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Deliverable

D7.4. Cost-benefit analysis guidelines R2

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List of definitions & abbreviation

Abbreviation	Description
AIS	Abbreviated Injury scale
BM	Business Model
BT	Benefit Transfer
CBA	Cost-Benefit Analysis
CS	Citizen Science
CV	Contingent Valuation
HP	Hedonic Pricing
KER	Key Exploitable Result
KPI	Key Performance Indicators
MRSI	Maroussi
NSB	Net Social Benefit
NPV	Net Present Value
PV	Present Value
R&D	Research and Development
SDG	Sustainable Development Goal
UN	United Nations
WTA	Willingness to Accept
WTP	Willingness to Pay
VSL	Value of Statistical Life

Executive Summary

This document presents state-of-the-art economic impact assessment techniques and methodologies, particularly when applied to citizen science (CS) projects. The scope is to provide the reader with a handy guide to understand the objectives, the logic, the requirements, and the drawbacks of implementing the different methodologies to impact assessment, with a particular focus on Cost-Benefit Analysis (CBA).

The second section provides a description of what is understood to be CBA, with a focus on what are the most common critiques to the methodology and the answers to such critiques. Additionally, it will also present a general overview of CBA, introducing the reader to the choices to be made by the analyst and the steps to be followed to accomplish the assessment. Each step will be tackled, in order to guide the reader through the analyst's decision-making process. Finally, the section will briefly address the issue of non-market effects, with particular attention to intangible effects, such as, for example: the increase in participation, the increased environmental sensibility, or the increase in social capital.

The third section will complement the previous one and, hence, the discussion on the implementation of CBA within the CS context by providing two commented examples of CBA.

The fourth section will delve into the most common quantification techniques for non-monetary values. The issue of estimating monetary values is common for both costs and benefits, but particularly poignant for the latter since they are often immaterial. The problem of obtaining such values is particularly relevant for CS projects. The practice of economics has, with time, developed different techniques to estimate market values for goods which are excluded by the market system. In this section, the reader will be introduced to the concepts of revealed preferences, stated preferences, Willingness to Pay (WTP), Willingness to Accept (WTA), and Hedonic Pricing (HP). Finally, the project's KPIs will be integrated in the estimation process. This attempt is presented at the end of the section.

The last sections will summarise the concepts presented in the previous sections by initially providing an indicative template of CBA, with some of the most common variables to be assessed. The underlying rationale is to provide a checklist with the main steps to a thorough CBA, each with the questions that the analysts should present themselves, and with indications on how to appropriately tackle them. Finally, the conclusion will introduce the reader to the plans for the practical implementation in the context of the second issue of the present deliverable. A reflection on the data needed for the assessment and how to collect it will be presented, together with the plan for future meetings within the project to coordinate the work of the analysts, the pilots and the data scientists supervising the data collection.

The literature review, the examples, the techniques explanation, and the provision of a template for CBA aim at providing practitioners with an easy introduction to impact assessment, particularly when applied to CS projects. The availability of a ready-to-use handbook to guide interested readers, practitioners and local policymakers through the inevitable hurdles and the needed contrivances inherent to such an analysis when applied to CS projects, will pursue the aim of favouring future replicability and scalability of SOCIO-BEE pilots.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Purpose of the document

As explained in deliverable D7.1, in the context of CS projects, there is still a widespread uncertainty on what an impact assessment is and how it should be done. The general lack of shared good practices should hint at the difficulties intrinsic in the analysis of such projects. The variability in methodologies and the lack of rigour in their application may be imputable to the lack of a clear and shared working framework, to the lack of data, or to insufficiently clear methodologies to exploit such data. In this sense, this deliverable aims at providing the reader with a useful guide through the most common economic practices and their application to the analysis of CS projects.

Given the growth in popularity of CS projects, possibly linked to the potential to provide for copious amount of data and the pervasive diffusion of information and communication technology, the problem of assessing the consequences of such projects rises. More often than not the outcomes of the assessment process seem to be either assumed or ignored, or they are simply speculations [15]. Additionally, the variety in objectives and purposes of CS projects, the usually limited resources and the mismatch in the timing of impact manifestation and impact assessment, are common hurdles explaining the lack of standardisation in the assessment practices [33].

In the literature, it is possible to find a number of articles trying to reflect and generalise on the needed characteristics of the impact assessment methodology when applied to any sort of CS project (see for example, Gharesifard et al., Granner et al., Groulx et al., Hassenforder et al., Jagosh et al.) [1][3]–[6].Usually, the issue of the reviews is the specificity of their focus. To give further examples, Hassenforder et al. and Jagosh et al. focus on the governance impacts of publicly participated projects [5][6], while Phillips et al. shift the attention to societal impacts [29], and Fazey et al. emphasise the role of knowledge exchanges in the narrow context of participated and interdisciplinary environmental change studies [11].

Since, as it seems, the practice of impact assessment lacks a shared understanding, a first task of the present document is to shed light on what economic impact assessment is and how it is usually done. On this basis, we will then reflect on what the challenges for the actual analysis are and what will be needed to perform it with success.

The closing section of the document will present the reader with the list of the identified challenges to the assessment and some hypotheses on how to face them.

1.2 Relationship with other deliverables

The present deliverable builds on the outcomes of D7.1, where the main methodologies currently in place for the socio-economic evaluation of CS projects have been presented, alongside with the main criticalities that can emerge in the practical implementation. Among the methodologies presented in D7.1, CBA has the advantage of allowing the monetisation and, as a consequence, the translation of project outcomes in comparable and, to some extent, objective units of measurement, encompassing all of the aspects of societal impact. In this respect, the current work presents in greater detail the steps required to compile a CBA, with reference to the main economic methodologies that are in place for the financial translation of non-monetary outcomes.

Drawing from the KPI framework set in D5.6 and evaluated *ad interim* in D5.10 and D5.12, the most relevant indicators have been chosen so as to provide further guidance on the socio-economic assessment.

This allows to build a solid conceptual framework for the implementation of the CBA methodology to one of the SOCIO-BEE pilots in deliverable D7.4, which represents the second release of the present work. In particular, Sections 5 and 6 of the present document will lead to the definition of the main points and questions that will need to be addressed in the practical implementation of the methodology. The work carried out in the present deliverable will also enable future initiatives of the like to build on the presented methodology and to provide a unique toolbox for the assessment of CS projects, or of any project that holds public interest characteristics and that impacts domains other than the financial one.

2 Cost-Benefit Analysis

Following Boardman et al., the CBA can be presented as an organic set of techniques aimed at cataloguing the impacts as Benefits (pros) and Costs (cons), and at associating to each of them a monetary value (weight), to compute the net benefit of the evaluated policy. The most challenging part of the CBA is related to the scope of the analysis, that is: the costs and benefits are not individual but social [4]. As a consequence, in the assessment we should speak of (social) benefits and (social) costs to compute the Net Social Benefit (NSB). The definition and the boundaries of the "society" to be studied must be pondered on a case-by-case basis.

Equation 2.1

$$NSB = B - C$$

The process of monetisation is a needed one for mainly two reasons. The first is that, as it has been said above, it allows the assessor to attach a degree of importance to each of the considered variables. This clearly results in a degree of arbitrariness on the assessor's part. The second reason is that monetisation allows to connect the variables, each one expressed using its measurement units, to a unique unit of count. The process of translating each dimension into a unique measure helps also in terms of comparison between similar alternatives, which is particularly important since CBA aims at improving the allocative efficiency of the social decision-making process.

Another important aspect of CBA is that the analyst is always able to compare at least two (or more) alternatives, with the first necessarily being the *status quo* or "no intervention" and the other (or others) being the proposed intervention(s). The rule of thumb is that the proposed policy should be accepted if the CBA shows positive incremental changes with respect to the baseline scenario.

Given the stated intention of being a method that maximises the social gains stemming from a decision process and, in turn, increasing the general well-being of people, the CBA system may appear to be fool proof. Nevertheless, two main kinds of critiques have been moved to the approach: one with a more philosophical flavour and a more technical one.

The first kind of critique contests the "utilitarian" assumptions of the CBA. Utilitarianism aims at maximising the overall welfare with little concern for matters of redistribution. In fact, in economics the utilitarian welfare function (the function representing the society's well-being) is represented as the sum of all individual utilities:

Equation 2.2

$$W(u) = u_1 + u_2 + u_3 + \cdots + u_n = \sum_{i=1}^{n} u_i$$

From the point of view of the assessor, the problem reduces to maximising only *W(u),* instead of every single utility to then sum up to obtain the increase in total welfare. This seemingly small difference in the timing of arithmetical operation is why the CBA has little regard for redistributive concerns. In theory, welfare maximisation may be reached by ceding all the additional benefit to a single member of the society, for example because she can exploit it best. Summing up, the utilitarian approach may imply the trade-off between the costs borne by some individuals of groups of the society and the benefits that accrue to other individuals or social groups.

The second kind of critique is technical, and it mainly concerns the timing of the impacts, the monetisation techniques and how to evaluate the trade-offs between present and future. For this reason, it will be sparsely and indirectly debated in the next sections since they will present the technical aspects of the CBA. The issue of choosing the best possible methodology for each of the CBA's technical aspects is not something that can be resolved definitively, and a case-by-case approach is suggested, even more so in the case of CS projects, where a shared methodology is still lacking.

On the other hand, the issues concerning the fundamental questions about the validity of CBA as an assessment tool should be expressed and answered more in-depth, before advancing to the technical aspects of the matter.

2.1 The Cost-Benefit Analysis (critiques to)

Following Ackerman & Heinzerling we can present some of the harshest critiques of the practice. As previously said, the assessor has a degree of freedom in deciding how to evaluate each of the variables, and this can lead to debatable results [1].

A famous example of that is the assessment concluding that a country should subsidise cigarette consumption since in this way it would save money. In fact, by eventually dying from respiratory diseases, the smokers would save the state the money for elder care [32]. Despite the conclusion being arguably correct, albeit cynical, the point is that CBA is not an inherently good tool whose results are to be blindly accepted. What should be kept in mind is that the methodology, more than the outcome, is of importance in judging the analysis.

In the cited article the main issues of CBA can be grouped into four sets:

i. Reliability on the estimation techniques.
ii. Underestimation of the future.
iii. Redistribution effects disregard.
iv. Lack of transparency.

The first concern relates to the trade-off between quantification and accuracy. In the attempt to value something which is not "priced" by markets, the analyst is forced to employ techniques for the indirect assessment of its value and, in doing so, must accept a degree of approximation.

The prime example of that kind of approximation is the Value of Statistical Life (VSL)[1]. This value is often obtained by inquiring individuals on how much they are willing to pay to reduce the risk of death (WTP) or how much they are willing to accept to see the same risk of death increasing by a small amount (WTA). Then, the estimated value is obtained by aggregating the individual preferences about risk perception

[1] The computation of this variable is strongly dependent on the source and the period in which the estimation is done. This may prove the unreliability of the estimation or simply reflect changes in preferences due to differences in population or other changes over time.

towards themselves, which do not consider how the individuals value the risk toward others. This approach might result unfitting for environmental decisions given their inherently collective nature. Also, an approach resembling the behaviour of a customer buying a good (clean air, in this case) may not considered to be a valid approximation of the problem of collective choice. A simple example is the choice of how much to pay for a large public project (e.g., a highway) should incorporate how much the other people involved are willing to pay on their part.

The second critique is that the CBA may understate the future, mainly in two ways: through discounting, and by not taking adequate account of catastrophic and irreversible events. On the one hand, the discount rate reflects the individual intertemporal preferences; thus, the choice involved in the discount factor is how much the future is valued with respect to the present. The risk is to postpone the harms, by using a high-enough discount factor, underestimating the damages implied by the decisions and, in fact, unloading present problems onto future generations.

The problem of procrastinating needed efforts to the future possibly compounds with the so-called "precautionary principle", asking the regulators to err on the side of caution and protection when risks are uncertain. The principle, when flanked with a strong preference towards the present (expressed through a high discount rate) may call for inaction, since the principle is inherently conservative.

The compounded problem is even more significant for environmental projects since for many programs, like hazardous waste clean-ups and control of persistent toxins, the benefits are usually placed far in the future, when the lives are saved, rather than in the short-term, when the risks are simply reduced[2].

The discounting approach illustrates once again the problem of not considering the possibility of individuals playing different roles and reducing them only to consumers. The common rationale for discounting is the assumption that it reflects people's risk preferences, as expressed in market decisions. But this may omit the possibility that people will have different preferences when they take on a different role. One example is the tension the Americans experience between either in the role of bank account holders or in the role of workers. Often, Americans are deemed poor savers, but 52% of private workers and 82% of public employee participated in retirement plans [34], highlighting a possibly different decision pattern between the same people when in the role of citizens and when in the role of consumers.

The third fundamental criticism is that CBA not only tends to ignore matters of redistribution and social inequality, but in doing so, it reinforces them. This process is heightened by the common practice of estimating benefits through the willingness to pay (WTP) of the stakeholders. Since, particularly for environmental issues, wealthy individuals are able to pay more, the risk is of provide a rational framework for already-existing patterns of environmental injustice, and imposing the environmental burdens on countries, communities, and individuals with the least resources.

Finally, the risk of CBA is the inability to deliver on the promise of more transparent decision making. CBA is a complex, resource-intensive, and expert-driven process. It requires a great deal of time and effort to attempt to deliver it. Few are the communities having access to the technical expertise needed to evaluate the correctness of the assessments made.

[2] Additionally, the problem of timing compounds with matters of intergenerational justice (and redistribution).

2.2 Answers to the critiques

Following mainly the article by Frank, it is possible to provide some answers to the arguments presented above. In any case, the first reason to attempt a CBA may be simply the fact that, by living in world of scarcity, inevitably the resource allocated to a project cannot be used for another and there are not enough resources to pursue every project, so that the choice is forced upon the decision makers. Hence, the question on how to best allocate those resources lingers [13].

It is of common understanding that comparing things belonging to disparate categories is extremely complex in practice. However, many critics insist that such comparisons cannot be made even in principle. For instance, if we assume the existence of two technologies, one clearly acceptable and one clearly unacceptable, then there must exist at least an intermediate solution neither better nor worse than the status quo by some dimension. Hence, any intermediate technology better than the latter is to be considered an improvement.

Scarcity is a simple attribute of the human condition. To have more of one good thing, we must settle for less of another. Claiming that different values are incommensurable simply hinders clear thinking about difficult trade-offs.

So, in the view of those refuting intertemporal trade-offs, if failure to adopt more stringent air quality standards today means that respiratory illnesses will be more common a generation from now, those illnesses should receive roughly the same weight as if they were to occur today. Of course, a complete cost-benefit calculation would also require including allowances for possible improvements in medical technology. Anyway, if analysts agree that future experiences should receive roughly the same weight as current ones, the costs and benefits associated with any policy change can simply be calculated on that basis.

Critics of CBA are correct that using unweighted WTP measures possibly skews the decision processes in favour of high-income people. But rather than abandoning CBA, the unweighted WTP measures can be unapologetically employed and compensated through the welfare and tax system for both the ex-ante and the ex-post harms. Low-income individuals could simply be granted the welfare and tax breaks required by distributive justice, plus additional concessions reflecting their expected loss from the implementation of CBA using unweighted WTP measures.

Opposition to cost-benefit analysis may also stem from the fact that the costs of a policy change are often far easier to quantify than its benefits, especially in the domains of environmental and health and safety policies [4]. Decisions on these topics tend to be driven primarily by cost considerations, resulting in a bias favouring the *status quo*.

The fact that benefits are more difficult to measure than costs does not provide a compelling reason to abandon CBA, in the same way as the fact that costs are easier to forecast than revenues does not provide a compelling reason for firms to abandon profit maximization. In each case, it is better to act on the best information available than to act on no information at all.

So, it appears that it does not exist a fundamental reason to restrain from employing the CBA as an assessment method. Nonetheless, the methods and techniques used for quantification and monetisation are to be adequately pondered before their use, since the analyst's freedom may lead her to hinder the results by use of inadequate methods and, as a consequence, propose biased prescriptions.

2.3 The technical aspects

Once the limitations and the rationales behind the CBA are understood, it remains to be understood how the analysis should be conducted. In the following paragraphs some ideal steps to conduct a CBA will be debated while section four will further delve into the technical aspects of the enactment of the steps and the technique hereby presented. Since the CBA may result as an obscure matter, we think best to provide the reader with some guidance on the handbook steps to be followed when approaching a CBA. It is to be understood the fact that, while being generally acceptable, the following steps can change and adapt to the context and resources available to each situation.

2.3.1 Explain the purpose.

The first step in any CBA is to clearly define the limits and the scope of the analysis. In short: "what is the rationale for considering a change in policy?"

Broadly speaking, the scope of CBA is to improve allocative efficiency and, in doing so, increase social welfare. The rationale for CBA is ingrained in economic theory and, particularly, the existence of market failures. The underlying assumption is that, in the absence of these failures, the market could efficiently allocate the resources to the projects. However, the existence of market failures makes the allocation unreliable, and another kind of decision rule is needed. In several situations, the implementation of the policy has to take into account also failures from the government side (e.g., red tape).

Hence, before even starting the analysis, an explanation on what failure is pushing for an assessment is in need.

2.3.2 Specify the alternatives.

In practice, the set of possible alternatives is quite small. Either because unfeasible or due to cognitive constraints on the side of the analyst and the decisionmakers, not all the possible theoretical alternatives to a project can be considered. Usually, CBA aims at comparing a limited number of projects (i.e., the chosen project and the direct alternative that would be displaced if the project under evaluation were to proceed).

The displaced project is called the *status quo* policy or no change in government policy. It does not mean "do nothing." Rather, it means that the government continues to do what it has been doing. Sometimes the *status quo* policy is not a viable alternative. If a project would displace a specific alternative, then it should be evaluated against the specific displaced alternative.

If, for example, the government has committed resources to either (1) constructing a new highway project and generating alternative routes or (2) expanding the capacity of the existing routes, and there is no possibility of maintaining the *status quo*, then the new highway project should be compared with the expansion of the capacity of existing routes, rather than with the "do nothing" alternative.

2.3.3 Standing – Define the affected subjects.

Next, the analyst must decide who has standing; that is, whose benefits and costs should be included and counted. The issue of standing is quite often contentious. While national governments usually take only national (i.e., domestic) costs and benefits into account, critics argue that issues that have significant negative impacts on residents of other countries should be analysed from a global perspective. Environmental issues that fall into this category include global climate change, ozone depletion, and acid rain.

At the other extreme, local governments typically want to consider only benefits and costs that accrue to residents of their constituency and tend to ignore costs and benefits borne by residents of adjacent jurisdictions or jurisdictions supervised by higher levels of government.

2.3.4 Identify the impact categories, order them, and measure them.

This step requires the analyst to identify the impacts of the proposed alternative(s), catalogue them as benefits or costs, and specify the metric for each impact category. The term "impacts" is broadly used to include both inputs (resources employed) and outputs (predominantly benefits). A list of the relevant impact categories is referred to as an impact inventory. Preferably, analysts will construct an impact matrix, which describes or summarizes the impact of each policy alternative (or the impacts of one policy alternative on different groups) on each impact category.

It is important to try to include the full range of consequences of each project. However, from a practical perspective, analysts can consider only a manageable number of relevant impacts. Of importance to the analysis is the fact that impacts associated with sunk costs should be ignored, although the sunk costs are not always easy to clearly define. An example might be the value of the land on which a road will be built. Once bought by the government, the analyst may consider the land cost to be sunk (unrecoverable) but, since the road is not built yet, that may still an alternative use (e.g., cultivation).

Additionally, matters of redistribution are ignored within the boundaries of CBA. As for the case of highway, one could consider the displacement of fuel demand (i.e., by building the highway, drivers will possibly prefer to refuel directly on the highway instead of refuelling in the town's gas station bypassed by the new road), but since this is a zero-sum game (the money is simply spent elsewhere, but the amount does not – substantially – change) this effect should not be considered. CBA focuses only on the incremental effect.

From a CBA perspective, analysts are interested only in project impacts that affect the utility of individuals who have standing[3]. Impacts that do not have any positive or negative utility to human beings are not counted. Suppose, for example, the highway project would decimate the population of a particular avian species. Birds do not have standing. This impact should only be included if some humans regard it as a cost.

[3] The caveat is that this applies only where human beings have the relevant knowledge and information to make rational decisions.

Another issue in impact identification is the tendency to record broadly defined effects, such as "community capacity building", "growth", or "regional development", to name a few. Those categories should be translated into explicit and quantifiable (and then monetisable) ways in which individuals with a standing in the project are better-off (e.g., improved skills, better education, higher incomes), or worse-off (e.g., increased pollution, higher mortality). This is simply because, the more limited is the conceptual category to be studied, the easier it is to define it and to find a metric for measuring it, at the same time enabling the monetisation.

Finally, if the chosen data is not available (e.g., the crime rate), the analyst might resort to proxy data (e.g., conviction rate). What she should bear in mind is that using surrogates implies the loss of information (e.g., the conviction rate increases while the real crime rate is stable).

2.3.5 Project expected life and impact prediction.

Almost all public projects have impacts that extend over time. The fifth task is to predict all the impacts in each year during the discount period (the life of the project) for each alternative. More specifically, the analyst must predict the incremental impacts.

The impact implies a cause-effect relationship between some physical outcome of the project and the utility of human beings with standing (as identified before). For some impacts, the expected cause-effect relationships are reasonably well established. An example is the causal relationship between motor vehicle usage and motor vehicle accidents.

However, for other impacts the causal relationships are less obvious. For instance, what, if any, is the impact of exhaust fumes from additional vehicle usage on residents' morbidity and mortality? Would this be offset by fewer airplane flights? Demonstrating and estimating such cause-effect relationships often requires an extensive review of scientific and social science research. Sometimes the evidence may be inconclusive or "ambiguous" (i.e., featuring deep disagreement among experts).

In this case, it is often good practice to rely on the existing literature and verify whether this kind of relationship has been proved or, at least, convincingly hinted, elsewhere.

2.3.6 Monetisation.

Sometimes, the most intuitively important impacts are difficult to estimate in monetary terms. In CBA, the value of a benefit is typically measured in terms of WTP, which is a handy way to estimate the value individuals attach to something.

The problems with this method arise when the market for the studied object does not work well or does not exist at all (simply because it is hard to attach a monetary value to something without any kind of reference). For that reason, the economic literature is filled with attempts to estimate monetary values of things not traded on markets. In practice, most CBA analysts do not reinvent these figures, but instead draw upon previous research: they use best-practice "plug-in" values whenever possible.

If no person is willing to pay for some impact or to avoid it, then that impact would have zero value in a CBA. For example, if construction of a dam would lead to the extermination of a species of small fish, but no person with standing were willing to pay a positive amount to save that species, then the extermination of this fish would have zero cost in a CBA of the dam.

A point has to be made on the topic, the monetary value need not to concern the current value of the fish (or, more generally, the biodiversity). For example, the policymaker or any stakeholder can make the argument that, while having no value currently, the fish may be useful in the future. If this is considered a valid argument to safeguard, then the cost of preserving the biodiversity is nothing less than an insurance premium on the future.

2.3.7 Discounting to present.

For a project that has impacts that occur over years, we need a way to aggregate the benefits and costs that arise in different years. In CBA, future benefits and costs are discounted relative to present benefits and costs in order to obtain their present values (PV).

The need to discount arises for two main reasons. First, there is an opportunity cost of the resources used in a project: they could earn a positive return elsewhere. Second, most people prefer to consume now rather than later. Discounting has nothing to do with inflation per se, although inflation must be taken into account.

The discounting computation is the inverse of the compounded interest operation. In fact, the proof takes few algebraic passages:

Equation 2.3

$$C_t = C_{t-1} + C_{t-1}i = C_{t-1}(1+i)$$

In the previous passage, *i* is the interest rate, and the equation simply states that the capital *C* at the year *t* is equal to the capital in the previous year (*t-1*) plus the interest computed on the same amount of capital.

One should imagine of repeating the computation several times, hence obtaining a series of iterated computations, for example:

Equation 2.4

$$\begin{aligned}
&C_0 = C_0 \\
&C_1 = C_0 + C_0 i = C_0(1+i) \\
&C_2 = C_1(1+i) = C_0(1+i)(1+i) = C_0(1+i)^2 \\
&C_3 = C_2(1+i) = C_1(1+i)(1+i) = C_0(1+i)(1+i)(1+i) = C_0(1+i)^3 \\
&\dots \\
&C_n = C_{n-1}(1+i) = C_0(1+i)(1+i)\dots(1+i) = C_0(1+i)^n
\end{aligned}$$

As it is possible to observe, the computation can be dragged for a number *n* of years. The only constant is the value C_0 in each computation. Hence, by reverting the computation, one can obtain the value C_0 in each year, which means obtaining the PV of the capitalised amount C_n (with *n* being the year considered in the computation). In practice, it can be written as:

Equation 2.5

$$PV_0 = C_0$$
$$PV_1 = \frac{C_1}{(1+i)}$$
$$\dots$$
$$PV_n = \frac{C_n}{(1+i)^n}$$

Finally, the computation can be generalised for each kind of amount, independent of the nature. So, the future flow of benefits and costs can be actualised, i.e., represented in terms of PV, according on the year they arise, and then summed. The operation is written as follows for shortness:

Equation 2.6

$$PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+s)^t}$$

Equation 2.7

$$PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+s)^t}$$

2.3.8 NPV computation

Finally, the net social benefit (NSB) can be computed as a simple difference between the PV of the future flows of benefits and the PV of future flows of costs. So as for Equation 2.1, the NSB is computed as the difference between benefits and costs, with only few slight differences. Since both costs and benefits may arise in different years, all the amounts are actualised as seen in the previous paragraph, hence the NSB results to be, in fact, the PV of itself. In simpler terms, the NSB present values equates the NPV, as follows:

Equation 2.8

$$PV(NSB) = NPV = PV(B) - PV(C)$$

The CBA assessment suggests that the project should be adopted when the NPV is positive. If more than one alternative project are compared, the CBA assessment suggests that the projects with the larger NPV should be preferred.

2.3.9 Sensitivity analysis

It should be clear that the PVs and NPVs discussed above are predicted values, based on certain assumptions. As the foregoing discussion emphasizes, however, there will be uncertainty about the assumptions – both the predicted impacts and the appropriate monetary valuation of each unit of each impact.

In order to get a handle on these uncertainties, the analyst might conduct sensitivity analysis which, with only one alternative, shows the values of a parameter that would change the recommendation from "go" to "no go," or vice versa. Also, analysts might examine different scenarios, with for example, "most likely," "optimistic," and "pessimistic" assumptions.

The main difference between sensitivity and scenario analysis is the amount parameters varying simultaneously. In the sensitivity analysis only one parameter varies at time, and in doing so it is possible to assess the magnitude of the impact of the single parameter, while the scenario allows for the variation of several parameters at time and, possibly, add different ones.

While the sensitivity analysis allows to better quantify the role of each element in the matter, the scenario analysis allows to study different approaches to same situation.

2.3.10 Making recommendations

Suppose that an individual is facing only two alternatives, A and B, one of which may or may not be the *status quo* policy. Alternative A has a higher expected NPV and lower risk (smaller variance) than alternative B. In this situation, the analyst would unambiguously recommend alternative A. Now suppose that Alternative A has a higher expected NPV but has more risk than alternative B. However, the analyst can usually act as if society were risk-neutral and should therefore recommend the alternative with the largest expected NPV.

While the NPV criterion theoretically results in a more efficient allocation of resources, it does not necessarily recommend the most efficient allocation of resources because the most efficient alternative might not have been actually considered by the analyst or might not have been feasible.

Finally, as this discussion emphasizes, analysts almost always make recommendations, not decisions. CBA concerns how resources should be (or should have been) allocated; it is normative. It does not claim to be a positive (i.e., descriptive) theory of how resource-allocation decisions are actually made.

What should be clear is the fact that CBA does not substitute the decision process. Generally speaking, that is left to the politics. The CBA process, through a clear decision rule, identifies a preferred alternative but the decisionmaker may have a different preference. Hence, in that case, the CBA simply provides an estimation of the cost of the preferred alternative (in terms of lost NPV).

3 CBA examples

In the attempt to make the previous section clearer to the reader and to introduce some of the discussion topics for the rest of the document and future meeting; in the following subsections we present a couple of CBA examples. The first of these will be a manual example of CBA, evaluating a real-life public project and functioning as a baseline scenario for the reader, the second will be a real-life application of CBA to a CS project. The idea is to highlight, either by comparison or directly drawing from the previous section, what will be the difficulties and strengths of conducting this type of analysis on a CS project.

3.1 Baseline CBA

Following previous works from Boardman et al., it is possible to present some of the main aspects of a CBA analysis done on a quite common public project: the construction of a new highway. The case presented particularly focused on the construction of a new highway in Canada and the main consideration was on the opportunity of charging tolls for the usage [3,5].

A CBA usually has a quite economical presentation, also depending on the point of view of the analyst and what she wants to highlight. In fact, anything can be reduced to a simple table with few rows and columns. In the highway example chosen for this subsection, the CBA can be summarised as:

	No Tolls		**With tolls**	
	Global perspective (A)	**Provincial perspective (B)**	**Global perspective (C)**	**Provincial perspective (D)**
Social Benefits:				
Time and operating cost savings	736.0	572.1	568.4	426.3
Safety benefits	70.5	52.8	49.3	37.0
New users	1.6	1.2	0.6	0.4
Alternate route benefits	28.6	21.3	18.4	13.9
Toll revenues	-	-	-	73.2
Highway terminal value	104.3	104.3	104.3	104.3
Total social benefits	**968**	**751.7**	**741.0**	**655.1**
Social Costs:				
Construction	661.8	661.8	661.8	661.8
Maintenance	14.9	14.9	14.9	14.9
Toll collection	-	-	16.4	16.4
Toll booth construction	-	-	0.6	0.6
Total social costs	**676.6**	**676.6**	**693.7**	**693.7**
Net social benefits	**291.2**	**75.2**	**47.3**	**-38.6**

Table 1: Coquihalla highway CBA (2016 mln.US$) [source: Boardman et al., 1993]

In the example specific case, one could immediately notice how the representation tries to highlight two of the aspects introduced in the previous section. First, they compare two different scenarios, which they are not “no highway” versus “highway”, but something minor as “no tolls” versus “with tolls”. This indicates how the CBA can be used to evaluate pros and cons not necessarily of some fundamental decision, like engaging in the construction of a highway, but also of specific aspects of the same project. This may help analysts and readers at once to avoid the confusion often linked with too wide analyses.

As a second aspect, one could notice how the example fits with both the local (provincial) and national (global) perspectives. This is, in fact, a relevant topic for discussion before engaging in the assessment process. As stated above, the perspective changes part of the assessment process. As it is possible to see, between column (A) and column (B) the figures change dramatically, implying a different value attached to each of the benefit considered.

In addition, the above discussion is particularly relevant for the benefits evaluation. In fact, one could easily observe how the estimation variations are due not much to the costs of the investment (the only difference is between “tolls” and “no tolls” and amounts to $ 20 mln.) but to differences in benefits evaluation.

What is left to understand is how they came up with the numbers in the table, and while it would exceed the scope of the present section to show a complete CBA analysis, we can partially explain some of the evaluations. In particular, we will leave the majority of the tables in Appendix A for the readers in order to provide evidence for the estimation of the environmental benefits of the new highway.

While the costs need not to be thoroughly explained, since one can expect them to be nothing more than values actualised to the base year and then summed, the benefits are not only actualised and summed but also estimated. Starting by the end, the residual value is what value is expected to be left into the project after the years considered in the study. To be clearer, for a project as a highway usually a timeframe of fifty years is used. At the same time, the road can be used longer than that. The residual value reflects that.

The toll revenues are nothing more than what it appears. It is the estimated cashflow when charging a toll, depending on the expected traffic flow.

The alternative route, instead, reflects the overall gain in security and emissions due to the reduced congestion in secondary roads. This evaluation is obtained by estimating the change in traffic flow and combining that with the data on road incidents (fatal and non-fatal) together with the computed VSL to obtain the amount of benefit (due to the reduction in human life loss). In a similar way, the benefit of reduced emissions is computed by estimating the reduced emissions on vehicle-types basis and estimating their value by weighting the VSL with the probability of linked pollution illnesses.

While the previous category is linked with the gains in secondary roads, the safety benefits and time and operating cost savings categories are the benefits computed for the highway specifically. So, they are computed in similar way by considering the travelling time saved, the reduction in travelled distance (since the highway is more direct route), the emission reduction, and the reduction in incidents probability.

We will leave the tables with some of the suggested monetised values and techniques in the Appendix of the present document.

3.2 A CBA with non-monetary impacts

Given the purpose of the present work, it is of further guidance to the reader to acknowledge the current state of progress of the application of CBA to the CS domain.

The example presented in the current section is to provide an indication of this, and to draw some remarks on the gaps and difficulties that are encountered when putting into practice the CBA rules that have just been outlined. In particular, the CS domain, as highlighted in D7.1, presents far-reaching impacts that go beyond the standard financial and economic ones.

The CS project INTAROS is an Horizon2020 project that involved 49 partners from Europe, North America, and Asia. It aimed at the development of an integrated Arctic Observation System encompassing atmosphere, ocean, and terrestrial data. Given the breadth of the project, the geographical span is multi-country and multi-region, as it involves all the countries from the Arctic region.

Within the work carried out by the project, a prerequisite to the economic assessment was the definition of the possible value chain involved for the products that result from the INTAROS implementation. In particular, two main streams of services can arise from Ocean observation systems. Firstly, data can be used for forecast, early warning systems and maritime services. Secondly, they can convey information on the state of the oceans and on climate change, which can be useful for the formulation of policies. A different exploitation results in different kinds of users and stakeholder groups. The end user communities are what allows to draw the final link between products and services, societal needs that are addressed, and benefit areas that are to be evaluated. Indeed, INTAROS has identified four main categories of end-users.[4] Operational users make use of ocean data and information to support operational needs related to safety, economic efficiency, and environmental protection, thereby obtaining mainly commercial benefits such as cost savings or increased revenue, as well as risk reduction in the domain of maritime operations. Policy users need to back up the formulation of new, as well as the monitoring and assessment of existing policies by means of ocean data and information. Public users make use of ocean data and observation in the context of leisure or recreational activities, and do not have a specified use for such data. Finally, scientific users use data for their research. All the possible benefits that can arise from the different uses of data and information need to be considered for an overall quantification of the societal value of ocean observation systems.

INTAROS did not perform an original CBA study for the initiative but relied on previous estimates by OECD and by the Horizon 2020 project AtlantOS to highlight the main costs and benefits that are associated with ocean observation systems.

While cost quantification is inherently simpler, an exact estimate cannot still be obtained, as costs are significantly affected by the level of maturity of the observation network. Nevertheless, an indicative estimate has been reached, grouping capital costs for the initial set-up of the technology and

[4] Buch, E. (2021). *Deliverable 6.18: Arctic Blue Economy and Ocean Observations Costs and Benefits*. INTAROS Project Report.

infrastructure with running costs for the maintenance, as well as for the harvesting and processing of new data. The estimates of costs for ocean observation networks are provided in the following table:

Network	**Maturity level**	**Annual CAPEX (€)**	**Annual OPEX (€)**	**Total Annual Running Cost (€)**
GO-SHIP	Mature	N/A	N/A	3,766,568
SOOP - European FerryBox	Pilot	1,875,066	1,538,993	3,414,059*
Continuous Plankton Recorder	Mature	N/A	N/A	2,076,652*
Argo	Mature	7,918,810	672,120	8,590,930
OceanSITES	Mature	2,754,000	910,000	3,664,000
Glider	Pilot	N/A	N/A	4,500,000*
PIRATA	Mature	1,200,000	5,107,100	6,307,100
Surface Drifter	Mature	804,300	332,751	1,137,051
Ocean Tracking Network	Pilot	N/A	N/A	2,466,032
Total				**34,762,992**
*Personnel cost included. For the remainer, personnel costs accounted to an additional amount of €10,297,500 per year.				

Table 2 - INTAROS estimated costs. Source: Buch (2021).

On the benefit side, while the main categories have been identified (Table 3), no quantitative estimate has been provided, thereby hindering the proper comparison between actualised costs and benefits which is a fundamental part of CBA, and necessary for evidence-based decision making.

Benefits	**Description**
Cost avoidance	Avoided costs and loss reduction (e.g., due to appropriate preparations that prevent storm damages)
Cost savings	Decreases in costs due to savings or reduction and social cost savings
Defence	Improved readiness of public defense
Employment	Increases in employment
Increased consumer surplus	-
Increase in GDP	-
Increased producer surplus	-
Increased revenues	Revenues, tourism expenditures, dollar value of exports and production value
Improved business management	Increases in efficiency or productivity that are not captured by increased revenues or cost savings
Improved environmental management	Increased efficiency in management decision-making regarding environmental management and protection
Improved forecasting	Reduction of risk and uncertainty, improved planning security, early warning systems and predictions of currents, waves, and weather and other ocean related phenomena
Lives saved	Additional lives saved
Research benefits	Benefits from collaboration of research institutions and joint data collection
Social welfare gains	-
Value added	Increases in value added

Table 3 - INTAROS benefits' description. Source: Buch (2021).

While some benefits categories, such as cost savings and cost avoidance, entail mainly economic quantification, which can be obtained by looking at market prices, some others, such as the improved environmental management or the lives saved, deal with non-marketable goods. To obviate to this issue, the following section will go through quantification techniques that are available from the literature to pin down a measurable value to non-marketable goods.

Moreover, the inclusion of the benefit category "value added" increases the risk of double counting, as previously listed categories of benefits, such as increased consumer surplus and increased revenues, are likely to have already captured value-added effects.

Another observation is that, despite the reporting of a CBA by the INTAROS project, the way it is reported does not bring to any actionable conclusions. This calls for a more meticulous application of the methodological approach, which is designed so as to capture all the possible domains of impact of any societal initiative.

4 Quantification techniques for non-monetary impacts

When evaluating a project that has social and environmental impacts, the quantification of benefits and costs for the CBA becomes even more complex. This is because these impacts are classified as non-marketable goods (e.g., improved air quality, community building), that, by definition, do not have a market valuation, hindering the comparison through a common unit of measurement with other monetary values that are considered in the CBA. For this reason, the literature has strived to offer a wide array of methodologies that aim to the monetisation of non-marketable goods, so as to provide an indication of the worth of social and environmental impacts [28]. Indeed, these sorts of impacts need to be fully accounted for when evaluating a policy or a project whose impacts are not fully captured by the financial dimension.

The environmental economics literature has proposed a wide array of methodologies to assess use and non-use values of environmental improvements. The application of such methodologies is often hindered by a lack of resources, both financial and in terms of human capital and skills, but the application of the "benefit transfer" technique can fill in these main obstacles, by exploiting the results of previous studies and making them applicable to the context of interest.

On the other hand, fewer techniques have been proposed for the assessment of social impacts. In this regard, this Section will also go through the main approaches that could be used to value impacts that cannot be monetised through the methodologies that have been so far proposed in the literature. Despite the overall lack of shared and reliable methodologies allowing the translation of these impacts into a monetary value to input into a CBA, public decision makers still should consider the full impact potential of initiatives that hold societal relevance. To at least partially address this issue, evidence of impact can be offered by quantitative and qualitative indicators, which can be used to complement the results of a CBA.

The scope of the current Section is not to fully delve into each of the methodologies that have been proposed in the literature, but rather to present the possible options that are available to measure the impact of projects with socio-economic and environmental relevance. This overview enables the identification of the most suitable methodology to measure non-monetary impacts. The choice will be affected by data and resource availability, and by the evaluation scope, as well as by the main categories of impact that are expected to stem from the implementation.

4.1 Environmental evaluation methodologies

Environmental goods, such as urban air quality, are characterized by use and non-use values. While the former category refers to the value of environmental goods that is intertwined with a specific use by the target audience of the evaluation, non-use values are more difficult to infer. However, given the nature of environmental goods, the second category of value appears to be predominant. Within non-use values, we can find existence value, which refers to the will to maintain a good in existence even in the absence of an actual or planned use for the target audience; altruistic value, namely the one associated with the will to leave the good available for others in the future generation; and the bequest value, that arise from the concern that future generations should have the option to use the good.

The array of methodologies that has been developed in environmental economics to encompass all the dimensions of value can be summed up in the two macro-categories of revealed preferences and stated preferences. The ultimate aim is to estimate the worth of (a change in) an environmental good through the assessment of individual willingness to pay (WTP) to retain that good or, conversely, for the willingness to accept (WTA) a specular amount of money to forego some of the benefits associated with the same good.

The main reference for this Section has been the OECD's guide on CBA and the Environment [28].

4.1.1 Revealed preferences approaches

Even if environmental goods are typically not traded in markets, hence they do not have a monetary evaluation, market behaviour of targeted audiences can still allow us to obtain inferences on the monetary evaluation of such goods. Indeed, related markets can be found for such goods, and values can be elicited from transactions occurring in those markets (e.g., the housing market).

We thereby briefly introduce each of the methodologies that are used to elicit individual WTP or WTA from the expressed behaviour of target audiences.

The **hedonic pricing (HP) approach** makes use of transactions in a related market through which the non-market good (e.g., environmental quality) is implicitly traded. The most common domain of application of this methodology is the housing market. The idea is to decompose every good into a bundle of attributes, each with its own evaluation. In doing so, it is possible to compare goods of a similar nature, diverging by only one dimension, that of the price of interest. More specifically, from the housing market prices, one can infer the WTP of target audiences for attributes such as a better environmental or noise quality in any given neighbourhood.

Clearly, the HP works best when individuals have full information about the market prices (meaning, both knowing all the different prices charged, and how they are composed) since the assumption of maximizing their utility, given any other monetary constraints, would be reasonable. This also means that all the houses should be traded within a public market, for the individuals' information to be complete. These requirements, obviously, limit the reliability of this methodology.

Another approach which stems from individual behaviour is that of **travel cost**. This methodology is suited for goods that have the possibility to be visited, such as natural and recreational parks. In this case, the costs of travel, both in terms of actual costs and of opportunity costs (i.e., the best alternative use of time the individual could have made instead of visiting the site) are used to elicit the individual WTP for the good to be evaluated. Clear limitations include the possibility of multi-purpose travels, which hinder the identification of the expenses uniquely linked to the good to be evaluated.

An additional revealed preferences approach relies on the **expenditures for defensive goods** or the averting behaviour. A notable example is that of double paned windows expenditures to protect from air pollution. The underlying assumption of the methodologies based on averting behaviour and defensive expenditures is that individuals can avoid the exposure to an environmental bad by adopting more costly behaviour. By engaging in that more expensive behaviour (e.g., buying the double paned windows[5]), they provide information on how much they value the good (i.e., unpolluted air). The main limitation of these approach is that it provides at best a partial estimate of the actual WTP for the good to be evaluated, possibly because the markets are not perfectly competitive, or because individuals do not have perfect information on prices (thereby causing non-perfectly competitive markets), or because the decision might be affected by multiple drivers (e.g., air pollution and sound pollution), hindering the establishment of a clear cause-effect relationship.

A similar approach is that related to the medical expenses related to morbidity or health effects that follow the exposure to some extent of environmental degradation. This is known as the **cost of illness** approach. The most critical issue with this approach is that it is not often immediate to determine the link between environmental degradation and the related increase in health expenses.

4.1.2 Stated preferences approaches

While revealed preferences approaches have the advantage of relying on actual behaviour of individuals and offer a more objective estimate of the measure of interest, they are limited to the assessment of use values. Indeed, eliciting estimates for non-use values requires the direct involvement of target population, by means of questionnaires and surveys. This line of reasoning is the basis for stated preferences approaches, which infer WTP or WTA of target individuals, by directly asking them questions.

There are mainly two approaches under the stated preferences umbrella.

The first is that based on **contingent valuation** (CV), and it infers people's WTP or WTA for a change in the provision of a given good. In order to do so, targeted individuals are presented with a set of questions that illustrate a hypothetical marketplace for the good to be evaluated, and then require them to act as in real market transactions. The design of surveys needs to be carefully assessed, as answers may be strongly affected by the way in which questions are presented. The main limitations of this approach relate to the replicability and scalability of the findings.

The second approach is that of **choice modelling**, and it differs from CV in that it does not directly ask individuals for their WTP or WTA of (a change in) a given environmental good, but it infers them from their answers related to its single attributes. In this sense, target individuals are presented with a set of alternatives which differ by the level of single attributes. This methodology is more suited to multi-dimensional problems, but it may be more difficult in terms of implementation of the survey design, as well as in terms of understanding by respondents.

[5] It must be noted that the concept of defensive good is context-dependent; for example, the very same consumption decision of buying multiple-layered windows may be driven by heat-loss avoidance needs in cooler countries. An alternative example of defensive good (service) is the security watch, needed as further mean to avoid theft. Further, A/C is a form of adaptation to heat waves and a defensive behaviour in response. Going back to the initial example of pollution, buying a bladeless heater with an integrated air purifier, may be also considered a defensive behaviour.

4.1.3 Benefit transfer

It may not always be feasible, due to timing and resource constraints, as well as due to the lack of data availability, to perform original studies implementing the methodologies outlined in the previous subsections for environmental appraisal.

For this reason, there has been an increased uptake of benefit transfer (BT). This approach relies on the use of original studies of non-market evaluation in a different context from the one it had originally been developed for (what in the literature is termed as *study site*).

In this regard, there are two necessary prerequisites for the implementation of BT. First, there needs to be an original study of sufficiently good quality[6] that can be deemed as comparable to the target study (what has been called *policy site* in the literature) to draw some WTP (or WTA) estimates from. Secondly, a number of subjective judgements by analysts needs to be performed, as there is no straightforward rule on how to choose comparable studies, and the appropriate BT approach to follow.

BT approaches range from the more "naïve" unadjusted ones, that basically transfer WTP (or other reference variables) from the study to the policy site, up to more sophisticated approaches, that adjust the original study's estimates for features of the policy site which may affect the WTP estimation, such as income, population, and physical characteristics. The meta-analysis approach brings this adjustment process one step further, by utilising several original studies, and fine-tuning their estimates to obtain the final one for the policy site.

One of the main limitations of BT is that there is a lot of subjectiveness involved in the evaluation process, which can significantly affect the resulting estimates. Moreover, finding appropriate original studies may be challenging, given that there is little availability of suitable analyses. However, in this last regard, the emergence of data sources, such as the Environmental Valuation Reference Inventory (EVRI)[7], that collects over 5,000 studies of environmental evaluation, have contributed to the availability of studies and to a more widespread and reliable application of BT.

4.1.4 Social Return On Investment (SROI)

Environmental evaluation constitutes a fundamental part of any assessment of initiatives that have a range of impacts that encompasses more than just the financial domain. A possible way to sum up the evaluation of outcomes stemming from the implementation of an initiative that has wide societal impacts is the Social Return on Investment (SROI). This evaluative framework has the advantage of translating social, environmental, and economic impacts into the common unit of measurement that is money and rendering a straightforward and easy-to-interpret result. Indeed, the outcome of SROI is a ratio, which tells us how much social value is created for every unit of local currency invested [10,26]. There are two types of SROI. Evaluative SROI is conducted after the outcome have already taken place, so that realised outcomes are used as inputs. Forecast SROI, on the other hand, uses predicted values of outcomes, assuming that the intervention will reach the desired results. In both approaches, the net SROI can then

[6] The definition of good quality studies is a matter of study in the evaluation literature, and it also involves some degree of subjective judgement by those who perform the evaluation.
[7] The EVRI website can be accessed via the following link: https://evri.ca/en.

be obtained as the ratio between the net present value (NPV), namely the discounted sum of expected benefits and costs, and the value of inputs (i.e., the total investment).

In order to do so, the reasoning is similar to that of a CBA and starts from the overall aim of monetising assets that are not traded in markets. The main difference is that SROI adopts a localised perspective and starts adopts a bottom-up approach, by interrogating stakeholders on the range of possible social, environmental and economic impacts of relevance.

The main advantage of SROI is that it summarises all the relevant information on the economic and non-economic impacts of a project or intervention in a unique number, which is easy to interpret, and mimics indicators used by financial analysts to perform investment decisions. Limitations include the lack of good outcome data to be used for the analysis, and the fact that the SROI inherits all the issues encountered in the monetisation of non-monetary impacts for the CBA.

4.2 Other methodologies and criteria

The wider array of benefits (and costs) to society that come with the implementation of a project is not limited to the environmental domain. Indeed, in order to perform a well-rounded social CBA one must also consider the full stream of impacts that stems from the implementation, and these include social and other non-monetary impacts.

In the case where this occurs, the monetisation is a necessary prerequisite for the inclusion of these impacts in a social CBA and to improve comparability, by use of the same unit of measurement.

However, monetisation is just not feasible for all kinds of impacts. In particular, social impact, such as community building and increased awareness on certain topics, are quintessentially qualitative. For this reason, they cannot be translated into monetary units, but represent nevertheless significant variables that are worthwhile for decision makers to be accounted for in the full appraisal of any initiative. As a consequence, an all-round evaluation of projects that hold public interest characteristics should complement the rigour of economic appraisal through CBA with the use of indicators, either qualitative or qualitative.

The following subsection briefly reviews the use of performance indicators, with particular reference to the case of CS.

4.2.1 Non-monetary indicators for quantitative and qualitative assessment

When methodologies such as the ones described in Sections 4.1 are not available to translate non-monetary impacts into a common unit of measurement, some metrics can still allow to pinpoint quantitative and qualitative indications of a project’s performance. In particular, the use of metrics and indicators is quite common in the CS domain, where many of the impacts are recorded in both the social and environmental domain.

A staple project has been the Horizon2020 MICS, which developed a standardised framework for the impact assessment of CS projects, through the use of a system which is based on metrics, scores and weights. The metrics are grouped in the main categories of Society, Governance, The Economy, Science and Technology and The Environment.[8]

Under each category, project planners self-report on impact, by answering a set of questions. Each question has an assigned score, which builds up to the final impact score of the CS initiative.

While this methodology abstracts from economic methodologies that are used by public decision makers when pursuing investment choices, it still allows to grasp the qualitative dimension of impact that characterise CS initiatives and associate a number to it.

For this reason, it may still make sense to pair rigorous economic assessments with indicators, so as to provide decision makers with a broader understanding of the overall impact of CS initiatives.

In the specific case of the SOCIO-BEE project, a Key Performance Indicators (KPIs) framework has been defined with the aim to continuously monitor and evaluate the progress of the project's implementation. KPIs provide a structured way to quantify the achievements, outcomes, and contributions of such initiatives. Impact assessment helps in understanding the effectiveness, outcomes, and contributions of CS initiatives. The revision of the SOCIO-BEE's KPIs framework has enabled the identification of the indicators which could potentially be used to complement the socio-economic impact assessment. For simplicity's sake, we report them in the Appendix B.

[8] More information on the indicators used in the MICS methodology can be found at the following link: https://about.mics.tools/indicators.

5 A CBA template

The definition of a CBA is highly dependent on the context of the evaluation, as well as on the scope of the analysis. For this reason, a standardised format would not be advisable for the uptake of this methodology.

Nevertheless, a level playing field can still be provided, through the identification of the essential steps that need to be taken for the proper implementation of CBA. For this reason, in what follows we endeavour to provide a checklist, which can be used by practitioners as a reference point. For each of the steps that make up the analysis, some questions that the analyst needs to face to appropriately tackle the evaluation are presented, along with some hypothesis on how to answer. Also, insights that are specific to the CS domain will be presented in the checklist. To this aim we particularly exploit the contribution of one municipality hosting one of the SOCIO-BEE's pilots (Appendix C), namely Maroussi in Greece, highlighting their perspectives and expectations on the socio-economic impact assessment.

Though simplistic in its nature, the very purpose of the checklist is to provide readers with a simple list of the steps to be followed in a CBA, and to foster the discussion on which questions represent the starting point to this kind of analysis. The relevance of the guide to SOCIO-BEE is assured by creating a connection with both previous deliverables and the results of SOCIO-BEE pilots. Particularly, the deliverable D5.12, which describes the results of the first round of pilots' implementation, is relevant to identify potential areas of impact. Following this checklist, a more applied approach will consist in the implementation of a simplified approach to CBA through quantifiable monetary costs and benefits and by building on the KPIs for more qualitative considerations on impact.

- **Step 1. Define the object of analysis for the CBA.**

What aspects of the initiative should be the object of socio-economic evaluation? What is the intended aim of the initiative? What is the purpose of the CBA?

This step, in the general approach to CBA, follows a top-down perspective. The inquiry is driven by the public decision makers, who determine the lens which draws the perimeter of the analysis. For example, one should understand if it is the whole initiative that is evaluated or only few features of it are the object of the analysis, which is the relevant case when the execution was already approved by the decision makers.

In the context of CS initiatives, the general approach should be mediated. Indeed, the promoters of CS initiatives are not the public decision makers themselves, who are more likely to be the recipients of the analysis. In this sense, the CBA would represent a tool for citizen scientists or CS initiators to obtain financing. If this were the case, the object of analysis can be determined by a dialogue between CS initiators and participants. Otherwise, project's mission statements, and reports on the products and services offered by the initiative can build the foundations on the possible streams that can arise from the project.

- **Step 2. Define the set of alternatives.**

What possible uses can be identified for products and services offered by the initiative? Which instruments could be deployed to obtain the same objectives as the proposed initiative?

Once the objective of the initiative to be implemented is defined at Step 1, it is possible to directly assess other ways through which the same objectives can be achieved. In the case where no other options are available, the main alternative for comparison is the status quo. Nevertheless, this step is crucial, as CBA will compute incremental benefits and costs with respect to suitable alternatives that are identified.

In the context of CS initiatives, determining the alternatives requires careful consideration of the possible uses that can be made of the products and services offered. This includes, for example, data collection, increased awareness, and greater sense of community. Depending on the foreseen uses, (more) traditional alternatives to achieve the same end goals could then include data collection through traditional air quality monitoring stations, organization of awareness-raising campaigns, and of other community-building events. In the SOCIO-BEE context, some insights on the possible alternatives and uses can be drawn from the work carried out in deliverable 8.4 “Exploitation Plan & SOCIO-BEE business strategy.R1”, which led to the identification of the key exploitable results.

- **Step 3. Determine the stakeholders of interest.**

Which subject categories hold an interest to the initiative? In the case where the initiative provides products and services, who are the foreseen users?

Based on the aspects of the project one wants to evaluate, one can define the possible stakeholders.

In the domain of CS, a possible pool of interested stakeholders can be found through the interaction (e.g., through survey forms, interviews and meetings) with pilot partners and final users of the technologies. This could give insights on the expected utility and on uses that can be made of such products and services. Identifying the value chain is essential to explore the different impact areas of the project. Focusing on the SOCIO-BEE pilots, the project’s stakeholders, from the standpoint of CBA, are different than those highlighted in the project’s documentation, such as deliverable D1.4. In fact, those are usually referred as *honey bears*, and are interested in the outcomes of the project, both in term of data and technology. For the CBA, instead, the (potential) stakeholders are all the subjects being affected (impacted) by the project and deemed worthy of being analysed. In this sense, the stakeholders could be the citizens and the institutions (e.g., municipalities) of the three SOCIO-BEE pilots: Ancona, Maroussi, and Zaragoza.

- **Step 4. Define likely areas of impact, and the relative quantification metrics and methodologies.**

What are the foreseen areas of impact of the initiative? How can the likely impacts be evaluated? How can useful data be collected? Which methodologies are in place for the quantification of these likely impacts?

The definition of value chains is propaedeutic to the identification of impact areas. The identification of the likely domains of impact affects the data collection process, as well as the non-monetary impact quantification methodologies which can be deployed.

For CS initiatives, likely areas of impact are not limited to the financial domain but encompass also the environmental and social domains. To tackle the translation of these impacts into values, the present issue of the CBA guidelines already provided the array of methodologies which can be found in the economics literature. These, for the specificities of CS initiatives, could be complemented by qualitative indicators. Specific to the SOCIO-BEE case, some examples of useful indicators can be found in deliverable D5.12. A potentially interesting example is KPI 12, which evaluates *scientific literacy*, then further decomposed into additional five KPIs: i) *increased interest or engagement in science,* ii) *intention to be involved in new citizen science projects,* iii) *improved participant understanding of science,* iv) *better participant attitudes toward science,* and v) *increased participant interest in science as a career*.

Additionally, of potential interest for the evaluation of social impacts could be:

- Gender composition of the participants, possibly highlighting an increased participation of women,
- Age composition, to highlight if the impacts are concentrated in specific cohorts,
- Income composition, since the participants to CS projects tend to be wealthy [27].

Further, some of the indicators that are measured in the pilot cities could be taken into consideration to gain further insights on the qualitative measures of impact, such as:

- Interest and attitudes,
- Air quality awareness,
- Inclusiveness.

As regards the future replicability and scalability of SOCIO-BEE projects, an important caveat is that qualitative considerations such as *experience with SOCIO-BEE* (as reported in D5.12) can only complement the picture of the overall SOCIO-BEE project's impact, providing a taste of the participants' direct experience and their conclusions, though their relevance to the CBA assessment of CS initiatives should be carefully investigated.

- **Step 5. Define costs.**

What are the investment costs that need to be incurred in the initial stages of the project? Which costs need to be incurred for the regular functioning and maintenance of the initiative?

Data collection on costs can be pursued by estimating the likely expenses which will be needed for the uptake and regular functioning of the initiative. Where exact quantities cannot be obtained, estimates can be used instead. Costs may also be non-monetary when the social and environmental dimensions are affected, which calls for the use of quantification methodologies for such costs.

In the case of CS initiatives, data on costs can be collected by involving the developers of the technologies that are utilized. A comparison of these costs with those of traditional alternatives identified at Step 2 conveys incremental costs information. In the SOCIO-BEE context, data collection of costs can be developed through a dialogue with the partners tasked with the technological development of the innovative solutions introduced by the project. Data collection will be aided by spreadsheets.

Specifically, the beginning of the process will start from the project budget. Assuming that the costs will be as reported in the SOCIO-BEE budget, this will be the ground for the computations. In addition, if there has been any deviation (e.g., additional funds required, or allocated funds not used) it can be easily considered in the computations. A collaboration with the partners, such as BETTAIR for sensors development costs, or BETTAIR for the user app development cost, or CERTH, UDEUSTO, HYP, HOPU for additional data is foreseen, so as to provide the analysis with additional detail on the costs side, and to make forecasts on future costs (e.g., maintenance of the platform, citizen engagement and bees' recruiting initiatives). The costs will be aggregated in *ad-hoc* categories, to highlight how the funds have been internally allocated. Some illustrative categories could be personnel costs, raw materials for sensor development, and communication materials' costs (e.g., printing of SOCIO-BEE brochures).

- **Step 6. Define benefits and how to compute them.**

What are the likely benefits? How can these benefits be estimated?

Survey forms should be submitted to relevant stakeholders to collect information on the possible benefits that are expected to stem for the initiative. The definition of the benefit categories is then instrumental to the choice of the optimal methodology that can be used to translate them into a monetary value, also drawing from the hypotheses developed at Step 4.

What could be considered a project's benefit is a positive outcome of it. The tricky part of pinpointing them for the sake of CBA is the fact that the benefits encompass much more than just positive financial flows.

In the SOCIO-BEE case, the project could have financial revenues (e.g., deriving by the subsequent commercialization of the technology) and those, by being already monetised, can easily contribute to compensate the costs already sustained within the SOCIO-BEE initiatives. But the main focus of CBA is on not already monetised positive outcomes; namely, those items, both material and immaterial, that are not traded in any market and hence do not have a price attached to them.

The scope of CBA is of providing a monetary evaluation to a list of the project's results and establish whether and to what extent the endeavour was overall worth it. This line of reasoning is not limited to financial sustainability, which is often not met in the case of fundamental research, where the majority of benefits accrue to society in a non-monetary form.

In the specific case of SOCIO-BEE, the roadmap for the identification of potential benefits builds upon the results of deliverable D5.12, which, for instance, has brought to light the initial levels of project participants' sensibility to air quality issues[9], or from the Key Exploitable Results (KERs), which provide an overall view of the results that are expected from SOCIO-BEE, allowing for the identification of potential benefit categories. In this regard, Table 4 presents a first attempt of linking KERs to benefits and impacts that can be evaluated for a CBA (for the complete list of KERs, please refer to Appendix C).

Table 4 Examples of potential benefits and impacts

KER #	Tool name	Lead developer	Potential benefits and impacts
1	Co-creation and campaign blueprints tool	CERTH	• Capacity Building: Empowers citizens with the ability to design and implement campaigns, fostering community leadership and skill development. • Increased Environmental Awareness: Raises awareness about air quality issues, contributing to informed and environmentally conscious communities. • Time and Operating Cost Savings: Streamlines the campaign creation process by providing a collaborative design tool, reducing the time and resources required. • Improved Environmental Management: Enables the creation of effective campaigns to raise awareness about air quality, contributing to improved environmental management. • Increased Engagement and Retention: Enhances engagement and retention rates by allowing citizens to co-create campaigns, fostering a sense of involvement.
8	SOCIO-BEE Engagement and CS implementation methodology	UDEUSTO	• Capacity Building: Equips stakeholders with the tools and knowledge to implement citizen science, contributing to capacity building. • Community Empowerment: Empowers communities to actively engage in citizen science, fostering a sense of ownership and responsibility. • Guidance for Stakeholders: Guides and empowers various stakeholder groups in implementing citizen science activities, fostering a collaborative approach.

The benefits will be evaluated with *ad-hoc* techniques and the process will require strict collaboration between UNIPD and the consortium to provide the necessary data on each of the items to be assessed.

[9] Future iterations could measure these same variables after the exposure to the SOCIO-BEE initiative, to gain evidence on any potential SOCIO-BEE impact on citizens' awareness of air pollution topics.

- **Step 7. Choose the discount rate and discount costs and benefits to obtain present values.**

What will be the expected life of the initiative? For how long should we record benefits and costs? Which discount rate should we apply to the economic flows?

The economic concept of time value of money requires to discount the expected value of future flows of benefits and costs to be comparable at the time of the evaluation. It is therefore essential to apply the discount factor to the years of useful life of the initiative.

The EU CBA Guidelines suggest a 3.5% discount rate and a 50-years' time horizon for infrastructure projects. These indications can be a starting point to define CS-specific parameters.

- **Step 8. Compute NPV of each alternative.**

What is the net present value? Do we need other indices?

The NPV is obtained as the difference between discounted benefits and costs. If needed, the analyst can incorporate a choice of other indices which can be used for the provision of evidence to decision makers (e.g., SROI, KPIs).

- **Step 9. Perform a sensitivity and scenario analyses and issue a recommendation.**

How would the results change if the value of the discount rate/the duration of the project/any other parameter involved in the analysis were different? What do the results tell us? How should we interpret them?

Estimates of NPV could be dependent on an array of decisions where subjective judgement by the analyst is involved. For this reason, to improve the robustness of the results, sensitivity analyses can be performed to test how the results change for different values of the parameters involved. The end results allow us to issue actionable recommendations and to gain conclusions regarding the socio-economic impact of the initiative.

6 Evaluation Strategy – Numerical example for SOCIO-BEE's Maroussi pilot

In this section we will provide a numerical example of CBA for the SOCIO-BEE project. As we will explain, while monetising benefits is theoretically feasible, the endeavour may result as too complex for many of the local authorities' offices that may be charged with the assessment. In the following sections, then, we will provide an explanation of the assessment technique we deem more feasible for the case of SOCIO-BEE and, by extension, similar projects on environmental topics employing CS techniques.

The discussion will be accompanied by the KPIs collected during the project. Indeed, these allow to attach quantitative indicators to the non-monetary benefits that we will identify from SOCIO-BEE. More considerations will be drawn also from the data and information from one of the pilots. The pilot selected for the examples of this section is the one in Maroussi (Greece) (MRSI), which is of interest to economic evaluation as it focuses on working-age population (see Table 5).[10] As a matter of fact, from an economic perspective, working-age population is often the most interesting demographic, since it directly links to the economic activity, and it enables a more proficient computation of related opportunity costs from the project's implementation.[11] As it will become more clear from the numerical example, while the non-monetary benefits are the same as for other kinds of demographics (e.g., retired people, children), working age population has an opportunity cost from volunteering in a CS initiative, which can be proxied by the average wage in the region.

Finally, the choice of focusing on only one of the three pilots is guided only by the necessity of keeping the explanation as simple as possible. Any of the following conclusions may be generalised to the case of several pilots as the need arises.

Table 5 - MRSI pilot: summary statistics for the two iterations.

Category	**Total**
Hives	15
Volunteers	89
Of which:	
19-65 years (working age)	*75,8%*
Queen Bees	6
Working Bees	81
Drone Bees	6
Campaigns	9
Sub-campaigns	36
Measurements collected	1.132

[10] The other two, instead, focus on children (Zaragoza), and elderly (Ancona).

[11] Opportunity costs, in economic doctrine, are to be considered in the same way as personnel expenses. These are computed with respect to the hours spent by volunteers to collect data during the campaigns, which is multiplied by the value of time of the volunteers, that is roundly captured by the hourly wage for the working age participants.

6.1 The context

As explained above, the need to both provide a methodology that anyone could implement to assess the impacts of the project pushed us to sacrifice some of the intricacies of a full-scope CBA and to limit the scope of the computations.

In this sense, the approach that will be adopted in the present numerical example is that of a simplified CBA, that limits the scope of the evaluation to the assessment of monetary benefits and costs, and to the (qualitative) description of non-monetary benefits and costs. The motivation for such an approach is to enable a more comprehensive assessment of the impacts that are related to the project without the need of applying complex non-monetary evaluation methodologies, as well as of data and resources (both in terms of expertise and to carry out a thorough analysis).[12] Despite the more limited scope of this kind of analysis, the idea is to convey suggestive evidence of the possible impacts of the implementation of a project whose main outcomes are likely to be non-monetary.

A project as SOCIO-BEE aims at producing several benefits that can range from more grounded and understandable as, for example, a technological advancement by favouring basic research in specific technical fields (e.g., urban air quality management, citizen engagement strategies), or the gathering of data and creation of sharable databases, to outcomes harder to quantify and assess, as the increase in political participation or the increase in environmental awareness. From this consideration and given the computational hurdles in the assessment of non-monetary benefits, we take a simplified approach to CBA in the present deliverable for the SOCIO-BEE project. This approach starts from the quantification of monetary costs and benefits, and then moving to more qualitative considerations on the non-monetary ones, exploiting the role of KPIs, focusing on the implementation of the MRSI pilot.

Given the nature of CS initiatives, this approach appears to be the most suited for economic appraisals, as it allows to appreciate non-monetary benefits in a way that matches the resources and expertise that are typically available to this sort of projects.

6.2 Monetary costs and benefits

6.2.1 Monetary costs

As stated above, when structuring a CBA, the cost computation is eased by the extant data records that are kept throughout project development. Cost measures are objective figures that refer to the expenses that have been sustained by carrying out the activities or the R&D (research and development) – or that are expended to be carried out for future maintenance. While the costs are usually identified, or identifiable, quantifying benefits is a completely different matter.

[12] A fully extensive CBA would require data on the baseline scenario (before project implementation) as well as a much wider time horizon for evaluation. Given also the scope of the present deliverable, that is rather centred in offering a methodology for future endeavours and given that the future users of this methodology will have limited expertise and resources, we abstract from comprehensive assessments and provide a solution that is easier to implement.

In what follows, we report the cost estimates by technological solution that have been developed within SOCIO-BEE.

Wearable Sensor Network

200 devices have been developed by SOCIO-BEE as the product of the work of BETTAIR. In this paragraph, we report actual costs that were sustained for the development of the devices, as well as an estimate of the future costs of maintenance. Both estimates are the result of a fruitful interaction with BETTAIR. We hypothesised a time horizon of 10 years and a discount factor of 3 percent. These have been chosen following a precautionary principle: as regards time horizon, the average life of a WS was chosen [2] [13]; as regards the discount rate, the lowest among those that are proposed by the EU Guide on CBA [8] was picked. Indeed, higher values of the social discount factor would have yielded a lower amount of maintenance costs. Full estimates can be found in Appendix D. The development and the relative maintenance costs are computed relatively to the full 200 devices from SOCIO-BEE's final outcomes, instead of just the number of sensors needed for a single campaign.

Computing the development cost for the full batch was deemed preferrable to avoid the risk of double counting that is implied in the alternative approach of ascribing the cost to each individual sensor. Since R&D costs are often indivisible and show higher returns to scale while often being one-off expenses (sunk costs), trying to compute the unitary cost of development would entail the risk of overestimating costs without the justification of a precautionary approach.

In the computation of the NPV, the development cost is hence considered only once, while the maintenance costs reflect the scenario in which a project similar in size to SOCIO-BEE were to use a similar amount of sensors up until their expected life span.

Maintenance costs represent roughly 60 percent of the overall development costs, and are represented, for the most part, by technical maintenance costs, while personnel expenses have a minority role. This is opposite to what occurs in the case of development costs, where personnel effort has a much greater relevance, possibly because of the need to research and develop more efficient solutions by testing and training different versions.

Drone campaigns

SOCIO-BEE data collection campaigns have been also conducted thanks to the help of drones, that enabled the measurement of many data points in a relatively short time window (one minute and a half per measurement). In Appendix D we report the full expenses related to drone campaigns in the specific case of MRSI.

In order to attach BETTAIR sensors to the drones, throughout the project, a 3D-printed drone clip has been produced, and expenses for that are included in the overall SOCIO-BEE costs. The publicly available 3D print for the drone clip will be another SOCIO-BEE outcome to be adopted also in future CS initiatives.

[13] Bernasconi et al. (2022) estimate a 10-year life horizon for Metal Oxide Semiconductor Sensors.

Finally, the SOCIO-BEE project has also aided the configuration and development of a new lightweight (i.e., about 155 grams) drone, that can fly in the EU without the need for a drone licence.[14] Development expenses are also included in the final cost prospect.

The estimates of the expenses for drone campaigns have been obtained thanks to the dialogue with ID2M. In this case, unlike for the sensor network, we do not report expected future costs of maintenance using a discounting approach, as these are highly interrelated with the size of the campaigns, which are context-specific and depend also on the number of adhering volunteers. We therefore only report yearly maintenance costs as a rough estimate, by reporting on the care plans that are offered by drone provider companies.

Finally, the costs for the internal production of the SOCIO-BEE lightweight drone will also be exploited for cost comparisons in the next subsection.

6.2.2 Monetary benefits

Despite the dimensions of SOCIO-BEE impact being more difficult to grasp and to translate in monetary terms, as they transcend typically quantifiable measures of impact, the following reports some estimates of the value generated by the project in terms of cost savings and in terms of the value of data.

Indeed, the technological solutions that have been developed and implemented in SOCIO-BEE are characterized by lower costs with respect to more traditional ways to measure urban air pollutions. In addition to that, data that have been produced within the project duration are also inherently valuable.[15] Hence, we adopt a cost-based approach to offer a benchmark that accounts for the value creation that is connected with this type of data, abstracting, for the moment, from any considerations on ancillary values of the like of community creation, social capital and greater awareness on pollution and climate change topics that are not measurable in monetary terms and cannot be attached with a numerical value. Also in this case, for the above-mentioned reasons, we use the MRSI pilot for our computations.

Data value: cost approach

There are several ways that one can measure the value of data. Given that the main purpose of data collection in the context of CS is not to make a marketable outcome, on this work we will depart from market-based measures, and stick to a cost-based approach [24]. A clear limitation of this approach is that more efficient technologies for data collection would lead to lower value of data, because of lower costs. Despite its limitations, mainly attributable to the fact that, by construction, it equates benefits and costs, this typically provides a low benchmark of the value generated by these data. In our case, given the economic inefficiencies that are inevitably related to the piloting nature of the data collection in MRSI, it is likely that this value is rather less like a low-benchmark. In Appendix E we report the full estimate of costs for data collection in the context of the two pilot iterations in MRSI, that warranted the collection of 1.132 records in the two iterations.

[14] Drone licences are required for drones of weight over 250 grams, while the SOCIO-BEE developed drone will be under this weight category, enabling air quality measurements without requiring CS participants to enrol for a drone licence.

[15] We abstract here from the caveats that relate to the accuracy and quality of the data produced, that have been discussed elsewhere, and focus on the purely financial dimension.

We estimate a cost per data record of around 90 €. Given that CS data are typically circulated for free, and that the work in D7.1 on previous CS initiatives did not yield to conclusive results on previous projects' costs' estimates, we do not have comparable results to assess this value against in terms of both value production and efficiency of the implemented technologies. Yet, we can safely say that this value is still highly affected by the piloting nature of the activities that have been carried out so far within SOCIO-BEE. It is indeed likely that, with economies of scale (i.e., greater number of data points collected) and more efficiency in the activities carried out, this cost will drop. On the other hand, this value does not account for the intangible values that are related to this data, such as greater awareness of citizens in environmental matters and direct involvement of CS participants in scientific activities. Clearly the estimated record-value is too high, but we deem it acceptable for two main reasons. First, we expect that value to also reflect the value of the intangibles; second, the value is computed using the value-of-cost approach that, as of itself, implies also considering fixed costs that surely contribute to increasing the final figure given the relatively small dataset size. In conclusion, more data would surely drive the value of the single record down but is reasonable to expect its value to be generally higher than with a pure value-of-cost approach since as a consequence of the intangibles.

Cost savings: use of SOCIO-BEE sensors VS static sensors

Following the report from the Environmental Defense Fund, we can compare the case of the Berlin campaign on the city air quality. As for the case of SOCIO-BEE, the city of Berlin aimed at collecting data on several air pollutants such as NO_2 and NO_X to improve the implementation of traffic policies, such as, for example, speed limits to contain emissions by, particularly, diesel engines.

The city combines sensors and passive samplers, the latter are used mainly to monitor the effect of speed limits by placing them in carefully selected hotspots. Specifically, the city technical endowment of sensors is composed by:

- 16 regulatory-grade reference monitoring stations located in the city and in its outskirts.
- A measuring vehicle fully equipped for automatic measurements
- A supplementary network of small and lower-cost samplers (at least 43 sites around the city, of which, 8 located near the monitoring station to ensure comparability of the measurement).

The cost of operating the monitoring stations totals between € 300.000 and € 400.000 annually for maintenance, plus € 60.000 for the network of low-cost samplers [16] [14].

On the other hand, the SOCIO-BEE sensors promise a much cheaper maintenance cost. In fact, the cost does not scale proportionally with the number of employed devices. This is due to the efficiency gain of maintaining several sensors within one streamlined process. With a time horizon of ten years, the discounted cost of keeping at full efficiency two hundred sensors is estimated to be € 141.094, only a fraction of the Berlin case [17]. Instead, the yearly cost is around € 14.805 making the sensors even cheaper than the low-cost samplers. The reported issues with data quality together with the price and the cost of

[16] Those figures do not consider staff costs.
[17] The table with the computations and the yearly discounted cash flows is in Appendix D.

maintenance, encourage comparing the SOCIO-BEE sensors with the static samplers rather than with the monitoring stations.

The upkeep cost of the stations reflects the continuous stream of high-quality data they provide and the technical complexity of maintaining them fully operative. SOCIO-BEE sensors, given all the limitations listed above, cannot and should not be compared to those stations. Instead, they could answer to the need for cheaper environmental data-collection tools to complement the more refined ones. In this sense, the sensors, while promising savings even with respect to the samplers may prove an overall improvement since they can provide for real-time local monitoring, hence covering the same role of samplers but with the possibility of sampling more pollutants at the same time and without the need for laboratory analyses.

Cost savings: internally produced SOCIO-BEE drone VS purchased drone

In the reference pilot, two externally produced drones were employed in the data collection process throughout piloting campaigns. Hypothesizing that, instead, two internally produced light-weight drones were used, a cost saving of € 7.473,4 would have been obtained. This figure builds the case for another solution, developed within SOCIO-BEE, that enables cost savings as opposed to more traditional approaches to air quality data collection. The limited costs of production, as well as the possibility to employ the drone without the need of a licence, favours the replicability and scalability of the SOCIO-BEE approach. In fact, the low requirements and costs may encourage the application of the methodology to contexts facing stronger limitations both in term of spending power and in term of skilled personnel.

Summary of monetary costs and benefits

In this subsection, we reviewed the costs that were associated to the development and use of the novel technological innovations that have been introduced by SOCIO-BEE. Despite the nature of CS, and the fact that the benefits that are associated to it are predominantly qualitative and not readily translatable in monetary terms, for two items we were still able to provide monetary estimates for the expected cost savings from the implementation of SOCIO-BEE solutions, as well as an estimate of the value of data produced within the project. Still, a comparison between monetary costs and benefits would be incomplete, as it would entirely neglect the presence of a wide array of non-monetisable benefits. For this reason, the following subsection provides a thorough description of the expected areas of non-monetary impact, with accompanying KPIs for a tentative quantification of these dimensions of impact.

6.3 Non-monetary benefits

As mentioned, SOCIO-BEE encompasses several areas of impact. In the present sub-section, we will review these impact areas and provide some qualitative considerations to wholly appreciate these dimensions. In this regard, the list of KPIs enables to pin down a non-monetary estimate of impacts that are not directly monetisable, and to enable a better overview of the outreach of a project of the like of SOCIO-BEE.

In what follows, there is a brief list of outcomes, accompanied by the corresponding KPIs, to give few examples.

- **Societal impacts** encompass the impacts of CS projects on the wider society. Examples that are true to SOCIO-BEE include *community building* and a sense of *responsibility towards pollution*

topics. Indeed, SOCIO-BEE, through hives' creation, facilitates the creation of a community, where roles and responsibilities are assigned through the bee-hive metaphor. On top of that, the direct involvement of citizens in data collection on the levels of pollutants at the urban level enhances their awareness.
In connection to these impact categories, we report the following KPIs that are part of the pilots' impact assessment framework laid out in D5.10:

KPI number	Description of the KPI	Value reached
KPI 8.1	# Queen Bees recruited by pilot and iteration	10 (2 in ANC, 3 MRSI in and 5 in ZGZ)
KPI 8.2	# Bears involved by pilot and iteration	5 (5 in ZGZ)
KPI 8.3	# Working Bees involved by pilot and iteration	301 (12 in ANC, 56 in MRSI and 233 in ZGZ)
KPI 8.4	# Societal groups involved	14 (3 in ANC, 7 in MRSI and 4 in ZGZ)
KPI 8.5	% Women participation	36% in ANC, 54% in MRSI and 36% in ZGZ
KPI 8.6	% Inclusivity rate target	73,7% in ANC, 73,33% in MRSI and 73,98% in ZGZ
KPI 8.7	# Citizens actively collecting air quality data via wearables	302 (20 in ANC, 49 in MRSI and 233 in ZGZ)
KPI9.9	Interest in the project by local populations	121 (in ZGZ)

The project successfully involved about 302 citizens in the data collection, of which 49 were from the MRSI pilot only. The definition of roles according to the bee-hive metaphor was efficient, as the number of citizens involved in each of the roles was consistent with the initial role definition. The project also enabled the inclusion of 14 societal groups, including senior citizens, scientists, volunteers, air quality experts and children. This allowed to reach an inclusivity rate of about 73% in all three pilots, based on pre-evaluation questionnaires' positive feedback from less privileged groups.

- **Technological impacts** refer to the generation of novel *solutions for air quality data* collection, namely portable devices that can be developed and maintained at a lower cost with respect to their stationary counterparts. These devices have also the advantage of being easily used by citizens in CS endeavours.
  The following KPIs address this domain of impact:

KPI number	Description of KPI	Value reached
KPI 2.1	Integrated, ready-to-use SOCIO-BEE compatible low-cost sensing devices integrated into personal wearables and drones	2

KPI 2.2	Availability of interchangeable and attachable sensor modules to SOCIO-BEE wearable device demonstrating versatility of the solution		6 (2 in ANC, 2 in MRSI and 2 in ZGZ)
KPI 2.3	Number of wearable devices produced		160 (44 in ANC, 47 in MRSI and 45 in ZGZ)

The KPIs on the technological solutions that are delivered by SOCIO-BEE mainly relate to the wearable devices that enable air pollution measurement from the citizenry. The project has successfully produced 160 devices, with attachable sensor modules.

- **Business impacts** mostly lie in the impacts on the overall economy as well as on the creation of business potential that is achieved through CS initiatives. In this sense, the reliance on *crowd-funding*, *sustainable business models*, and any impact on *access to finance and entrepreneurship*, as well as *cost-benefit* and *return on investments* that stem as a result of project's implementation can be viewed as a business impact. While the previous subsection has already reported on the cost savings and value of data impacts of SOCIO-BEE, some other dimensions of impact can be appreciated by looking at the following list of KPIs:

KPI number	Description of KPI	Value reached
KPI 7.1	Business model canvas for 2 types of business and financing models	2
KPI 7.2	Deliver a focused business plan at the end of the project to demonstrate the sustainability and reproducibility of the project in at least 2 different cities	2
KPI 7.3	Preparation for post-project exploitations: IPR agreements between project partners, agreement on individual/ joint exploitation plans and business plan preparation activities	1
KPI 9.5	Proof of Value Outside the consortium uses of SOCIO-BEE artefacts	1
KPI 9.11	Impact on employment - new employments	5 (in MRSI)
KPI 9.12	Relevant financing institutions involved in the seminars	3

The overall economic impacts of SOCIO-BEE concern the creation of business potential, the protection of intellectual property that is generated by the project and the impacts on employment. Employment increased through the generation of 5 new positions that were employed in the MRSI pilot activities.

- **Educational impacts** refer to, for example, *increased citizens' knowledge on pollution topics*, thanks to the implementation of a CS initiative. In the SOCIO-BEE project, the main impacts under these domains relate also to the improved technology literacy on the side of the participants.

KPI number	Description of KPI	Value reached
KPI 3.1	% of EU citizens use the micro volunteering app to gather evidence	46%
KPI 3.2	Technology acceptance rate	68% in ANC, 87% in MRSI and 78% in ZGZ
KPI 3.2a	User's appreciation (satisfaction) of the SOCIO-BEE (AcadeMe) platform	62% in ANC, 85% in MRSI and 79% in ZGZ
KPI 3.3	Perceived usability score related to how the solution fits in their everyday life	62% in ANC, 76% in MRSI and 54% in ZGZ
KPI 3.3a	Level of usability and accessibility of pilot artefacts	82% in ANC, 77% in MRSI and 77% in ZGZ
KPI10.1	Visualizations of AcadeMe tutorial video	200
KPI10.2	Accesses to SOCIO-BEE AcadeMe portal	1000

The main impacts under the educational domain within SOCIO-BEE have been recorded in the implementation metrics of the AcadeMe platform, that collects all the training materials for the platform users. Then, some indicators have also been recorded to assess the overall acceptance and usability of the technological solutions.

- **Research and scientific impacts** refer to outputs that *improve general knowledge on the topics* that are addressed by the CS project, possibly also thanks to the availability of *open-source data and research*. Furthermore, in line with the overall goal of CS, that is to involve citizens directly in some of the phases of the scientific method, users' attitude towards science is typically expected to be improved thanks to the implementation of CS initiatives.

KPI number	Description of KPI	Value reached
KPI 4.2	Number of relevant datasets from pollutants types analysed, at least 5 datasets per pilot case	3
KPI 4.2a	Publication of open datasets generated in two iterations of pilots	3
KPI 4.3	Accessibility and adoption rate of the intelligence supporting tools	73% in ANC, 74% in MRSI and 74% in ZGZ)
KPI 4.4	Number of experts/researchers participating and mentoring in the SOCIO-BEE platform	6
KPI 12.1	Increased interest or engagement in science	69% in ANC, 55% in MRSI and 68% in ZGZ

KPI 12.2	Intention to be involved in new citizen science projects	58% in ANC, 52% in MRSI and 94% in ZGZ
KPI 12.3	Improved participant understanding of science	58% in ANC, 62% in MRSI and 63% in ZGZ
KPI 12.4	Better participant attitudes toward science	63% in MRSI and 65% in ZGZ
KPI 12.5	Increased participant interest in science as a career	50% in ANC, 52% in MRSI and 65% in ZGZ

The main domains of scientific impact of SOCIO-BEE revolve around the production of new, open source, data on urban air quality, encompassing up to five different types of pollutants, and around the involvement of citizens in scientific research and activities. Specifically, on average across the three pilots, 61 percent of citizens reported an improved understanding of science, while 56 percent improved their interest in science as a career, building the case for the creation of social capital thanks to the project's implementation.

- **Environmental impacts** of CS initiatives include the *increased sensitivity* of participants towards pollution topics, and the capability to *contribute to the change in user behaviour*.

KPI number	Description of KPI	Value reached
KPI 1.1	# EU citizens involved in the design process (surveyed or interviewed)	116 (42 in ANC, 39 in MRSI and 35 in ZGZ)
KPI 1.2	% of EU citizens more aware of air pollutions issues through SOCIO-BEE	78% in ANC, 87% in MRSI and 77% in ZGZ
KPI 1.3	Availability of integrated, ready-to-use CS co-creation platform and the engagement toolkit	1
KPI 1.3a	SOCIO-BEE platform open-source releases at https://eu-citizen.science/	4
KPI 1.3b	Publication in GitHub repository of SOCIO-BEE platform and toolkits	4
KPI9.8	Percentage of participants that are willing to adjust their behaviour to reduce pollution (e.g., by taking public transport or walking cycling instead of using the car)	73% in ANC, 85% in MRSI and 76% in ZGZ

In the realm of SOCIO-BEE, environmental impacts have been recorded in terms of greater awareness of participants on urban air quality issues. Specifically, on average across the three pilots 81 percent of citizens have become more aware of air pollution issues through SOCIO-BEE, while 78 percent have declared their willingness to adopt a more pro-environmental behaviour. While the focus of these KPIs may be more on users' reported attitudes and views, but the recording of a well-rounded environmental impact would require information on actual behavioural changes and estimates of willingness to pay (accept) to improve (forego) urban environmental air quality.

- **Political impacts** refer to overall *decision-making improvement*, or may refer, more specifically, to the capacity to *increase citizen participation in civic-society*, and to the capability to *influence policies and institutions*.

KPI number	Description of KPI	Value reached
KPI 8.9	National institutions reached by the project	5 (in ZGZ)
KPI9.4	Meeting with European Institutions regarding the management of citizen initiatives	2
KPI9.6	Cities using SOCIO-BEE	3
KPI9.7	Institutional toolkit sent to local authorities	505

The SOCIO-BEE project enabled the involvement of public institutions, at different levels of authority, by engaging national and local authorities with project outcomes and the institutional toolkit.

As mentioned, some of the above benefits can be said to increase the *social capital* of a community.

Social capital can be defined as "features of social organization, such as a trust, norms, and networks, that can improve the efficiency of society by facilitating coordinated actions" [31]. So, it may be considered as an expression of trust. At the same time, though, it also expresses the society members' willingness to cooperate based on their interpersonal relationships and the value they attach to them. It can, then, be viewed as an all-encompassing factor that captures the effects of social networks in a determined geographic region [6,18,22].

Unfortunately, the quantitative assessment of this dimension may result far too complex to be feasible in any context; in fact, also the Institute for Social Capital recognises that there are numerous possible hindrances to a certain assessment of the social capital.[18] While those effects undoubtedly occur, it is difficult to quantify them convincingly and, subsequently, monetise them. That is so because social capital cannot be directly measured but it must be inferred using other indicators deemed to be connected to it (e.g., a steady decrease in crime rate). The difficulties are connected to:

1. The abstract nature of the concept of social capital itself. As Daly & Silver report, a degree of confusion is visible even among scholars, leading to multiple and ambiguous definitions [7], rendering it difficult to construct standardised measures for its assessment.
2. Linked to the previous point, there is a generalised lack of consensus on definitions. Different disciplines may adopt different conceptualisations.
3. Multidimensional and context dependent. The social capital composes itself of several dimensions (e.g., structural, cognitive and relational) and each one of them, by being difficult to be directly measured, must be inferred through other means. Additionally, by being context dependent, the effect of social capital may vary from case to case [9].

[18] https://www.socialcapitalresearch.com/measure-social-capital/

4. Often, studies on social capital rely on qualitative measures and self-reported data obtained through surveys and interviews, introducing biases on the data itself, and then hindering any subsequent analysis.
5. Since vast survey or interviewing campaigns are costly and time-consuming endeavours, the field often lacks the necessary data to conduct its studies.

To better convey the complexity of a correct estimation of social capital , while attempting to keep the explanation not too technical, we may go back to the example of the decreasing crime rate. In fact, the crime rate is considered to be inversely related to the amount of social capital (i.e. the crime rate lowers as the social capital increases), meaning that the improvement of social relations causes the people involved to not commit crimes. The problem is that the decrease may be also due to other factors, such as the ageing of population.

The problem of the indicators' covariance (i.e., the fact that they may vary due to different happenings than the project itself) is compounded by the social capital definition. As said above, the definition of social capital is a question by itself. As reported in a vast literature, the definition of social capital involves a vast amount of ambiguity [12,21,23,30], but even in case one is able to select a unique definition and bases research on it, further difficulties may arise.

Tracing back the present discussion to the SOCIO-BEE, and to similar projects, one should consider that indicators of social capital may vary due exogenous effects before varying thanks to the positive impact of the project. To give an example, the increased environmental sensibility may vary due to a generalised increase sensibility in the country (e.g., the news reports an alarming surge in respiratory diseases across the country; hence, the increased interest towards air pollution may – or may not – be caused by those news). In a situation like this, establishing the project's causal effect, and quantifying it, would require measuring environmental sensibility across the country and compare those results to those – measured in the same way – collected locally (e.g., in one of the pilots).

In a project such as SOCIO-BEE, which is voluntary in nature, there is also the problem of the so-called *self-selection*, meaning that that the people already more receptive to the topics of the project (i.e., environment, pollution, activism) are more likely to participate in it. To this phenomenon, the effect of *social homophily* must be considered as well. Social homophily entails the tendency of people to stick with similar people, meaning we (as humans) are generally attracted to those we deem similar to us [25]. The consequence is that the self-selection effect may result reinforced, since the first volunteers (already predisposed to environmental topics) may attract other people similarly interested, and further skewing the results of the analysis.

In this sense, since the sample of population involved in the project is so skewed towards environmental sensibility, any attempt at measuring effects may result either overestimated or underestimated. For example, when assessing the importance of such topics within the population, it may result that they are considered capital ones by them, but, since the sample does not represent the population at large, the assessment may overestimate the importance of the environment as a topic. On the other hand, when assessing the increased sensibility, it may result scarce to no effect, but this may be due to the fact that the involved population is already as sensitive as humanly possible to the problem; hence, undercutting the project's results.

Given how complex the analysis may easily result, often requiring technical knowledge in the fields of statistics and econometrics we suggest the local authorities to generally avoid attempting this kind of analyses and to focus to collect the data and the indicators to a future use while describing qualitatively or through the use of descriptive statistics and infographics. Obviously, any indicator (such as KPIs) may result relevant for future analyses.

6.4 Suggestions for future implementation

The SOCIO-BEE project proved to be an ambitious one trying to achieve several objectives at once, namely: developing a low cost, mobile sensors to analyse several air pollutants, integrate them with drones while having them be wearable and usable by common citizens. At the same time, the project aimed at involving said citizens in the activity of collecting data, either leveraging their existing environmental sensitivity or trying the reinvigorate their awareness in the attempt to improve their participation in the political decision-making process. The data collected should also be made openly available for future research or to public institutions interested in those. In fact, part of the project's aims was to actively integrate the data into the decision-making process of local authorities.

The sensors developed during the duration of SOCIO-BEE proved insufficient to the expectations of a rigorous scientific research, both on terms of quantity and quality. Obviously, that comes as expected since, during the project's runtime, the sensors had to be developed and, immediately after, people needed to learn how to use them properly. Despite the drawbacks in their implementation, the sensors can prove a valuable (and cost-effective) supporting toll for any municipality aiming at checking pollution in specific urban areas. This integration would help in collecting localised data but would also help in implementing traffic regulations. For example, as for the case of Berlin, the municipality could implement localised traffic speed limitations and check whether those limitations contribute at improving the local air pollution. Additionally, since municipalities may impose limitations on traffic circulation, when pollutants reach specific thresholds, the sensors may help in promptly identify the need to impose, or the possibility of lifting, those traffic bans.

As a final consideration, data are valuable dots of information, but it is hard to attach a unitary value to each record. It could be said that datasets are more than the mere sum of their parts, but more precisely data draw most of their value from their employment. So, for example, improving productivity, efficiency or the decision-making. With larger datasets and of higher quality, it could be possible attempting to assess the value of the data directly drawing from the outcomes stemming from the decisions made by using them. In doing so, it would be possible to further assess the degree of success of any project by considering the value of collecting (and then using) the data.

7 Conclusions

In the previous sections, the foundations for a CBA were laid out, aiming at favouring the replicability of the methodology implemented in the SOCIO-BEE project. Accordingly, the purpose of this document, aside to provide early guidelines to CS project assessment, is to lay the foundations for future discussions on what is the best course of action to take advantage of the available data and how to employ them to quantify the project's impacts.

To summarise our findings, the CBA is the technical process of linking several variables of interest to a monetary value in the attempt of quantifying the weight attributed to each of the elements by the decision process. It is not to be intended as a way to attribute a price to each of variables with the idea of trading any of them. The monetisation serves the scope of comparing thing of different nature with one another by having each of them measured through a common unit of measure.

The decision rule normally applied for CBA is that of NPV, meaning that the alternative obtaining the highest actualised outcome is the one to be favoured since it is the one obtaining both the best resource allocation (among the considered alternatives) and the highest increase in welfare. As stated above, the CBA is not directly concerned with redistributive justice, neither between income classes nor on an intergenerational basis.

Additional to the lack of distributive concerns, the CBA risks to leave outside its field of analysis also environmental impacts since, due to the concept of standing, those would be relevant only as long as at least one of the stakeholders has a quantifiable concern on the matter. That risks of aggravating the problems both of redistribution, since it risks unloading the worse of the problems on the poorer classes, and of intergenerational justice by postponing problems to the future and leaving the future generations to deal with them.

These may be hindrances to the adoption of CBA as analysis tool but, to a more attentive gaze, they may result in strengths. For once, by leaving outside the analysis redistribution and environmental concerns, this dimension is left to the political decisionmakers to decide. Then, if by the decisionmaker standards any of the topics left outside the analysis are of primary importance, then there is nothing in the analysis to prevent their consideration.

In preferring the "less allocative efficient" (i.e., the one with the lesser NPV), the decisionmakers can use the monetary evaluations to estimate the social cost of their option, meaning the value they associate to the right to choose one alternative over the other. Alternatively, when favouring the alternative with long-term effects (e.g., preserving the biodiversity) the monetary value can be considered as the option value of preserving the right to choose in the future.

The difficulties in correctly estimating sometimes the costs and often the benefits, together with the costs of conducting the analysis may also push for a simplified version of the CBA. In this case, the analyst might not provide a thorough monetisation of all the costs and benefits, and, while quantifying the costs, provide a more qualitative evaluation of the benefits stemming for the project. This consideration will, quite probably, be an interesting starting point to reach a sound and convincing characterization of the procedure to assess CS project by the tools of CBA.

In conclusion, the CBA despite appearing as a rigid decision rule, hungry for data, time, and resources, is to be considered as an adaptable tool capable of supplying the decisionmaker with an additional take on the available information, and adaptable according to the context in which both the analysis is conducted and the decisionmaker operates.

The final release of the present deliverable, drawing from the present work's theoretical, though simplified, overview on the matter, and by building on the comparison that D7.1 operated between the main estimation techniques to be found in the CS domain, further reinforced the choice of CBA as the preferrable alternative to CS's socio-economic impact assessment.

Deliverable D7.4, by also drawing from the previous work presented in deliverable D7.1, defined exactly the fields of inquiry for the SOCIO-BEE project by presenting an example of CBA applied to one of the pilots involved in the project. In doing so, the theories here presented saw application and the researchers gained valuable insights for the practical application of the method to CS projects. More specifically, pairing the availability of data and resources with the largely qualitative nature of SOCIO-BEE's impacts, the numerical example has been carried out by adapting the CBA methodology to that of a simplified approach to CBA, which consists in the computation of monetary costs and benefits, accompanied by qualitative considerations on non-monetary benefits and costs. In this last realm, the use of SOCIO-BEE KPIs has been instrumental.

As previously said, while computing the costs is not too burdensome of a task, it is often more complex to attach a monetary value to the outcomes when those are not measured by any market. Despite that, it is obvious that the project created the basis for future useful applications of the technology created and implemented (e.g., the sensors and the drones) and, despite some drawbacks, there is clearly room to effectively apply those and the data in the decision-making process of many municipalities. With the idea of providing an attempt to at least quantify part of the effects that are imputable to the new technologies and to the data created, we estimated cost savings from BETTAIR sensors compared to static ones, abstracting from considerations on data quality, and from the new drone solutions developed by ID2M. The vast majority of potential benefits do relate to non-quantifiable variables, which were presented with the help of KPIs. In this sense, the project exerted impacts on societal, business, technological, educational, research, environmental and political domains.

On addition to the potential impacts, the project showed how difficult it may result to encourage common people to participate in data-collection campaigns, but if these campaigns were to operate effects on public decision-making, and those effects were correctly advertised, more and more people would be encouraged to join.

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Appendix A: plug-in values for CBA

In the following table, a list of possible shadow prices for a number of car-accidents related injuries is presented. Obviously, many of the following variables are not directly related to SOCIO-BEE but they provide a useful idea of the monetary magnitude of injuries, that can be useful in the phase of estimating similar values. On the other hand, the papers provide the methodology that might be adapted for the necessities of the project.

Figure 1: Examples of shadow prices [source: Boardman et al. (2018)]

Category	Shadow price value	Comments
Value of statistical life (VSL)	$ 11 million for US	Based on Viscusi and Masterman (2017). Must adjust for income and risk level.
Value of a life-year (VLY)	$ 515.100 per person per year	Based on a VSL of $ 11 million, 40-year life expectancy, and a discount rate of 3.5%.
Monetary Injury costs		
1. Eventually fatal	$ 694.975 per injured person	Based on Rice, MacKenzie, and associates (1989). Includes monetary costs only, not pain and suffering.
2. Hospitalised (non-fatal)	$ 75.020 per injured person	
3. Non-hospitalised (non-fatal)	$1.131 per injured person	
4. Average cost of injury	$ 6.086 per injured person	
A. Motor vehicle injury	$ 19.817 per injured person	
B. Falls	$ 6.653 per injured person	
C. Firearm injuries	$ 117.909 per injured person	
D. Poisonings	$ 11.036 per injured person	
E. Fire injuries and burns	$ 5.663 per injured person	
F. Drowning and near drownings	$ 142.397 per injured person	
G. Other	$ 2.548 per injured person	
Cost of work-related occupational injuries		
A. Fatal injuries	$ 4,6 mln per injured worker	Based on Miller and Galbraith (1995). Includes quality of life losses
B. Non-fatal injury with compensable lost work	$ 2.943 per injured worker	
C. Non-fatal injury with worker non-compensable lost work	$ 1.218 per injured worker	
D. Non-fatal injury, no lost work	$ 2.274 per injured worker	
E. Average injury cost	$ 23.454 per injured worker	
F. Average motor vehicle work-related injury cost	$ 137.949 per injured worker	

Value of one year of work impairment due to injury	$ 178.586 - $ 277.510 per year	Based on Dilinmgham, Miller, and Levy (1996)
Category	**Shadow price value**	**Comments**
Social cost of motor vehicle crash injuries		
1. Spinal cord	$ 3,9 million per victim	Based on Zaloshnja, Miller, Romano, and Spicer (2004). All means are arithmetic and so not reflect the distribution of injury severity within each body region.
2. Brain	$ 1,56 million per victim	
3. Lower extremity	$ 0,61 million per victim	
4. Upper extremity	$ 0,20 million per victim	
5. Trunk/abdomen	$ 0,38 million per victim	
6. Other face, head, or neck	$ 0,51 million per victim	
7. Minor external	$ 0,01 million per victim	
8. Burn	$ 0,71 million per victim	
Motor vehicle accidents costs		
PDO (property damage only)	$ 3.511 per vehicle	Based on Blincoe et al. (2002). Figures reflect per-person costs related to motor vehicle accidents of varying severity. AIS (Abbreviated Injury Scale)
AIS1 (Abbreviated Injury Scale)	$ 20.812 per injured person	
AIS2	$ 218.879 per injured person	
AIS4	$ 435.391 per injured person	
AIS4	$ 1.013.750 per injured person	
AIS5	$ 3.329.831 per injured person	
AIS6 (fatal)	$ 4.664.800 per fatality	

Figure 2: Social cost of air pollutants (in US$ 2016) [source: Matthew and Leave (2000)]

CATEGORY	# of studies	Min	Median	Mean	Max
Carbon monoxide (CO)	2	2	890	890	1.796
Nitrogen oxides (NO_x)	9	3776	1.813	4.790	6.251
Sulfur dioxide (SO_2)	10	1.317	3.079	3.421	8.040
Particulate Matter (PM_{10})	12	1.625	4.790	7.356	7.713
Volatile organic compounded (VOC)	5	274	2.395	2.737	7.527
Global warming potential (in CO_2 equivalents)	44	3	24	22	39

Appendix B: list of relevant KERs from SOCIO-BEE

The table below provides a connection between the KERs of the SOCIO-BEE project and the KPIs measured during the project's implementation. This linkage serves to demonstrate how the various tools and innovations developed within SOCIO-BEE contribute to its broader objectives, and how they can be assessed in terms of cost-benefit analysis. Each KER is associated with relevant KPIs that measure its effectiveness, adoption, and impact across different dimensions (societal, environmental, educational, and technological).

For example, tools like the **Micro-volunteering Recommendation Engine (MVRE)** and **SOCIO-BEE Mobile App** are assessed by KPIs such as **citizen engagement** (KPI 8.8) and **technology acceptance** (KPI 3.2), which reflect their success in mobilizing large numbers of citizens to participate in air quality monitoring. Similarly, the **CAPE tool** is evaluated by the **number of hypotheses tested** (KPI 5.2) and **adoption rate** (KPI 4.3), highlighting its role in advancing data-driven urban pollution insights.

Key Exploitable Result	KPI	KPI Value	Type of Impact	Explanation
1. Co-creation and Campaign Blueprints Tool	**KPI 5.3**: Number of blueprints and templates for reducing air pollution in cities	Total = 6 templates	Environmental, Societal	Shows how many actionable blueprints have been created to guide cities in pollution reduction.
	KPI 8.4: Societal groups involved	Total = 14	Societal	Reflects the engagement of societal groups through the co-creation process, leading to wider participation.
2. Micro-volunteering Recommendation Engine (MVRE)	**KPI 8.8:** Citizens using the microvolunteering app	Total = 302	Societal	Highlights the engagement of citizens using the tool.
	KPI 3.2: Technology acceptance rate	Average = 78%	Technological, Societal	Measures how well citizens accept and integrate the MVRE into their participation in citizen science.
		Average = 64%	Technological	Indicates how well the MVRE fits into

	KPI 3.3: Perceived usability score			the users' everyday lives.
3. CAPE (City Pollution, Citizen Exposure and Profiling Tool)	**KPI 4.3**: Accessibility and adoption rate of intelligence-supporting tools	Average = 78%	Technological, Environmental	Shows the adoption of the tool measuring its accessibility.
	KPI 5.2: Number of hypotheses or what-if scenarios tested	Total = 20 hypotheses	Scientific, Environmental	Reflects the CAPE tool's use in testing hypotheses related to air pollution.
	KPI 8.7: Citizens actively collecting air quality data via wearables	Total = 302	Societal, Environmental	Measures the participation of citizens in providing pollution data.
4. Bee-MATE Audiovisual Crowdsourcing Tool	**KPI 8.7b:** Citizens collecting multimedia data on pollution sources	Total = 302	Societal, Environmental	Highlights the engagement of citizens in reporting pollution sources via audiovisual data collection.
	KPI 8.3: Working Bees involved by pilot and iteration	Total = 302	Societal	Shows the level of engagement.
5. Wearable Device for Air Quality Measurements	**KPI 2.3**: Number of wearable devices produced	Total = 160 devices	Technological, Environmental	The production output of wearable devices for air quality monitoring.
	KPI 8.7: Citizens collecting air quality data via wearables	Total = 302	Societal, Environmental	Shows the effectiveness of wearable devices in citizen engagement and pollution monitoring.
6. SOCIO-BEE Engagement and CS	**KPI 8.1:** Queen Bees recruited	Total = 10	Societal	Reflects the success of SECM in engaging

Implementation Methodology (SECM)				community leaders to lead citizen science projects.
	KPI 8.2: Bears involved	Total = 9	Societal	Measures the engagement of organization and institutions engaged that were interested in using the generated data.
	KPI 8.4: Societal groups involved	Total = 14	Societal	Demonstrates the methodology's success in involving a diverse range of societal groups in citizen science activities.
	KPI 12.2: Intention to be involved in new citizen science projects	Average = 68%	Societal, Educational	Reflects SECM's ability to inspire future participation in citizen science initiatives.
7. SOCIO-BEE Guidelines for CS Evaluation (GECS)	**KPI 9.7:** Institutional toolkit sent to local authorities	Total = 25	Institutional	Indicates the dissemination and potential adoption of the SOCIO-BEE guidelines by local authorities for project evaluation.
8. SOCIO-BEE Mobile App	**KPI 8.8**: Citizens using the microvolunteering app to gather measurements	Total = 302	Technological, Societal	Measures the app's success in enabling citizen participation in air quality data collection.
	KPI 3.2a: User satisfaction with SOCIO-BEE (AcadeMe) platform	Average = 75%	Technological, Societal	Demonstrates the level of satisfaction and user appreciation

				for the SOCIO-BEE mobile app.
	KPI 12.1: Increased interest or engagement in science project	Average = 64%	Educational, Societal	Reflects the mobile app's role in fostering greater engagement in science through air quality campaigns.
	KPI 8.7: Citizens collecting air quality data via wearables	Total = 302	Environmental, Societal	Shows the role of the app in enabling real-time, wearable device-driven air quality data collection.

Appendix C: MRSI's local impact assessment and contribution

In evaluating the impact of Citizen Science (CS) projects implemented by local authorities / municipalities, it is essential to undertake a comprehensive cost-benefit analysis that delves into various aspects/dimensions of these initiatives. From economic benefits and environmental impact to scientific discoveries and public engagement, CS projects and in particular those focusing in fostering pro-environmental actions like SOCIO-BEE can generate a wide range of outcomes. These outcomes could impact not only the local authorities but also the public and the environment, supporting actively the One Health approach, towards balancing, protecting and optimising in an integrated and holistic manner the health of human beings, animals and the environment as they are interdependent and bound to each other. To accurately assess the effectiveness and value of such projects, we have defined key subcategories and corresponding Key Performance Indicators (KPIs) that offer a structured approach to evaluating their impact.

The KPIs, by being collected since the beginning of the project, might be useful in quantifying some of the phenomenon's aspect that would otherwise be impossible to assess. Through the thoroughness of the aspects they inquire and the time-span they cover, they can surely help in forming an idea of the project evolution. So, they will not only help in understanding the cost-efficiency and resource requirements but also in quantifying the broader benefits CS projects bring to society, to the environment, and to wider scientific advancement. MRSI, as a pilot partner and end-user of the SOCIO-BEE toolkit, can significantly contribute towards this direction by providing their expertise, data, and insights.

Thus, MRSI foresees that the CBA should encompass all the following sub-categories. To complement CBA insights, specific Key Performance Indicators (KPIs) can be defined for each one of these areas.

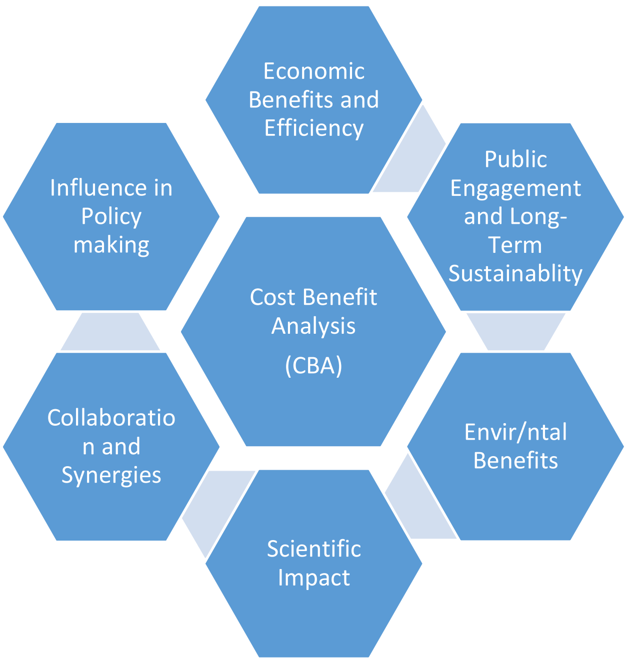

Figure 3 Main aspects / dimensions to be covered in the Cost Benefit Analysis framework for Citizen Science projects implemented by local authorities / municipalities.

Economic Benefits and Efficiency

- Expected Cost: Consider and make an estimation of various types of resources required for the successful implementation of a CS project, including financial resources (equipment, technology, staff, etc.), human resources (employees, trainers, volunteers, researchers, etc.) technological resources (technologies, platforms, etc.), time and effort (invested in planning, recruiting volunteers, execution and post campaign activities)
- Comparative analysis: Estimate the amount required by utilizing CS data compared to traditional data collection methods.

Public Engagement and Long-Term Sustainability

- Citizen engagement and public awareness: MRSI can actively participate in data collection efforts to measure the level of community involvement and interaction within CS projects (number of hives, number of volunteers in total and per hive or per role, through tracking adoption of SOCIO-BEE's Mobile App, the percentage of recommendations accepted, etc.) and assess the increase in awareness about environmental or scientific issues and in particular for SOCIO-BEE project about air pollution among EU citizens (via surveys, perform self-assessment tests to measure the percentage increase in participants' correct responses to air pollution-related questions before and after their participation, etc.)
- Long-term sustainability: MRSI could measure the sustained engagement (number of participants active, level of their activity via data provided in the Academe platform, acquired data etc.)
- Scaling Potential: MRSI could investigate the potential for scaling the CS project to other municipalities within Athens capital.
- Inclusivity: MRSI can provide quantitative data on engagement rates by pilot iteration and inclusivity within their pilot area, by sharing qualitative insights on their observations of different societal groups' involvement (the gender balance, age distribution, educational level, occupational status, etc.)
- Communication: MRSI can contribute to communication KPIs by providing data on the number of local workshops, webinars, and events, the respective number of attendees, number of visitors and reactions to SOCIO-BEE's web portals and social media channels, etc.

Environmental Benefits

- Behavioural change: With the support of the rest of the consortium partners, possible MRSI could analyse whether CS participation leads to behavioural changes in the community, such as reduced usage of private vehicles, and other.
- Policy Influence: MRSI could assume of the foreseen impact to the environment a potential future project, influenced from CS results, could have.

Scientific Impact

- Research Publications: MRSI could measure the number of research publications, contributions to conferences or citations from CS project data, and in SOCIO-BEE case from the colocation activities and the measuring campaigns.
- Participants perception: MRSI can administer surveys and assessments to gauge changes in participants' scientific literacy, attitudes toward science, and their interest in science as a career. They can share the results of these assessments and provide insights into the impact of SOCIO-

BEE on participants' scientific literacy. For example, MRSI can report on how participants' attitudes and interests in science have evolved.

- Data quality and quantity: MRSI can evaluate the quantity of data collected through the CS initiative, while with the support of the consortium partners it could assess also the quality of data collected by participants in CS projects and participate in efforts for any improvements.

Collaboration and Synergies

- Synergies: MRSI can document and report on the creation of new collaboration opportunities and synergies within their pilot region. They can provide information on collaborative efforts, partnerships, and collaborations with local organizations, other EU projects, experts, local businesses, etc.

Influence in policy making

- Assessment of Policy Influence: As a pilot partner, MRSI can offer qualitative insights into how SOCIO-BEE's activities may influence policy changes and raised awareness in their local context.

Therefore, by actively participating in information and data collection, providing real-world examples and insights, and contributing to surveys and assessments, MRSI can play a vital role in assessing the impact of the SOCIO-BEE project through the aforementioned KPIs. MRSI's involvement in these areas will enhance the overall evaluation of the project's benefits and costs as described also in T7.2.

Appendix D: Monetary costs estimates

1. Wearable Sensor Network – Full estimates of costs

Table 6 - Estimated development and maintenance costs for SOCIO-BEE's WSN.

Development costs	**(€)**
Personnel cost	**158.953,72**
Total WSN cost	**69.820**
Sensor module board	*30.464*
Main Board	*12.640*
Case	*26.716*
Total development costs	**228.773,72**

Expected costs	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
(Estimated) future maintenance cost	*9.982*										
Cloud/Data storage	*600*										
Personnel	*4.223*										
Total yearly maintenance	**14.805**	**14.805**	**14.805**	**14.805**	**14.805**	**14.805**	**14.805**	**14.805**	**14.805**	**14.805**	**14.805**
Discount factor	*1*	*1,03*	*1,06*	*1,09*	*1,13*	*1,16*	*1,19*	*1,23*	*1,27*	*1,30*	*1,34*
Discounted cash flow for future maintenance costs	14.805	14.373,79	13.955,13	13.548,67	13.154,05	12.770,92	12.398,95	12.037,82	11.687,20	11.346,80	11.016,31

Total maintenance cost in expected future	**141.094,65**

2. Drone campaigns – Full estimates of costs

MRSI campaign drone measurements[19]

MRSI	**14420**
Drone purchase (DJI Mavic 3)	*1.949*
Drone purchase (DJI Mavic 30)	*6.647*
Batteries cost	*5.824*
Volunteer opportunity costs	*2,34*
Drone clip	*50*
Total costs	**14.472,34**

Drone maintenance costs

Drone maintenance (DJI Care Pro)	**239**

Drone clip: development costs

Personnel costs	*700*
Drone clip materials and printing	*50*
Development costs	**700**

[19] Costs are referred to the actual costs needed to carry out the campaign in MRSI, using the same types of drones, and batteries. Personnel costs are obtained as opportunity costs for volunteers, by exploiting the number of obtained data points, the time per measurement and the average hourly wage in MRSI (Eurostat, 2023).

Light-weight drone: development costs

Cost category	Price (euros including VAT)
Frame	4,5
Engine	71,8
ESC	40,59
FC	76,9
Propeller	2,9
Radio receiver	21,9
GPS	24,9
Battery	17,81
Sensor	300
Total component costs	**561,3**

Appendix E: Monetary benefits estimates

1. Value of data in MRSI pilot estimation: cost approach

Cost category	**(€)**
Personnel cost (beekeepers)	*53.178,00*
Communication costs	*5.655,00*
Cost of sensors (at purchase value)	*42.000,00*
Volunteers opportunity cost	*868,17*
Ratio of working age volunteers	0,76
Average hourly wage	5,55
Hours of volunteering	206,33
Number of data points collected	*1.132,00*
Cost per unit of data	**89,84**