing	**/** Road Hazard Warning
	/ GLOSA
To be implemented	**/** Road Works Warning
	/ Emergency Vehicle Warning
	/ Signal Violation Warning
	/ Warning System for VRUs
	/ Time To Green/ Red
	/ Cooperative Traffic Light for VRUs
	/ Flexible Infrastructure
	/ In-vehicle Signage (Speed)
	/ Mode and Trip Time Advice
	/ Probe Vehicle Data

Table 28: C-ITS services current (2017) and future (2020) status in the Thessaloniki Deployment Site

Figure 23: 2020 costs breakdown for the Thessaloniki Deployment Site
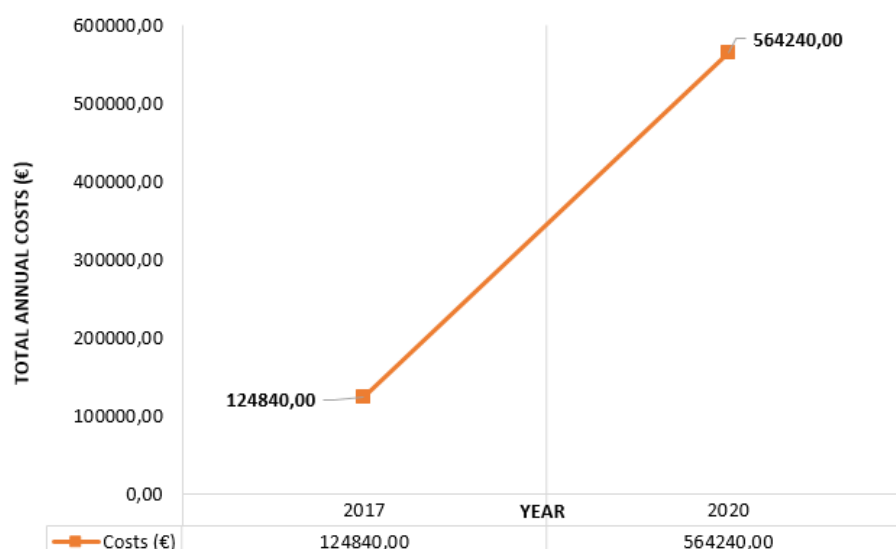
Figure 24: Total annual costs for the Thessaloniki Deployment Site

The C-ITS services deployment is expected to affect the current situation in the Thessaloniki deployment site in a positive manner, in terms of road safety, traffic efficiency and environmental pollution. The C-ITS services impacts at deployment site level were estimated fo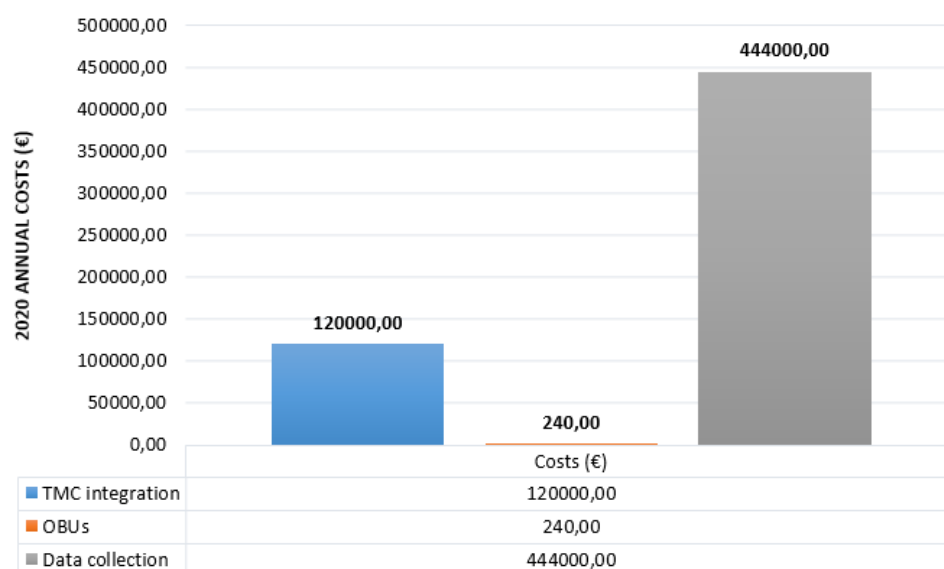llowing the extrapolation/ scaling down methodology (see Chapter "3.4. Economic Analysis"). Since the most recent available data on total vehicle kilometres refer to a regional level (Region of Central Macedonia), an overestimation regarding the percent values of the impacts at deployment site level is possible. Nevertheless, for the scope of this analysis it is assumed that the estimated impact rates refer to the deployment site.

Valuable data were collected from the Thessaloniki deployment site, enabling the estimation of the total annual benefits for the year 2020. Road accidents data is based on evidence referring to the years 2015 and 2016, though it is assumed to depict the current situation. The average speed used as an input for the analysis represents the average speed of all vehicle types circulating in the city of Thessaloniki during morning peak hours. Data on CO_2 emissions was extracted from the Compass4D project, while data on air pollutants emissions was available only at city level, hence it was not taken into account. The 2020 total annual benefits for the Thessaloniki deployment site were estimated as of € 1.541.038. The following table presents the data collected from the deployment site, while benefits estimates and the respective monetary equivalent are explicitly presented below.

Thessaloniki Statistical Data			Area of reference
Total annual vehicle kilometres in motorways (Vkm)	1.588,19 M		Region of Central Macedonia (RCM)
Total annual vehicle kilometres in inter-urban roads (Vkm)	1.146,1 M		Region of Central Macedonia (RCM)
Total annual vehicle kilometres in urban roads (Vkm)	2.982,05 M		Region of Central Macedonia (RCM)
Modal split in urban roads (%)	Private cars	67	Thessaloniki city
	Buses – public transport	23	
	Light Commercial vehicles – e.g. emergency vehicles	N.A.	
	Heavy vehicles – e.g. trucks	N.A.	
	Motorcycles	4	
	Non-motorized modes (e.g. bicycles)	2	
Average speed in urban roads (km/h)	Passenger vehicles – private cars and taxis	36,8	Thessaloniki city
	Buses – public transport	36,8	
	Light Commercial vehicles – e.g. emergency vehicles	36,8	
	Heavy vehicles – e.g. trucks	36,8	

Annual fuel consumption (tons)	Passenger vehicles – private cars and taxis	23.871	Deployment site
Annual CO_2 emissions (tons)	Passenger vehicles – private cars and taxis	72.559	Deployment site
Annual CO_2 emissions (tons)	Passenger vehicles – private cars and taxis	64.600	Thessaloniki city
	Buses – public transport	100	
	Light Commercial vehicles – e.g. emergency vehicles	25.500	
	Heavy vehicles – e.g. trucks	3.200	
Annual NO_x emissions (tons)	Passenger vehicles – private cars and taxis	4.400	Thessaloniki city
	Buses – public transport	2.200	
	Light Commercial vehicles – e.g. emergency vehicles	1.300	
	Heavy vehicles – e.g. trucks	7.100	
Annual VOC (NMVOCs) emissions (tons)	Passenger vehicles – private cars and taxis	7.800	Thessaloniki city
	Buses – public transport	50	
	Light Commercial vehicles – e.g. emergency vehicles	3.000	
	Heavy vehicles – e.g. trucks	2.000	
Annual fatalities in motorways	Passenger vehicles – private cars and taxis	2	Thessaloniki city – roads included in the deployment site
Annual fatalities in inter-urban roads	Passenger vehicles – private cars and taxis	1	Thessaloniki city – roads included in the deployment site
Annual fatalities in urban roads	Passenger vehicles – private cars and taxis	2	Thessaloniki city – roads included in the deployment site
Annual severe injuries in urban roads	Passenger vehicles – private cars and taxis	6	Thessaloniki city – roads included in the deployment site
Annual slight injuries in inter-urban roads	Passenger vehicles – private cars and taxis	13	Thessaloniki city – roads included in the deployment site
Annual slight injuries in urban roads	Passenger vehicles – private cars and taxis	13	Thessaloniki city – roads included in the deployment site

Table 29: Statistical data from the Thessaloniki Deployment Site

Benefits per impact area – Thessaloniki	2017 scenario	2020 scenario	Reduction
Safety			
Road fatalities	5	4,2	0,8
Severe injuries	6	4,8	1,2
Slight injuries	26	20,9	5,1
Traffic efficiency			
Vehicles' average speed increase	36,8	37,9	0,1
Environment – Energy			
CO_2 emissions (tons)	72,559		
Equivalent diesel consumption (l)	27.277,82	26.261,46	1.016,36

Table 30: Benefits estimates for the Thessaloniki Deployment Site
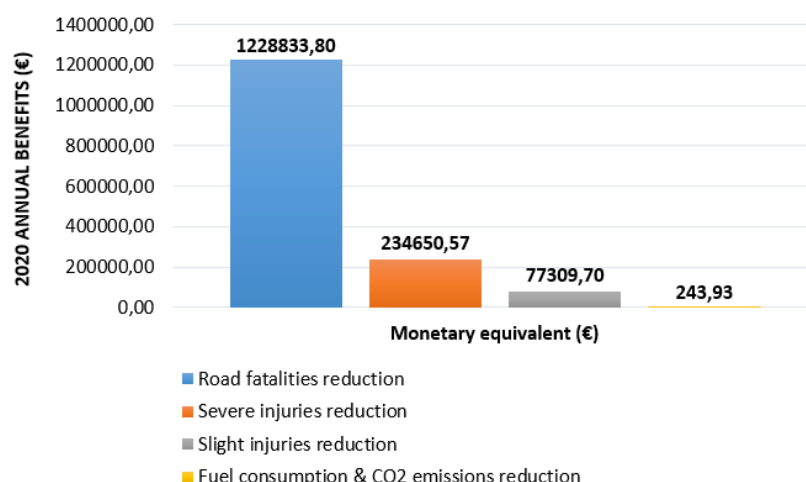
Figure 25: Monetary equivalent of the 2020 annual benefits for the Thessaloniki Deployment Site

The division of the total value of the benefits by the total value of the costs for the year 2020, resulted in a BCR of 2,73, indicating a positive return. In other words, the C-ITS services deployment appears to outweigh its costs significantly, proving the profitability of the investment.

4.1.8. Vigo

Vigo has employed in the past a total of thirteen light vehicles, two emergency vehicles and twenty buses for the demonstration of specific C-ITS services (Red Light Violation Warning, Road Hazard Warning and GLOSA) in the context of the Compass4D project. Data associated to the total annual costs of the current infrastructure, i.e. TMC, RSUs, OBUs, end-users, were not available from the Vigo deployment site, hence estimations of the current costs were based on the data collected from the literature review. The existing infrastructure, supporting the C-ITS services, comprises of 49 intersections equipped with RSUs and 30 vehicles equipped with OBUs. The communication technology used for the services' operation is ITS G5. In terms of end-users, Vigo provides the C-ITS services to 10 bus drivers and 20 truck drivers. Considering the current situation, 2017, total annual operational and maintenance costs were estimated to range between € 104.661,96 and € 122.786,92.

Figure 26: Equipped corridor in the Vigo Deployment Site

In the timeframe of the C-MobILE C-ITS services demonstrations, the Vigo Deployment Site will implement and operate services from bundles related to infrastructure-to-vehicle safety, to traffic efficiency and to vehicle-to-vehicle safety. Prior to the operational phase certain actions, such as installation of additional RSUs, traffic info cloud, interoperability with Scoop@F project on interurban environment, will take place, in order to establish an effortless integration of the newly implemented C-ITS services [35]. Regarding technology equipment extensions, the number of the additional RSUs is yet not determined from the Vigo Deployment Site, hence in the framework of the analysis it is assumed that the support of the C-ITS services will be provided through the upgraded existing RSUs. Upgrades and installations are assumed to take place in a road network of in total 100 km (1 RSU/ 20km, data from the Vigo deployment site),

supporting both ITS G5 and cellular based services. As far as the in-vehicle technology equipment is concerned, Vigo will employ 5-10 additional emergency vehicles, which are assumed to be equipped with new OBUs. An average number of 8 emergency vehicles is assumed for the scope of the analysis. User extension includes as well 30 private car drivers and 10 motorcyclists, while the number of pedestrians is still to be defined.

The outputs of the analysis showed a significant increase in the costs associated to the future deployment. More specifically, costs are expected to rise and range between € 899.885,28 and € 1.056.841,36. The following table presents an overview of the current and future C-ITS services implementation in Vigo. Costs breakdown for 2020 and total annual costs for the years 2017 and 2020 are depicted in the figures below.

C-ITS services implementation in Vigo	
Existing C-ITS Services	/ Road Works Warning / Road Hazard Warning / Emergency Vehicle Warning / Signal Violation Warning / Green Priority / Time To Green/ Red
To be implemented	/ Warning System for VRUs / In-vehicle Signage (Speed) / Probe Vehicle Data / Emergency Brake Light / Urban CACC / Slow/ Stationary Vehicle Warning / Motorcycle Approaching Indication

Table 31: C-ITS services current (2017) and future (2020) situation in the Vigo Deployment Site

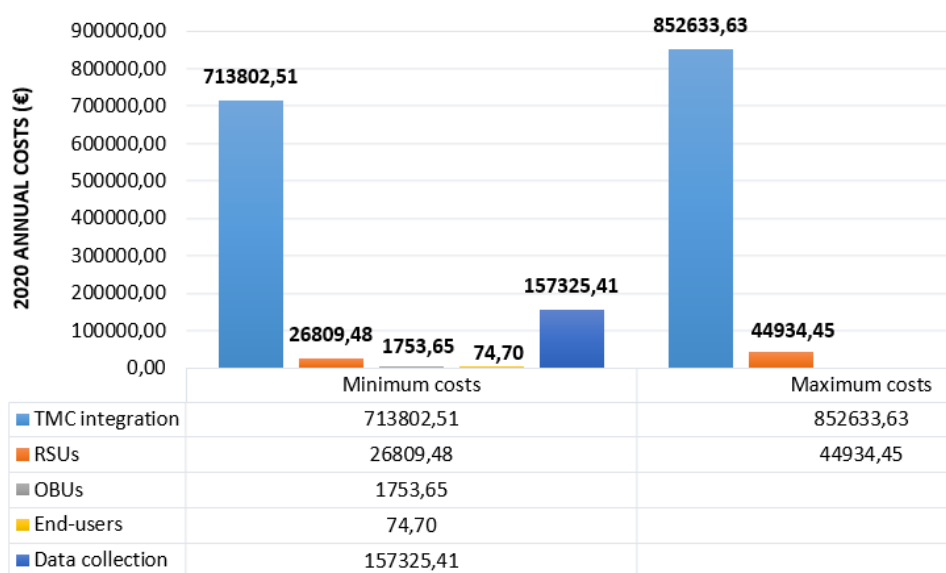|	Minimum costs	Maximum costs
■ TMC integration	713802,51	852633,63
■ RSUs	26809,48	44934,45
■ OBUs	1753,65	
■ End-users	74,70	
■ Data collection	157325,41	

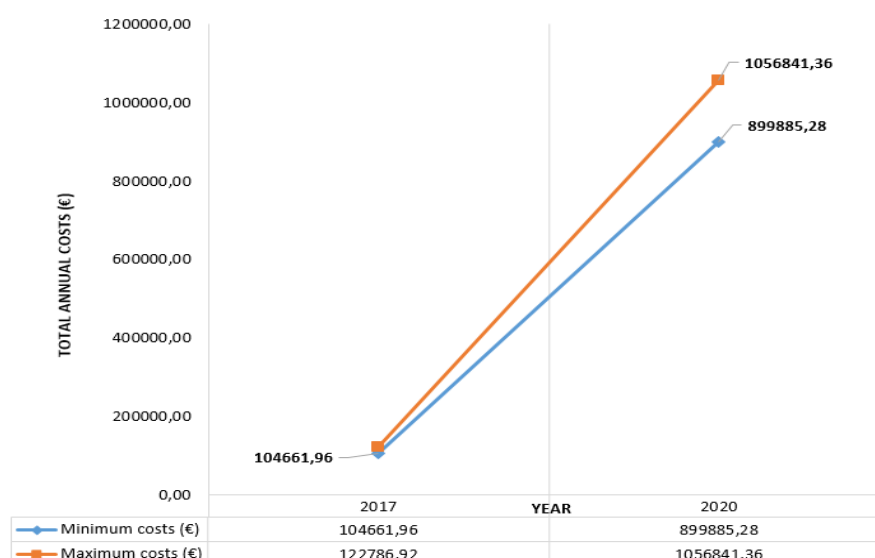Figure 27: 2020 costs breakdown for the Vigo Deployment Site

Figure 28: Total annual costs for the Vigo Deployment Site

The C-ITS services to be implemented in the Vigo deployment site are considered to contribute in whole in the reduction of road accidents (fatalities, severe and slight injuries), in the increase of traffic efficiency, in the reduction of fuel consumption and induced CO_2 emissions, as well as in the reduction of air pollutants. The individual impacts rates of each C-ITS service were estimated according to the methodology described in Chapter 3.4. "Economic Analysis". Since data on the modal split were not provided from the Vigo deployment site, it was assumed that the modal split of the Vigo deployment site consists of 68% of cars, 19% of pedestrians and 13% of public transport [52].

Current data on road safety, fuel consumption and emissions were not provided from the Vigo deployment site as being unavailable, imposing constrains in the benefits estimations. The most recent data available, concerning fuel consumption and CO_2 emissions, was derived from the Compass4D project, hence constituting the inputs for the analysis. In terms of road safety, it is assumed that the C-ITS services implementation will lead to reductions of incidents resulting from average values. In the field of traffic efficiency, an increase in the vehicles' average speed was estimated. Benefits resulting from air pollutants' reduction were not estimated, since data representing annual emissions of NOx, PM and NMVOCs was not available and speculations would lead to inaccurate results.

The 2020 total annual benefits for the Vigo deployment site were estimated to rise to the amount of € 2.295.877,72. The following table presents the data collected from the deployment site, while benefits estimates and the respective monetary equivalents are explicitly presented below.

Vigo Statistical Data		Area of reference
Total annual vehicle kilometers (Vkm)	133.000	N.A.
Annual vehicle kilometers (Vkm) per road type	Inter-urban roads: 33.000 Urban roads: 100.000	N.A.
Total annual hours traveled (hours)	2.600	N.A.
Average speed in inter-urban roads (km/h)	/ Passenger vehicles – private cars and taxis: N.A. / Buses – public transport: N.A. / Light Commercial vehicles – e.g. emergency vehicles: N.A. / Heavy vehicles – e.g. trucks: 60	N.A.
Average speed urban roads (km/h)	/ Passenger vehicles – private cars and taxis: N.A. / Buses – public transport: 30 / Commercial vehicles – e.g. emergency vehicles: N.A. / Heavy vehicles – e.g. trucks: 30	N.A.

Table 32: Statistical data from the Vigo Deployment Site

Benefits per impact area – Vigo	2017 scenario	2020 scenario	Reduction
Safety			
Road fatalities			0,8
Severe injuries			1,2
Slight injuries			5,1
Traffic efficiency			
Buses' average speed increase (km/h)	30	30,5	0,5
Trucks' average speed increase (km/h)	45	46,9	1,9
Environment – Energy			
CO_2 emissions (tons)	17		
Equivalent diesel consumption (l)	6.390,98	6.163,809	227,168

Table 33: Benefits estimates for the Vigo Deployment Site
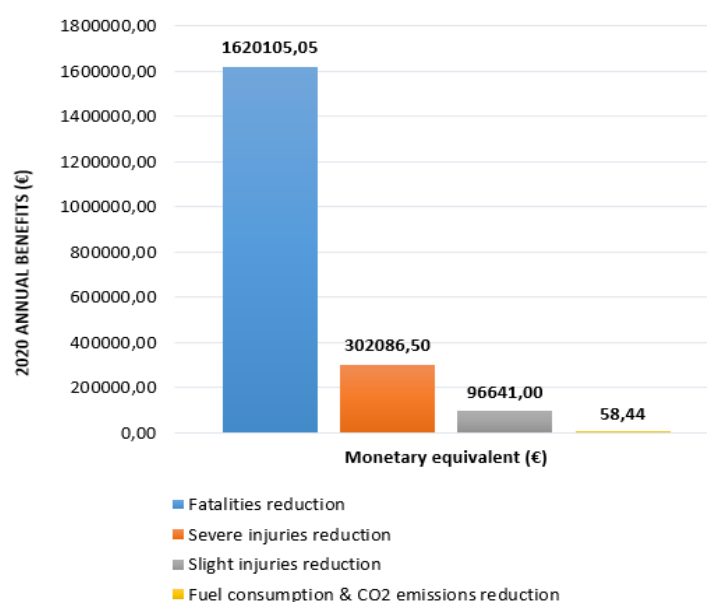
Figure 29: Monetary equivalent of the 2020 annual benefits for the Vigo Deployment Site

The outputs of the analysis, in terms of total annual costs and benefits for the year 2020, led to the calculation of a BCR ranging from 1,91 to 2,24. The BCR is rated "acceptable", proving that the social benefits, to be accomplished through the C-ITS services implementation in the Vigo deployment site, will exceed the costs, labelling the deployment as absolutely efficient.

5. Main Conclusions and Recommendations

Alongside an extensive literature review and a thorough data collection exercise, a methodological framework for the execution of the ex-ante Cost-Benefit Analysis was defined. The performance of the analysis provided insights into the costs and benefits of the C-ITS services deployment in the C-MobILE Deployment Sites. Overall, the outputs of the analysis indicated that the implementation and operation of the C-ITS services is beneficial at deployment site level, with the majority of BCRs in the range of 2-5 achieved in 2020. Consequently, the C-ITS services deployment is considered favourable from a socio-economic point of view for each deployment site, contributing to a significant socio-economic return for every monetary unit invested in the implementation.

The scope of this document is to assess the profitability of specific C-ITS services, to be deployed within the context of the C-MobILE project, by defining their expected impacts and obtaining economic appraisal results, in order to overall assist in prioritisation and implementation support. A number of clear conclusions and recommendations can be drawn from the procedure followed for the execution of the ex-ante CBA, as well as from the outputs of the analysis. The main conclusions and recommendations from the whole process are summarized below.

In general, the performance of an ex-ante CBA constitutes a challenging task, since a precise calculation of costs and benefits is hampered by the fact that they have not yet occurred. Therefore, the analysis requires the integration of a significant number of assumptions, possibly yielding in less accurate results. An extensive literature review combined with a detailed data collection can be considered as the main source of inputs, in order to proceed with the analysis.

More specifically, in the field of C-ITS, valuable data can be derived from past studies and projects, having executed ex-post CBAs to allocate the calculation and comparison of benefits and costs, generated from the implementation of various C-ITS services. Among these documents, a diversity in the recorded values, expressing the respective costs and benefits, is spotted, as these attributes depend highly on the specific characteristics of each case study. The scale of the C-ITS services deployment constitutes the main factor, shaping the range of their costs and expected impacts, as it embodies the substantial parameters depicting the extent of the implementation. In other words, costs and benefits attributed to the implementation and operation of the C-ITS services rely basically on the geographic coverage of the deployment, the status of the available infrastructure, the equipment and technology to be used for updates and extensions, and the number of end-users having access to the C-ITS services. For the C-MobILE case, the results of the analysis showed a variance in the costs and benefits of each deployment site, since the aforementioned characteristics differ among them.

The outputs of the ex-ante CBA demonstrated the dominance of certain costs and benefits, aligned respectively to specific systems of the C-ITS services deployment and to particular impact areas. Costs associated to TMC integration, as well as to data collection, made up by far the greatest portion of total costs for the majority of the deployment sites, i.e. Barcelona, Bordeaux, Copenhagen, Newcastle, Thessaloniki and Vigo. These costs are in line with the scope of the large-scale deployment, to be achieved within the framework of the C-MobILE project, which aims for the implementation and support of a significant number of new C-ITS services in each deployment site, and for extensions in the C-ITS equipped network, both in terms of road kilometres and of end-users. Costs resulting from roadside and in-vehicle equipment, proved to remain low, as most of the deployment sites are already equipped in a certain degree, requiring mostly updates for the support of the new C-ITS services. The biggest contributor to monetised benefits were benefits from reductions in road accidents and in travel time, followed by fuel consumption savings, across all deployment sites. Such a result could be explained by the fact that almost all of the C-ITS services have a certain contribution in the improvement of road safety and traffic efficiency. Reductions in fatalities, in severe and slight injuries, and in travel time correspond to high cost-unit rates, hence generating significant benefits.

Through the assessment of the separate BCRs, each one aligned to an individual deployment site, it has been established that the C-MobILE C-ITS services deployment constitutes a profitable initiative. With most of the 2020 BCRs ranging among 2-5, it is proved that the anticipated benefits could outweigh costs significantly. The BCRs imply as well that the C-MobILE bundling concept, aiming for a comprehensive and coordinated C-ITS services deployment, enables significant benefits to be accrued under reasonable costs. In other words, through the bundling concept, initial investment costs could be spread across more services, each one of them providing individual benefits, which would overall result in significant gains.

Whilst the data collection exercise identified sufficient evidence to enable an ex-ante assessment of the costs and benefits of the C-ITS services, the lack of certain data prevented a more precise estimation. In particular the provision of data describing the current situation scenario (2017), as well as the specific characteristics of the future C-ITS services deployment (2020) in each deployment site, would limit the number of assumptions, preventing errors in the outputs.

Since the results presented in this document are based on methods and approaches used in past studies and projects, it is considered worthwhile to express certain doubts, in an attempt to address uncertainties associated to the determination of various parameters affecting the CBA. The determination of the C-ITS implementation discount rate constitutes a worth discussing issue. The literature review provided no specific values referring solely to C-ITS services deployment. Discount rates used in previous studies and projects were mainly derived from guidelines for various transport investment projects. Moreover, single case studies demonstrating C-ITS deployments in different countries used the same discount rate across all

locations. Both approaches could be considered questionable, since doubts arise from the fact that a generic discount rate for transport investments may not be the most appropriate for C-ITS implementation (i.e. too high), as well as from the fact that different discount rates, in line with each country, could possibly allocate more precise costs estimations.

Concerning costs projections, a logical implication would be that higher future costs are expected for cities with no existing infrastructure compared to the already equipped ones. More specifically, investments in C-ITS infrastructure could be considered responsible for triggering higher costs. A discrimination among investment, as well as operation and maintenance, costs for cities with and without C-ITS infrastructure based on literature review data was hard to conduct, since such distinctions were not provided. In order to produce logic results, two approaches are recommended: either to deploy different C-ITS roadmaps in different cities or to ask cities for costs estimations (approach followed in this analysis). Another important issue to be taken into account is that each equipment, having different specifications, pertains to a different price, as well as to a different level of performance and functionality. The majority of sources provided average prices, not distinguishing sufficiently if they were aligned to prototype or market prices. Price variations between prototype and after-market products though exist, leading to different costs estimations. For the scope of this analysis, it was assumed that prices correspond to after-market products. Furthermore, costs referring to equipment installation may vary from one country to another. Lack of data concerning such variations among EU countries forced the use of common initial prices across the different deployment sites. In an attempt to produce as much accurate results as possible, the prices were converted according to the HICP methodology, so as to align to the different countries represented by the deployment sites.

Regarding the expected benefits of the C-ITS deployment, no clarifications associated to the correlation of impacts and technology were derived from the literature review. However, communications technologies comprise a significant parameter affecting the performance level of systems/ services, hence their benefits. In other words, systems/ services based on cellular network cannot achieve the same level of quality compared to 802.11p, and especially for safety-related services. This aspect was not taken into account in the context of this analysis due to lack of data, remaining potentially as an open issue to be analysed and validated within the context of the ex-post CBA.

Considering the general contribution of an ex-ante CBA to the decision-making process, there are pros and cons affecting various aspects of the process, something evident to other evaluation methods as well. Nevertheless, it should be taken into account that the scope of this document is to provide insights into the potential costs and benefits of the C-IST services deployment. This ex-ante CBA could be used in cities to justify the prioritisation of C-ITS deployment, thus supporting deployment. Overall, it is demonstrated that the cumulative benefits of clustering C-ITS applications under a bundling concept and integrating multiple transport modes and end-users in the C-ITS ecosystem, could overweigh deployment costs, creating a sustainable environment for almost all stakeholders.

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Annex 1: C-ITS Services Components Costs Breakdown

C-ITS services components	Cost category	Communication technology	Stakeholder	Year	Costs range (2017 €)		Units
					Min	Max	
TMC integration							
Integration of RSUs into TMC – Interface to inter-urban/urban standards/protocols	Installation	V2I	/ Road Operator	2016	856.421,88	2.400.000,00	Per area of reference
Interface from RSU to local traffic controller (inter-urban/urban)					1.000.200,00		Per interface
Back office operations and maintenance (inter-urban/urban)	/ Operation				250.050,00		Per year
Application development costs (inter-urban/urban)	/ Maintenance				296.765,90		
RSUs							
Upgrades to existing RSUs to enable ITS-G5 (urban areas)							
Equipment/ Hardware	Installation	V2I	/ Road / OEMs / End-user	2016	2.500,50	3.500,70	Per intersection
Installation/ Mounting					500,10	2.500,50	
Regular maintenance	/ Operation / Maintenance				25,01	125,03	Per year
Power consumption					19,90		Per RSU Per year
Data					195,08		Per year
Secure communications					37,27		
Installation of new RSUs to provide additional ITS-G5 coverage (inter-urban areas)							
Equipment/ Hardware	Installation	V2I	/ Road / OEMs / End-user	2016	6.001,20		Per 1km of inter-urban road
Installation/ Mounting	Installation				3.000,60	12.002,40	
Regular maintenance	/ Operation / Maintenance				150,03	600,12	Per year
Power consumption	/ Operation				45,60		

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	/ Maintenance						
Data	**/** Operation				195,08		
	/ Maintenance						
Secure communications	**/** Operation				37,27		
	/ Maintenance						
DSRCSs at Intersections							
DSCR-Signalised Intersection with Controller upgrade							
DSRC Equipment and Deployment	Installation	**/** V2I **/** V2V	**/** Road	2016	15.859,25		Per intersection
Backhaul Upgrades and Deployment			**/** OEMs		27.753,69		
Traffic Signal Controller Upgrades			**/** End-user		2.883,50		
Total Cost					46.496,44		
DSRC-Signalised Intersection without Controller upgrade							
DSRC Equipment and Deployment	Installation	**/** V2I **/** V2V	**/** Road	2016	15.859,25		Per intersection
Backhaul Upgrades and Deployment			**/** OEMs **/** End-user		27.753,69		
Total Cost					43.612,94		
DSRC-Other/non-signalised location							
DSRC Equipment and Deployment	Installation	**/** V2I **/** V2V	**/** Road	2016	15.859,25		Per intersection
Backhaul Upgrades and Deployment			**/** OEMs **/** End-user		27.753,69		
Total Cost					43.612,94		
DSRC Operation & Maintenance							
Power	**/** Operation **/** Maintenance	**/** V2I **/** V2V	**/** Road **/** OEMs **/** End-user	2016	90,11		Per DSCR per year
Traditional DSRC Maintenance					450,55		
DSRC License/Maintenance Agreements					180,22		Per 1 license per year
DSRC SCMS Certificate License					45,05	45,66	
DRSC Replacement					991,20	1.982,41	Per DSCR per 5-10 years
In-vehicle devices							

Retrofit device						
DSRC Transmitter/ Receiver (2)	Installation	V2V	/ OEMs / End-user	2016	133,17	Per vehicle
DSRC Antenna (2)					13,87	
Electronic Control Unit					62,42	
Global Positioning System (GPS)					19,42	
GPS Antenna					5,55	
Wiring					13,87	
Displays					20,81	
Total Cost					269,11	
Self-Contained device						
DSRC Transmitter/ Receiver (2)	Installation	V2V	/ OEMs / End-user	2016	105,42	Per vehicle
DSRC Antenna (2)					13,87	
Electronic Control Unit					62,42	
GPS					19,42	
GPS Antenna					5,55	
Wiring					11,1	
Displays					9,71	
Total Cost					227,49	
Vehicle Awareness device						
DSRC Receiver	Installation	V2V	/ OEMs / End-user	2016	48,55	Per vehicle
DSRC Antenna					6,94	
GPS					15,26	
GPS Antenna					4,16	
Total Cost					74,91	
ITS-G5 device						
DSRC transmitter/ receiver	Installation	/ V2I / V2V	/ OEMs / End-user	2016	97,84	Per 2 DSRC transmitters/ receivers
DSRC antenna					7,52	Per 2 DSRC antennas

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Electronic Control Unit					33,87	Per vehicle
Wiring					6,77	
Installation					5,17	
Development & integration					15,09	Per passenger vehicle
					49,97	Per freight vehicle
Vehicle software development					1,51	Per passenger vehicle
					5,00	Per freight vehicle
Maintenance	/ Operation / Maintenance				7,55	Per vehicle per year
Secure communications					2,36	Per vehicle
Vehicle software development					3,02	Per passenger car per year
					12,70	Per freight vehicle per year
ITS-G5 & Cellular device						
DSRC transmitter/ receiver	Installation	/ V2I / V2V	/ OEMs / End-user	2016	98,74	Per 2 DSRC transmitters/ receivers
DSRC antenna					7,52	Per 2 DSRC antennas
Electronic Control Unit					33,87	Per vehicle
Wiring					6,77	Per vehicle
Installation					5,17	Per vehicle
Development & integration					15,09	Per passenger vehicle
					49,97	Per freight vehicle
Vehicle software development					1,51	Per passenger vehicle
					5,00	Per freight vehicle
Maintenance	/ Operation				7,36	Per vehicle per year

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Secure communications	**/** Maintenance				2,36	Per vehicle
Vehicle software development					3,02	Per passenger car per year
					12,70	Per freight car or bus per year
Cellular data					2,49	Per vehicle
Mobile Phones						
Data	**/** Operation **/** Maintenance	V2I	**/** End-user **/** Equipment provider	2016	2,49	Per use per year
PNDs						
Equipment	Installation	V2I	**/** End-user **/** Equipment provider	2016	123,66	Per PND
Traditional Data Collection						
Initial capital cost	Installation	**/** V2I **/** V2V	**/** Data provider **/** End-user	2016	15.855,31	Per centreline km
Recurring cost	**/** Operation **/** Maintenance				147,21	Per year

Table sources: [13], [14], [15], [16], [20], [22], [25], [26], [29], [31], [32], [33], [34].

Annex 2: Deployment Sites 2020 Cost-unit rates

Deployment Site (Country)	Cost-unit rates for road accidents					
	€/ Road fatality		€/ Severe injury		€/ Slight injury	
	Year 2010	Year 2020	Year 2010	Year 2020	Year 2010	Year 2020
Barcelona (Spain)	1.913.000,00	2.025.131,31	237.800,00	251.738,75	17.900,00	18.949,22
Bilbao (Spain)	1.913.000,00	2.025.131,31	237.800,00	251.738,75	17.900,00	18.949,22
Bordeaux (France)	2.070.000,00	2.206.329,75	289.200,00	308.246,65	21.600,00	23.022,57
Copenhagen (Denmark)	2.364.000,00	2.510.570,92	292.600,00	310.741,56	22.900,00	24.319,83
Newcastle (UK)	2.170.000,00	2.442.678,62	280.300,00	315.522,04	22.200,00	24.989,62
North Brabant (Netherlands)	2.388.000,00	2.595.390,05	316.400,00	343.878,31	25.500,00	27.714,59
Thessaloniki (Greece)	1.518.000,00	1.528.464,11	198.400,00	199.767,64	15.100,00	15.204,09
Vigo (Spain)	1.913.000,00	2.025.131,31	237.800,00	251.738,75	17.900,00	18.949,22

Deployment Site	Cost-unit rates for traffic efficiency					
	Goods hours during transport (€/ ton hr)		Passenger Travel Time – Light Vehicles (€/ hr)		Passenger Travel Time – Public Transport (€/ hr)	
	Year 2016	Year 2020	Year 2016	Year 2020	Year 2016	Year 2020
All	1,00	1,00	4,00	4,00	3,00	3,00

Deployment Site (Country)	Cost-unit rates for climate change and air pollution							
	CO₂ – Climate change cost (€/ diesel litre)		NOx – Damage cost (€/ ton)		PM – Damage cost (€/ ton)		VOC – Damage cost (€/ ton)	
	Year 2010	Year 2020	Year 2010	Year 2020	Year 2010	Year 2020	Year 2010	Year 2020
Barcelona (Spain)	0,243	0,260	4.964,00	5.254,97	48.012,00	50.826,24	1.135,00	1.201,74
Bilbao (Spain)	0,243	0,260	4.964,00	5.254,97	48.012,00	50.826,24	1.135,00	1.201,74
Bordeaux (France)	0,243	0,260	13.052,00	13.911,60	64.555,00	68.806,58	1.695,00	1.806,95
Copenhagen (Denmark)	0,243	0,260	6.703,00	7.118,59	40.760,00	43.287,17	1.531,00	1.626,21
Newcastle (UK)	0,243	0,270	6.576,00	7.402,33	47.511,00	53.481,15	1.780,00	2.004,03
North Brabant (Netherlands)	0,243	0,260	11.574,00	12.579,16	48.352,00	52.551,21	2.755,00	2.994,79
Thessaloniki (Greece)	0,243	0,240	3.851,00	3.877,55	50.605,00	50.953,84	854,00	860,04
Vigo (Spain)	0,243	0,260	4.964,00	5.254,97	48.012,00	50.826,24	1.135,00	1.201,74

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