Guidance report on a multi-tiered flexible methodology for integrating social, economic and biophysical methods

Deliverable D3.4

Guidance report on a multi-tiered flexible methodology for integrating social, economic and biophysical methods

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ESMERALDA

Enhancing ecosystem services mapping for policy and decision making

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Preface

Mapping and assessment of ecosystems and their services (ES) are core components of the EU Biodiversity (BD) Strategy. They are essential if we are to make informed decisions. Action 5 sets the requirement for an EU-wide knowledge base designed to be: a primary data source for developing Europe's green infrastructure; resource to identify areas for ecosystem restoration; and, a baseline against which the goal of 'no net loss of BD and ES' can be evaluated.

In response to these requirements, ESMERALDA (Enhancing ecoSysteM sERvices mApping for poLicy and Decision mAking) aims to deliver a flexible methodology to provide the building blocks for pan-European and regional assessments. The work will ensure the timely delivery to EU member states in relation to Action 5 of the BD Strategy, supporting the needs of assessments in relation to the requirements for planning, agriculture, climate, water and nature policy. This methodology will build on existing ES projects and databases (e.g. MAES, OpenNESS, OPERAs, national studies), the Millennium Assessment (MA) and TEEB. ESMERALDA will identify relevant stakeholders and take stock of their requirements at EU, national and regional levels.

The objective of ESMERALDA is to share experience through an active process of dialogue and knowledge co-creation that will enable participants to achieve the Action 5 aims. The flexible methodology proposes to integrate biophysical, social and economic mapping and assessment methods. ESMERALDA is organized based on six work packages, which are organised through four strands, namely policy, research, application and networking, which reflect the main objectives of the project (Figure 1).

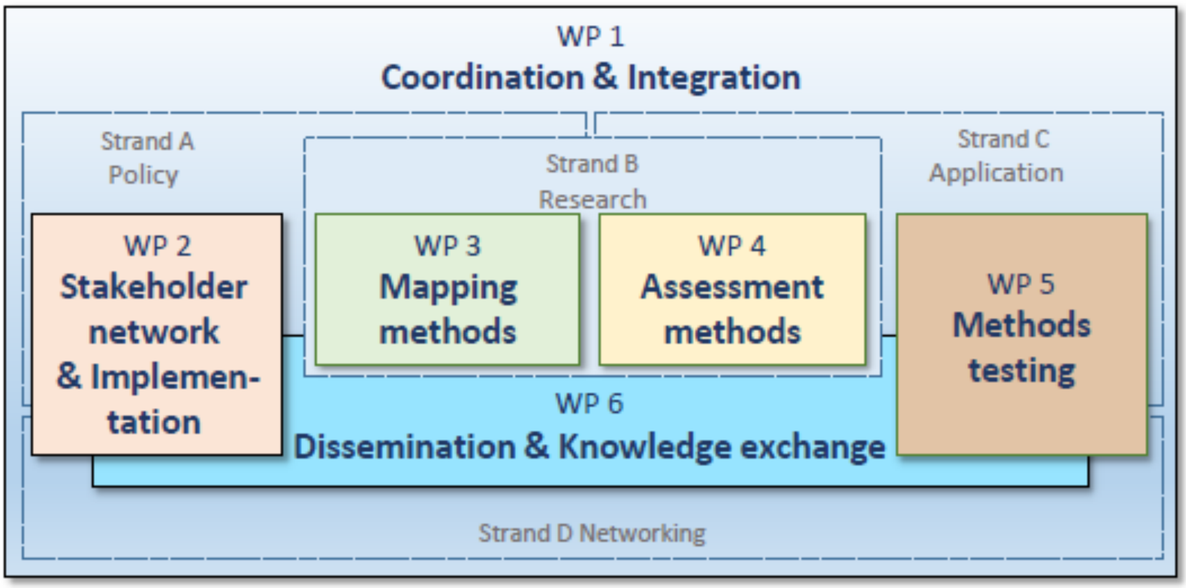


Figure 1: ESMERALDA components and their interrelations and integration within the four project strands.

This report sits within work packages WP3 "Mapping methods" and WP4 "Assessment Methods". The key message here is as follows: in the best case, all categories of social, economic and biophysical methods are interlinked and can be integrated, depending on the policy question they try to answer. This report brings the individual deliverables on social (D3.1), economic (D3.2) and biophysical (D3.3) mapping and assessment methods together, underlining the need for integration among methods defined by disciplinary boundaries. Additionally, Deliverable 4.8 (Potschin-Young (ed), 2018a) provides guidance on an integrated assessment framework for ecosystem services. Together, all these deliverables address the challenge of improving the applicability of these approaches and are illustrated with specific examples, particularly with respect to the MAES process and the ESMERALDA case studies.

The methods-oriented Deliverables from ESMERALDA Work Packages 3 and 4 make up the largest block within the ESMERALDA MAES Explorer[1]. The open access online ESMERALDA MAES Explorer brings together and cross-links all ESMERALDA products such as reports, methods and case study documentations and open access publications. The overall aim is to provide guidance on ecosystem service mapping and assessment for stakeholders from science, policy and society in EU member states along a systematic 7-step MAES cycle. Step 4 is the 'mapping and assessment process' block providing the technical/methodological core of MAES.

The work done under this deliverable contributed to the following publications (title pages including abstracts are to be found in Appendix 1):

Potschin-Young, M.; Burkhard, B.; Czúcz, B. and F. Santos-Martín (2018): Glossary of ecosystem services mapping and assessment terminology. OneEcosystem 3: e27110…. https://doi.org/10.3897/oneeco.3.e27110

Santos-Martín, F.; Viinikka, A.; Monomen, L.; Brander, L.; Vihervaara, P.; Liekens, I. and M. Potschin-Young (2018): Creating an operational database for Ecosystems Services Mapping and Assessment Methods. One Ecosystem 3: e26719 doi: https://doi.org/10.3897/oneeco.3.e26719

Summary

This report provides guidance on how social, biophysical and economic methods can be interlinked and integrated within ecosystem service mapping and assessment studies. The ESMERALDA framework for an integrated ecosystem assessment (Brown et al., 2018) was developed to provide assessment practitioners and decision makers with a framework that enables them to flexibly bring together different activities of existing ecosystem assessment approaches in an integrative way. The level and extent of integration is at the users' discretion according to the level of data, time and resources they have available. Beyond the biophysical parameters at the core of the framework, emphasis is given to the inclusion of

[1] http://www.maes-explorer.eu/

social and economic factors to ensure policy relevance. Furthermore, the ESMERALDA integrated ecosystem service assessment framework places at its heart key mapping activities around ecosystem services, which are fundamental to the work of MAES as well as ESMERALDA. The framework places the spatial element of analysis within the wider landscape of activities, which are undertaken within an ecosystem assessment. See Potschin-Young (Ed., 2018a) for the development and examples of testing the framework.

Further to this conceptual framework, this report provides guidance on how to link mapping and assessment methods and how to integrate results from different methods. In an ecosystem service mapping and assessment study, it is generally necessary to combine the results from one method to another in a sequence of steps to answer a specific policy question. The output from one method is therefore an input into the next method along the assessment chain. In this sense, methods defined by disciplinary boundaries are complements rather than substitutes in providing information on the importance of ecosystem services in decision-making.

The combination of biophysical, economic and social methods along the assessment chain is what we mean by *interlinking methods,* i.e. that the outputs of one method are used as inputs into another method. A mapping or assessment application may involve several linked steps using multiple methods to produce a final map or other information that is presented to decision makers. This report provides specific guidance on how to link methods for mapping and assessing ecosystem services.

In addition to linking methods in a knowledge production process to produce policy-relevant information, there may be a need to integrate separate outputs from biophysical, economic and social mapping and assessment applications. By *integration* we mean the combination of complementary pieces of information that address different aspects of an ecosystem service (e.g. sustainability, value and distribution) to support decision making. In the context of complex decision, a number of frameworks and approaches have been developed for structuring the information and factors that are relevant to a specific decision. Moreover, these methods help to reveal the synergies and trade-offs between different effects and dimensions. The choice of method for integrating information will largely be determined by the type of research or decision problem as well as the availability and nature of information. This report provides guidance on the currently available methods for integrating information from mapping and assessment methods to help decision makers to structure the information and factors that are relevant to a decision.

In this report, we provide practical guidance on interlinking methods for mapping and assessing ecosystem services and on the methods that can be used for integrating information from different sources. Examples used in this report are inspired by the case studies of the ESMERALDA database (Santos-Martin et al., 2018) as well as additional cases that demonstrate the nature of these methods. This report on interlinking mapping and assessment methods and methods for integrating information contributes to the development of ESMERALDA main objective to develop a flexible methodology for mapping and assessment activities in the EU.

1. Introduction: from an integrated assessment framework to a methods integration approach

The ESMERALDA integrated assessment framework (Brown et al., 2018) provides the conceptual basis for the development of guidance on interlinking methods and methods for integrating information from multiple sources. We begin here with an introduction of the ESMERALDA integrated assessment framework followed by an introduction to the practical challenges of linking methods and integrating information in mapping and assessment studies.

1.1. The ESMERALDA integrated assessment framework

Taking into account the multiple dimensions associated with the supply of and demand for ecosystem services (TEEB, 2010; Gómez-Baggethun et al., 2015), ESMERALDA supports the idea that any assessment of ecosystem services requires an integrated ecosystem assessment framework that considers all three dimensions and different types of mapping and assessment approaches. See Brown et al. (2018) and Potschin-Young (Ed., 2018a) for details on the debate. In particular, an integrated ecosystem assessment framework should offer a clear idea about the interdependencies between the multiple dimensions associated with different ecosystem services. For example, the biophysical dimension, i.e. an ecosystem's capacity to supply services, determines the range of potential uses by society, which also influences its social and economic values. Social values might also have an influence on economic values because ethical and moral motivations determine the 'utility' that a person obtains from a particular service (Martín-López et al., 2012). These interdependencies between assessment dimensions and the different information provided by them justify the need to link biophysical, social and economic methods and to integrate the information they produce to properly inform the environmental decision-making process (Santos-Martín et al., 2017).

ESMERALDA's 'Integrated Ecosystem Assessment' (IEA) framework (**Figure 2**) was designed to give the user flexibility as to when, where and to what extent they use integrated methodologies in their assessments. Due to its link to MAES (Burkhard et al., 2018) the IEA framework places mapping ecosystem condition and ecosystem services at the core of its integration, however extensions to this core aim to encompass other social and economic processes. An understanding of how users interpret and determine integration has been crucial in the development of the final framework (see Potschin-Young (Ed.), 2018a).

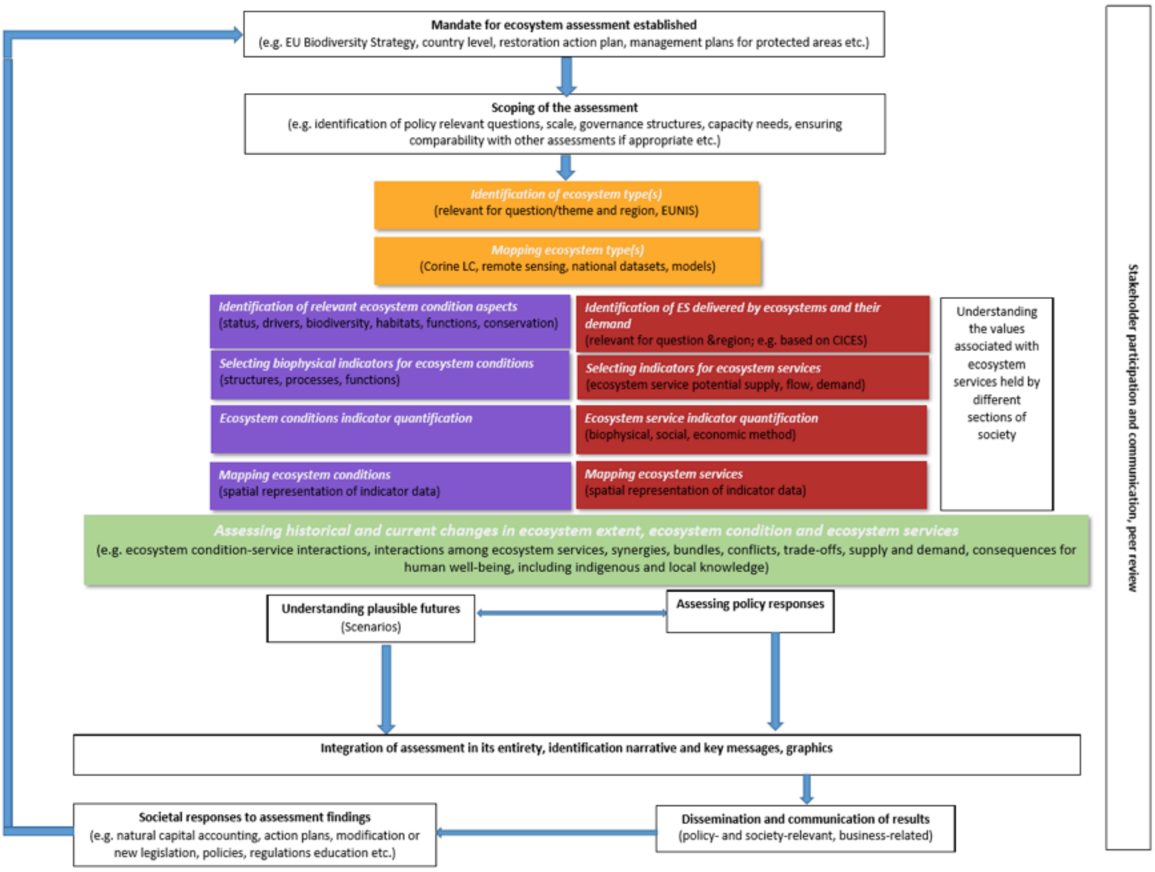


Figure 2. ESMERALDA Integrated Assessment Framework. Source: Brown et al. (2018), Potschin-Young (Ed., 2018a)

In addition to the ESMERALDA integrated assessment framework, the terminology for various types of data, models and methods has been clarified within ESMERALDA (Potschin-Young et al., 2018). The organization of the plural terminology that is used in ecosystem service literature was arranged in a logical framework by Vihervaara et al. (2018) (**Figure 3**). The mixture of terms was divided in three main categories of assessment, data and mapping, and decision-support. Inside those main themes, terms were grouped in more detailed classes. Direct and indirect measurement can produce data, indicators or indices that can either feed into models, methods and integrated modelling frameworks, or to decision support frameworks (directly or via other methods). After that the integrated information can be used in wider ecosystem assessment processes that can have different aims, for instance, reporting for policy targets, or detecting status and trends of ecosystems. Finally, this loop from data to methods and decision-support tools can be repeated for new mapping and assessment studies.

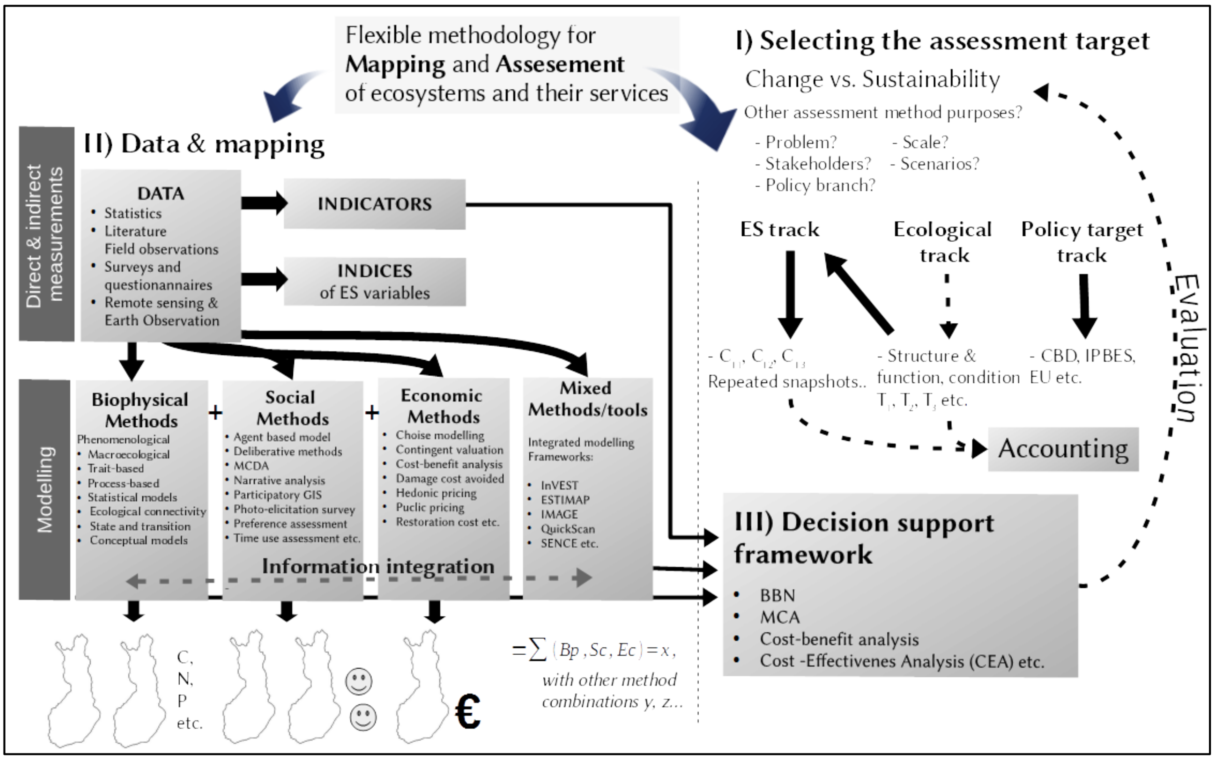


Figure 3. Data flow and information integration through method classes to support decision-making. Integrated assessment Framework. Source: Vihervaara et al. (2018)

1.2. Interlinking methods and methods for integrating information

On the basis of the conceptual frameworks introduced above, this report develops guidance on how to link mapping and assessment methods that address different aspects of ecosystem service provision and value (and are based in different disciplinary fields) and what methods are available for integrating information representing multiple dimensions and factors relevant to an assessment.

Methods for mapping and assessing ecosystems and the services they provide can be classified into three general groups: biophysical, economic and social. Biophysical methods describe how ecosystems contribute to the supply of services to society (Vihervaara et al., 2018), while economic (Brander et al., 2018) and social (Santos-Martín et al., 2018) methods both examine the relative importance of ecosystem services (ES) to people, thus reflecting the demand side of ES. Additionally, social methods are distinguished from economic ones, because they do not express value in monetary terms (de Groot et al., 2010;) and apply a broader conceptualisation of the value of ecosystems services (Maes et al., 2013). These three groups of methods and the types of information they produce are represented in **Figure 4**. In general, biophysical methods report physical units of ecosystem supply; economic methods report values for ecosystem service use in monetary units; and social methods report qualitative measures of ecosystem service value. These outputs can be reported separately or jointly to directly inform decision-making.

In the context of complex decision-making, the informational inputs from different sources can be many and diverse in terms of units, scale, timing etc. Dealing with multiple types of information in complex decision making can be aided by the use of methods and frameworks for structuring and combining the information and factors that are relevant to the decision. This is what is meant by “methods for integrating information”. Methods for integrating different types of information are represented in the lower part of **Figure 4**. The choice of which integrating method to use will largely be determined by the type of research or decision problem as well as the availability and nature of information. In this report we describe the available methods for integrating information from mapping and assessment studies and provide guidance on the selection of appropriate integrating methods.

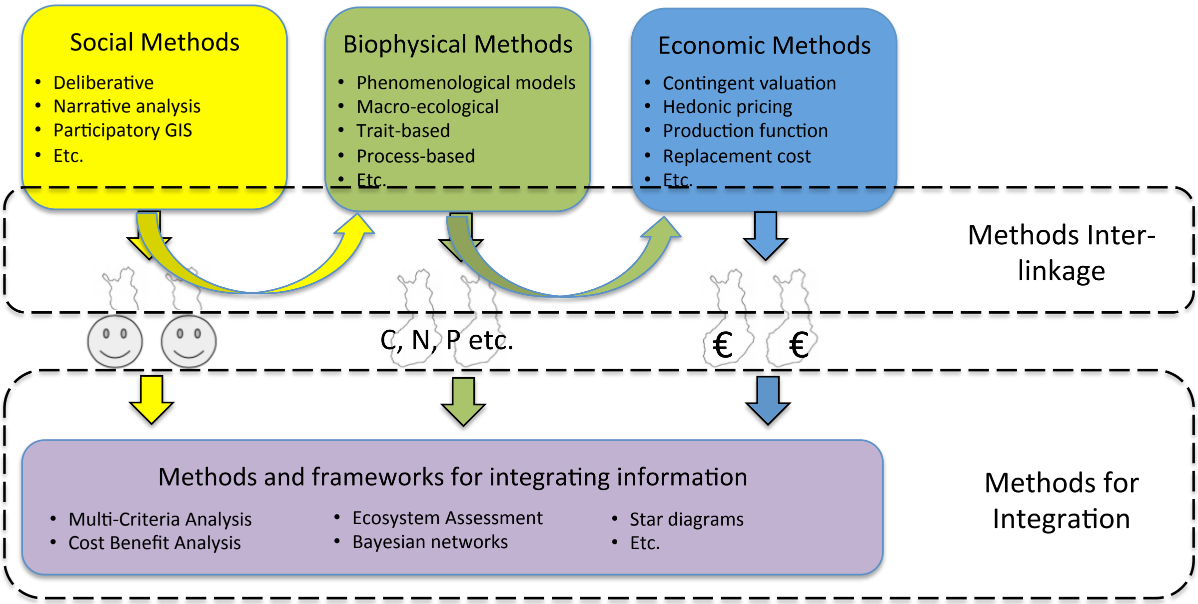


Figure 4. Graphical representation of the definitions of methods interlinkage and methods integration used in ESMERALDA.

It is also the case that informational output from one method is used as input into another method to produce the information that is finally reported to decision makers, i.e. methods are linked together in a knowledge production process to produce policy relevant information. This is represented in Figure 4 by the arrows between method groups. In practice the flow of information between methods can be multi-directional and involve many steps along the path to a final information output that is reported/disseminated. This is what is meant by “interlinking methods”. In the following section we provide guidance on how to interlink methods in a mapping and assessment study.

2. Classification methods integration using a tiered approach

2.1. Conceptual framework for methods integration based on a tiered approach

In Figure 5 we describe how different methodological approaches can be used in ecosystem service mapping and assessment to intergrade information from biophysical, social and economic dimensions. The integration of knowledge will be reached through three main alternatives: 1) Interlinking methods and information, 2) Integrated modelling methods, 3) Linking and Integrating modelling methods (Figure 5). The challenges and possibilities to select each of these alternatives or combinations of several of them will be discussed in the following sections. Each of these alternatives will be also demonstrated by real world examples. In addition, it will be presented how to choose the appropriate methods integration based on a tier approach tiers. Finally, it will be discussed how these alternatives options can be linked to overall ecosystem assessments and policy questions with the aim to operationalize methods integration for policy and decision-support contexts.

Tier 1 involves linking methods from social, biophysical and economic method domains. This implies that information from one method domain is used in the calculation of values in the other method domain, without internal feedbacks build in the procedure. The outcomes of tier 1 methods are of one domain only. A classical example of a tier 1 method in which two domains are linked is the calculation of the coastal protection value of mangrove ecosystems, where various types of biophysical information are used (e.g. area size, mangrove species) to estimate the value of the avoided storm damage resulting from healthy mangrove systems. Typical policy questions linked to tier 1 include, for example, whether nature-based solutions such as mangrove restoration is a cost-effective measure in the context of adaptation to climate change.

Tier 2 involves integrating methods from social, biophysical and economic method domains. This implies that information from two of more method domains are combined to make well-informed decisions in the ecosystem services context. For example, Multi-Criteria Analysis (MCA) often combines economic, social, environmental and institutional information in ranking various alternatives. These various domains generate variables in different units which through weighted summation are aggregated in a final score. An example of a policy question of tier 2 methods is the ranking of various future landscapes representing a varying degree of nature-based policies, which generate different levels of social benefits (e.g. employment), economic benefits (e.g. financial revenues), and environmental benefits (e.g. biodiversity).

Tier 3 involves linking and integrating methods from social, biophysical and economic method domains, which implies not only the combination of two or more domains in the final outcome, but also the mutual linking of information from these domains underlying the tier 3 method. A typical example of tier 3 method is the extended cost-benefit analysis (CBA) based on ecological-economic models in which ecological processes and economic mechanisms are mutually linked. Feedbacks between ecosystems and the economy occur in both directions. A policy question that requires tier 3 methods is for example the question what kind of measures and policies are most effective in avoiding further decline of coral reef ecosystems in which both financial costs (e.g. coral reef restoration costs) and social and environmental benefits (e.g. cultural values, fish abundance) are strongly interrelated.

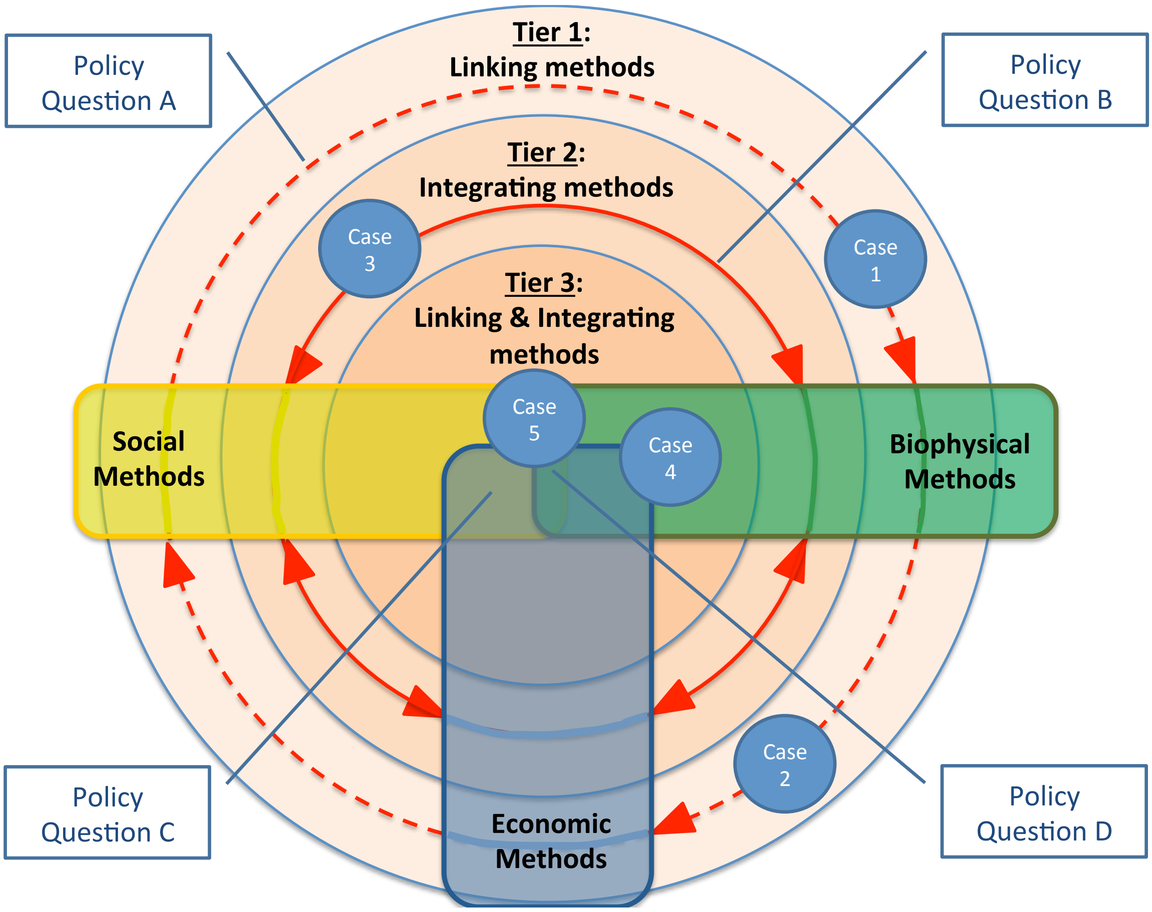


Figure 5. Conceptual framework for linking and integrating social, biophysical and economic methods for the purpose of mapping and assessing ecosystem services based on a tier approach.

2.1. Guidance to choose the appropriate methods integration based on a tier approach

Choosing the right level of detail for mapping and assessment of ecosystem services is crucial in order to provide information that is useful and supports decision-making. Choosing the appropriate tier level means avoiding the application of over-complex methods as well as over-simplified methods and thus increases the efficiency of ecosystem service mapping and assessment (**Figure 6**). The approach is illustrated in the 'Ecosystem Services Mapping Handbook' (Grêt-Regamey et al., 2017) in detail. The required tier level and the requirements are defined according to the purpose of the assessment: If a rough overview is sufficient, a tier 1 approach is suitable. This is often the case at the beginning of a decision-making process or for larger areas where no previous information (especially quantitatively) about ecosystem services is available. If the purpose requires a more detailed understanding of ecosystem services, for example focusing on trade-offs and impacts of different scenarios, a tier 2 approach is suitable. Finally, a very detailed tier 3 approach is required to evaluate the impact of explicit measures on different aspects of socio-ecological systems for example that allows considering interactions and feedbacks. The increasing level of detail from tier 1 to tier 3 usually goes along with and finer resolution and either more detailed datasets or models that are more detailed. Details about how the tiered approach can be adapted to social, biophysical and economic mapping and assessment are presented in the respective deliverables.

The understanding of system dynamics, i.e. the feedbacks of biophysical and / or socio-ecological processes usually requires the interlinkage of methods also described as a combination of linking and modelling integrating methods. Such approaches are suitable to adequately consider various aspects of human-environment systems, including social, economic and biophysical aspects and their mutual interlinkages, dependencies and feedback loops. Usually, this is associated with complex modelling approaches, which require quite some experience. This is however not always needed, in contrary; the modelling efforts are minimized if very detailed information is available. This could be a fine-scaled data that combines information about social, economic and biophysical aspects. As an example, one could think of cadastral information about housing, inhabitants, costs and amount of green space. To summarize, the linking and integration of methods can be either through model-based or data-based approaches. Social, economic and biophysical aspects can also be considered separately or sequentially (i.e., step by step) through a simple linking of methods in a tier 1 approach which is sufficient to provide an overview and does not require further expertise in all of these fields. However, making the various services provided by nature explicit is seen as a major strength of the ecosystem services concept. Thus, for an analysis which goes beyond a first overview, the proper integration of methods in a tier 2 approach is often needed. The appropriate interlinkage and integration of methods is however very challenging and linking methods of different tier levels can introduce uncertainty and potentially lower the quality of the information provided (e.g., linking an economic valuation of tier 1 to a biophysical approach of tier 2). Ultimately, it is essential that the interlinkage and integration of methods consider the appropriate tier at each step of the mapping and assessment process.

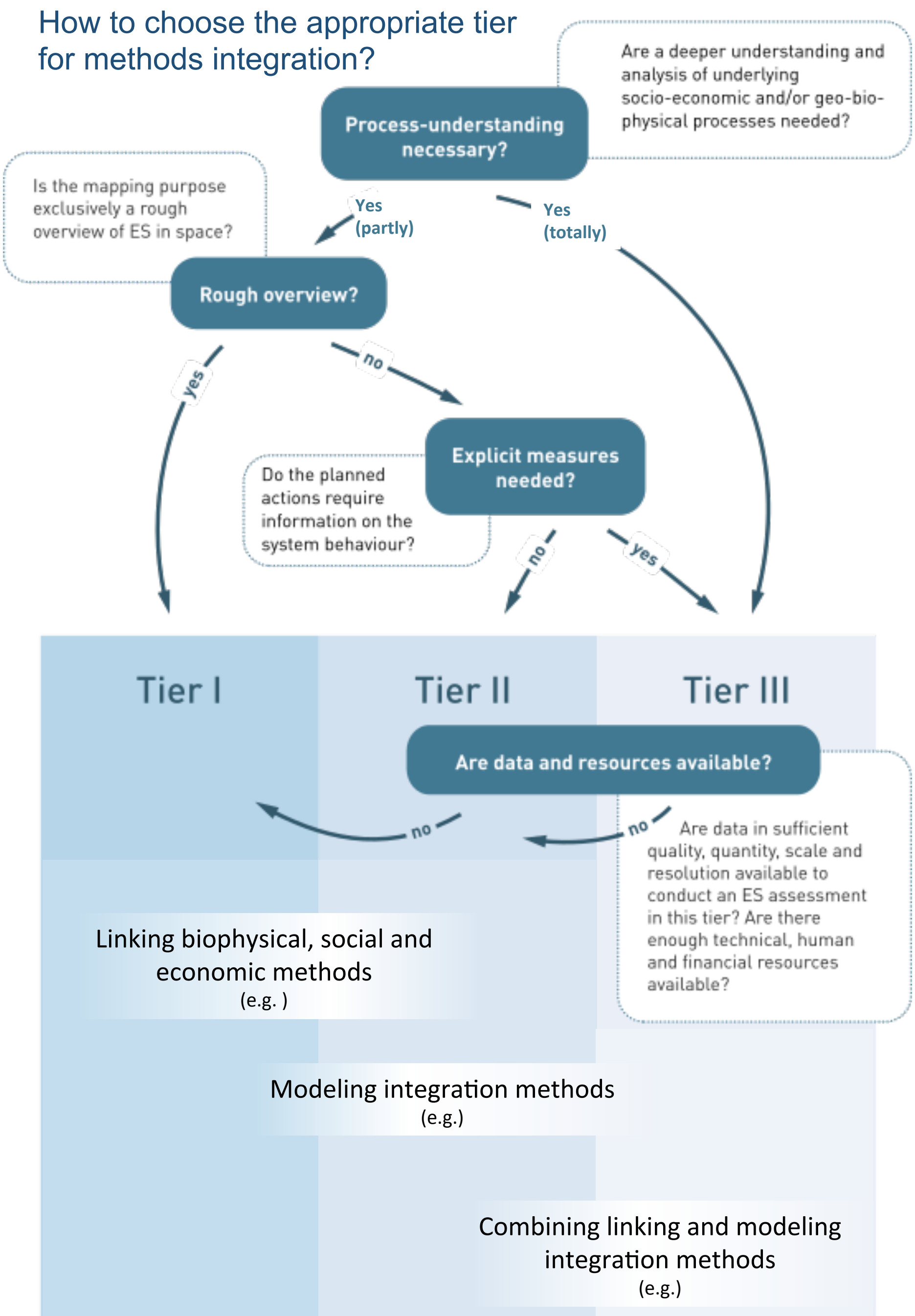


Figure 6. Classification of methods integration based on a tier approach (Adapted from Grêt-Regamey et al. 2017).

3. Tier 1. Guidance on interlinking biophysical, social and economic methods

In this section, we describe the process of reviewing examples of how different combinations of methods have been linked to answer specific policy questions and draw general recommendations based on the review.

Interlinking methods is the combination approaches from different disciplines (e.g. biophysical, social, economic) to derive an information output to inform decision-making. Interlinkages can involve relatively simple stepwise processes to complex representation of the relationships between system components and their dynamic feedbacks.

3.1. Review of method interlinkages from case studies

In order to generate a boarder understanding of the ecosystem service assessment process from policy question to study design, method linkage, and information output, we conducted a review of existing applications to specifically examine which methods were used and how they were linked. The review process started with the policy question that each study aimed to inform, identified the type and sequence of methods used, and examined how links were made. We also used sessions and the expertise available at three ESMERALDA workshops to work through the study design process for specific policy questions with a focus on specifying the linkages between methods. The purpose of this exercise was to explore how multiple methods can be linked and to subsequently draw out general guidance for future applications. Three examples of this process are represented in **Boxes 1 and 2.** These examples address a policy question. To answer this question a sequence of social, biophysical and economic methods were selected.

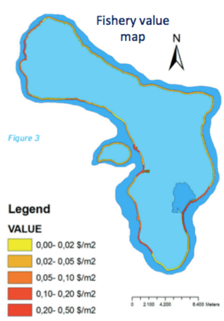
Box1. Example of tier 1 linking biophysical and economic methods to identify important coastal habitats for fisheries in Bonaire.

Policy question: What are the most important coastal habitats for fisheries?

Biophysical Method:
- Habitat mapping
- Ecological process model

Linkage:
- Maximum sustainable yield

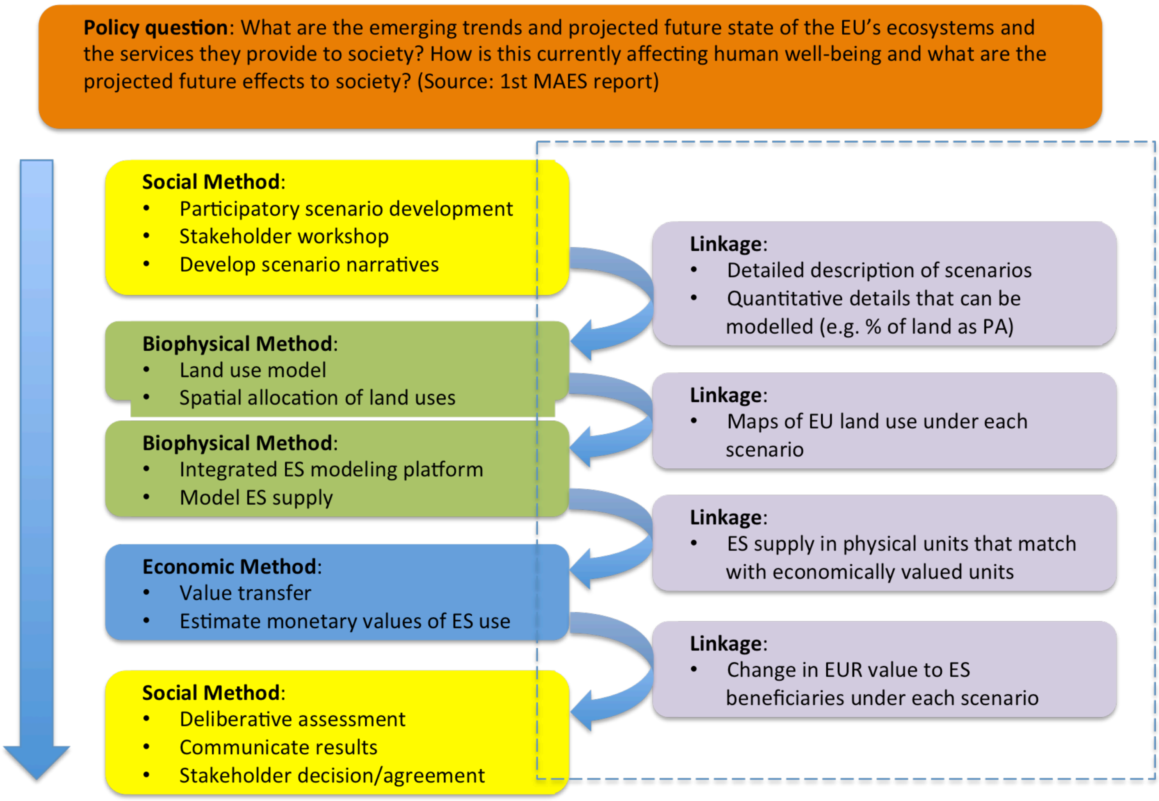
Economic Method:
- Market price of fish harvest
- Choice experiment to value recreational fish catch



A synthesis of the results presented in this report and previously compiled in workshops and other expert meetings throughout the ESMERALDA project revealed possibilities and challenges on linking different methods. A few examples of case studies that have linked methods are provided in Boxes 2 and 3.

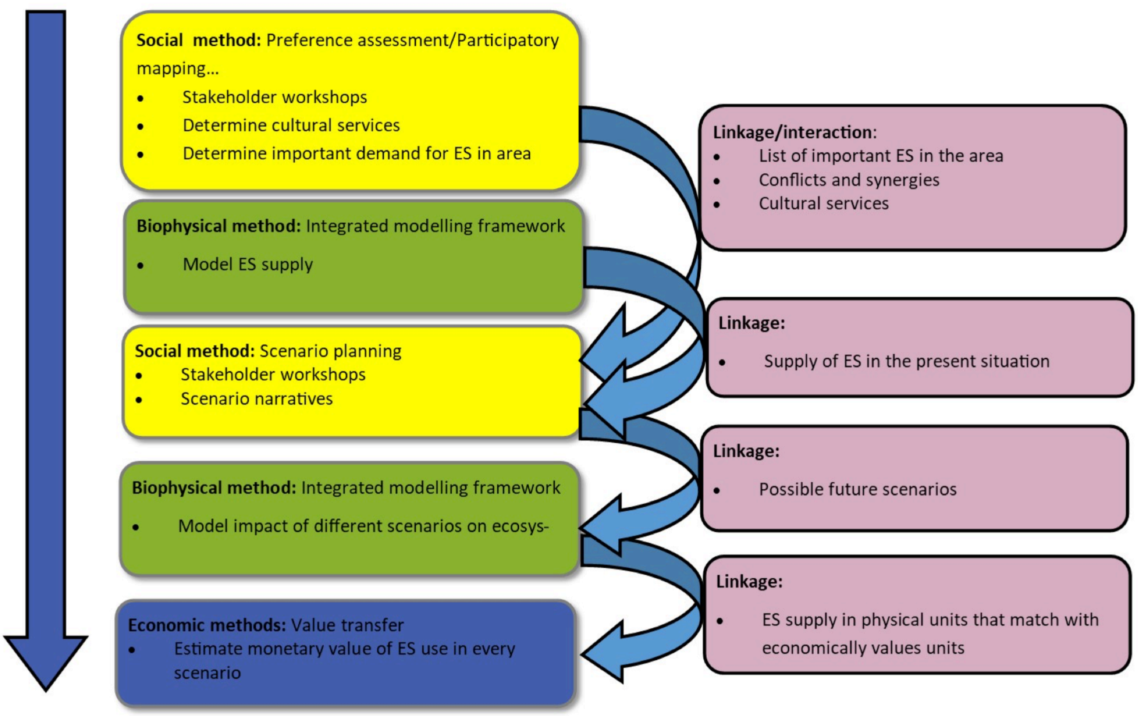
Box 2 tries to answer the policy question for the entire EU using a tier 1 interlinking approach. The first step in the progress is to develop possible scenarios through participatory stakeholder groups, by combining social methods and biophysical methods. Through the social methods stakeholders can indicate the detail description of the scenarios and provide quantitative details that can be modelled using biophysical methods. Combining both methods can provide EU land use maps under each scenario. After doing so, it can be calculated the impact of these changes on monetary values of ES supply in the area. The final step will be to take a second participative round with stakeholders in order to define some final decision agreement that might affect beneficiaries under different possible future scenarios. Based on these results the answer above will be answered and a decision can be made based on what are the projected future effects of the condition of ecosystems to society.

Box 2. Example of Tier 1 approach to understand how methods can be linked to answer a policy question about the projected future state of EU´s ecosystem.



A final example tries to answer the following policy question was posed: Can habitats, important for providing different ecosystem services and biodiversity benefits, meet the growing needs of agricultural production or demands from society for recreational and open space amenities? This question cannot be answered with a simple yes or no. It is very much depending on the area itself. In order to answer this question for a particular area you could run through the above path way (Box 3). The first step in the progress is to determine the important ecosystem services for the area, combining social methods and biophysical methods. Through the social methods stakeholders can indicate the most important ES for the area and point out conflicts and synergies between them. An important category that is hard to grasp in biophysical terms are the cultural services as identity, religious meaning etc. In addition, try to quantify as many ES as possible for the area. Combining both methods indicate which ES are important to safeguard. Take these results in a second participative round with stakeholders in order to define some possible future scenarios. These scenarios can change the management of the areas in order to meet the growing need for food or recreational demand. After doing so, calculate the impact of these changes on the important ES in the area. In a next step you may translate these impacts to monetary values to see what are the economic gains or losses. Based on these results the answer above will be answered and a decision can be made to keep the habitat as it is or go for one of the scenarios.

Box 3. Example of Tier 1 approach to understand how methods can be linked to answer a policy question about the current state of EU´s ecosystem.



4. Tier 2. Integrated modelling methods for combining information from multiple sources

The term "integrated modelling methods" was defined in ESMERALDA as the modelling tools designed specifically for ecosystem services modelling and mapping that can assess trade-offs and scenarios for multiple services. They integrate various methods for different services, which are usually organized in modules each of them designed for particular service. Many of these integrated modelling tools utilize GIS software as a mean to operate with spatial data and produce maps. They can work as extensions of commercial or open-source software packages, stand-alone tools or web-based application. They are designed help researchers in ES assessment and enable decision makers to assess quantified trade-offs associated with alternative management choices and to identify areas where investment in natural capital can enhance human development and conservation.

Integrated modelling methods are frequently developed at a single scale level, e.g. for a region or the globe, but some also include cross-scale linkages in the form of a cascade of boundary conditions from the global to continental and/or national/regional scales, for example, global trade effects on European food production. Integrated modelling methods are the only methods available to quantitatively assess future changes in socio-ecological systems that account for the non-linear, interconnected nature of their multiple components (IPBES, 2016). However, this benefit does not come for free. Compared to simpler, single component models (single driver versus multi-driver, or single sector vs multi-sector), integrated modelling methods have increased structural model complexity adding additional uncertainty to the model outputs and their interpretation.

Kelly et al. (2013) identified four main classes of modelling methods allowing integration: (i) System dynamics, (ii) Bayesian networks, (iii) Coupled component models, (iv) Agent-based models, and (v) Knowledge-based models. *System dynamics models* typically belong to the latter, are particularly good for modelling feedbacks, delays and non-linear effects, and are more commonly found in climate change related impact assessments. *Bayesian networks models* fit probabilistic relationships between system variables, and are therefore often found in modelling assessments where uncertainty needs to be properly quantified, such as for supporting decision-making and management. *Agent-based models* (ABMs) are based on defined interactions between autonomous entities in a system, often humans (individuals or groups) but also species or biophysical entities (e.g. water). Some entities (usually humans) are agents that share the same resources, can communicate and react to changes in their environment. *Knowledge-based approaches* encode knowledge elicited from experts using a logic system to infer conclusions. These categories can be used to encapsulate a wide range of complex methods and tools, which are difficult to explicitly incorporate in quantitative methods, but care should be taken in using such approaches where knowledge about the system is uncertain or incomplete. Such methods and tools are often associated with a larger representation of impact indicators including nature, ES and a good quality of life (or a combination of all three), which is possible due to the simplified way in which system relationships are represented. Several examples of these integrating approaches are given in the following section.

4.1. Review of Integrated modelling methods from case studies

Here we provide an overview of the available methods and frameworks for integrating information from multiple sources that address different dimensions and factors that are relevant to ecosystem service assessment. Such methods range from very simple graphical approaches (e.g. star diagrams) usually used in ecosystem services assessment studies to more complex modelling approaches (e.g. Multicriteria or Cost-benefit integrated assessment analysis).

Ecosystem Service Assessments to integrate information at different scales

An ecosystem service assessment is an appraisal of the status and trends in the provision of ecosystem services in a specified geographic area. Ecosystem service assessments can take various forms in terms of the scale of assessment (ecosystem, municipal, sub-national, national etc.), ecosystems included (key habitats, terrestrial, marine etc.) and the type of information produced (bio-physical quantification, economic values, analysis of future scenario). The general aim of an ecosystem service assessment is to highlight and quantify the importance of ecosystem services to society. An ecosystem service assessment may therefore incorporate a broad range of economic methods but differs from economic evaluations such Cost-Efficiency Analysis (CEA), Cost-Benefit Analysis (CBA) and Multicriteria Analysis (MCA), which aim to appraise specific policies or investments; and also differs from ecosystem service accounting, which aims to provide a structured way of measuring the economic significance of nature that is consistent with existing macro-economic accounts. Ecosystem service assessments may involve the development and assessment of possible future land use scenarios.

In this section, we provide a selection of ecosystem service assessments that illustrate alternative approaches to integrate information at different scales and topics. **Box 4** provides a good example to presents how the UK National Ecosystem Assessment (NEA) put together the development of plausible future scenarios using different socially developed story lines, modelling the impacts of these to understand biophysical changes and then building on this to understand changes in economic terms. **Box 5** presents a national map of the value of agricultural production in Spain in economic units and its spatial correspondence with ecological values. **Box 6** presents an ecosystem service and biodiversity assessment done by a private company for the management of quarries.

Box 4. Integrating information in the UK National Ecosystem Assessment

The UK National Ecosystem Assessment (NEA) provides a good example of bringing together the development of plausible future scenarios using different socially developed story lines, modelling the impacts of these to understand biophysical changes and then building on this to understand changes in associated monetary and non-monetary values. The scenarios used had similar foundations e.g. aging populations and declining global resource availability, but were augmented with different emphases on development choices ranging from environmental awareness and ecological sustainability to national self-sufficiency and pursuit of economic growth irrespective of the wider implications. To compare the outcomes, a range of market and non-market ecosystem service benefits were valued. This included, for example, ranking scenarios in terms of their economic value, but excluding scenarios which led to a decline in biodiversity; and also by presenting maps of the market and non-market values alongside the estimated impacts of the chosen indicator of biodiversity (bird diversity) as illustrated in the maps below. The links between the economic value and the biophysical underpinning is clear for example in the maps of changes in urban green space value (fourth from left), which are focused around major cities. Being unable to value biodiversity means that cost benefit analysis (CBA) alone cannot be used to judge between scenarios, but as the UK NEA itself points out CBA is simply an informational input to the decision making process, using more of the supporting information by comparing across maps of values (monetised or not) more of the trade-offs and complementarities become visible.

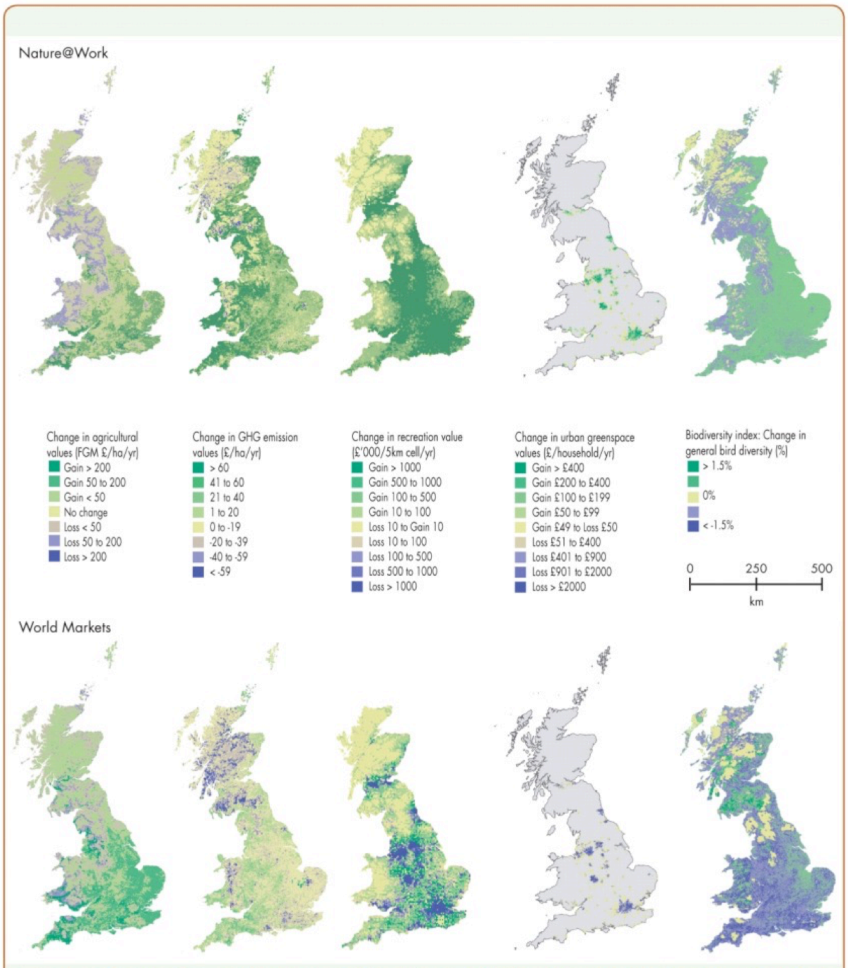


Figure 22 Spatial distribution of changes from the baseline in five ecosystem service related goods (agricultural production (FGM: Farm Gross Margin); greenhouse gas (GHG) emissions; recreation; urban greenspace; biodiversity) under the *Nature@Work* scenario (upper row) and the *World Markets* scenario (lower row) for Great Britain.

Source: UK NEA, 2011

Box 5. Integrating economic and ecological information of agricultural ecosystem services in Spain

This study presents a nationwide assessment for Spanish agro-ecosystems in which economic and ecological spatial distribution of food provisioning services indicators has been integrated and mapped. Firstly, we quantify and mapped the value of Spanish agricultural provisioning services expressed in biophysical (T/ha/yr) and monetary (€/ha/yr) units. Secondly, we mapped "High Nature Value farming areas" in Spain, with the aim of identify important and valuable habitats for species with a high ecological value. Finally, we explore the spatial correlations between the economic and ecological value with the objective to identify those areas with high values on both dimensions that should be considered as priority for landscape management intervention. These results show how integrated information can be useful to make decision based on different land-uses strategies.

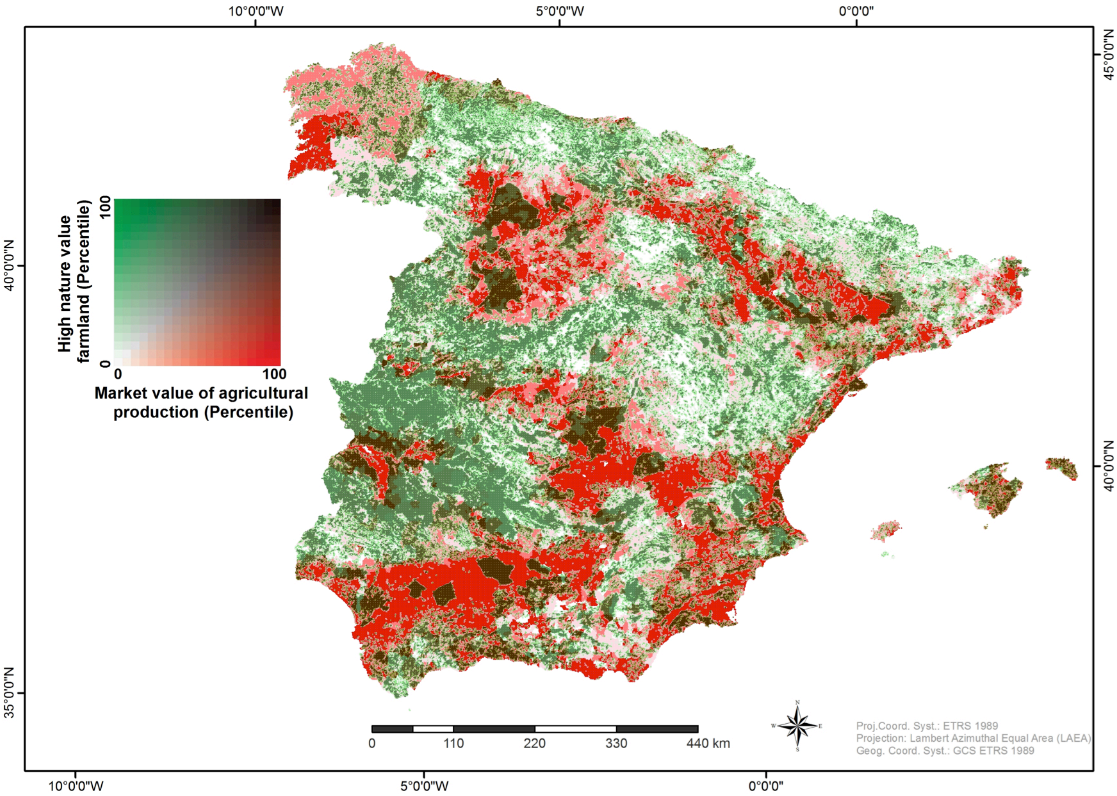


Figure Box 5. *represents the superimposition of the spatial representation of the economic value of the agricultural production of Farming Areas with High Nature Value in Spain. In red: areas with a high economic value and a low ecological value; In green areas with a high ecological value and a low economic value; in black: areas with a high economic value and a high ecological value. (Source: Santos-Martín et al., 2016)*

Box 6. Ecosystem service and biodiversity management of quarries.

Sibelco is a global material solutions company. The company has a lot of quarries that have an impact on the environment they are operating in. But it creates also opportunities for (future) recreation and biodiversity e.g. walking path with a view point; Old quarry classified as Natura2000 area. A tool for ecosystem service assessment was created by VITO together with SIBELCO (Broekx et al., 2013) SIBELCO wanted this to measure and improve its sustainability performance and reduce its environmental footprint. The tool compares different land use scenarios and also takes into account specific management options based upon the specifics of the quarry and its location. Inspiration was found in the 'natuurwaardeverkenner.be'; an online webtool that calculates the impact of land use and management changes on ecosystem services. The development of the tool followed the flexible mapping methodology of Esmeralda. The Sibelco tool needs as input the land use of the quarry and surrounding in the different scenarios (before quarry, during exploitation, restoration afterwards) and the management options you want to take during and after exploitation of the quarry. It gives you as output the impact on ecosystem services for the different scenarios in a qualitative and quantitative way.

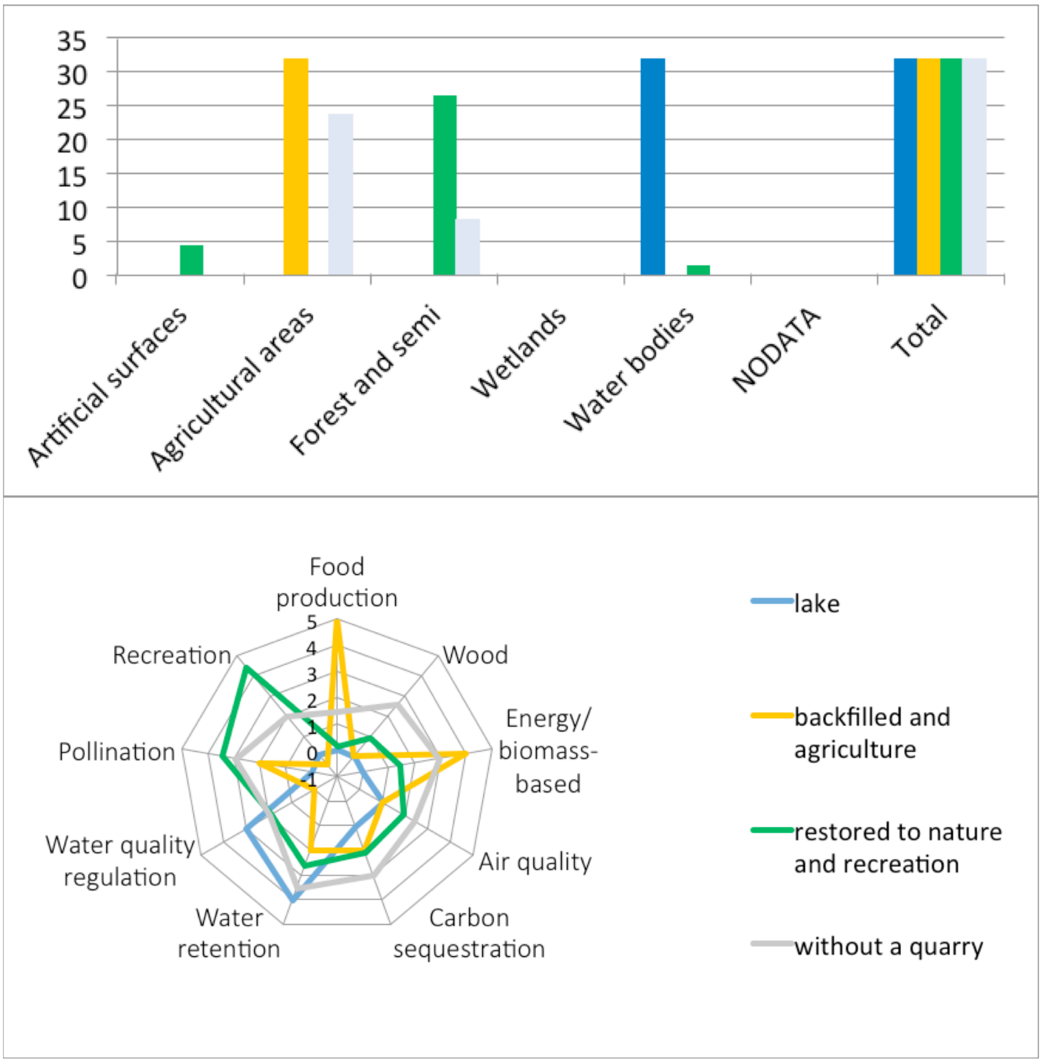


Figure Box 6. *Visualisation of the land use and qualitative impact on ecosystem services for 4 scenarios of an example quarry.*

Multi-Criteria analysis to integrate information from social, biophysical and economic methods

Multi-criteria analysis (MCA) has become a well-established tool for decision-making that involves conflicting or multiple objectives. MCA can be used to establish preferences between alternative options by reference to a set of measurable criteria that the decision making body has defined. Unlike in a Cost-Benefit Analysis (CBA), criteria do not need to be quantified in a common metric (i.e. money). Instead MCA provides a number of alternative ways of aggregating the data on individual criteria to provide indicators of the overall performance of options. This allows the inclusion in the analysis of effects that cannot be expressed in monetary terms. The basic idea behind MCA is to allow the integration of different objectives (or criteria). The main steps in performing a MCA are presented in **Figure 7**.

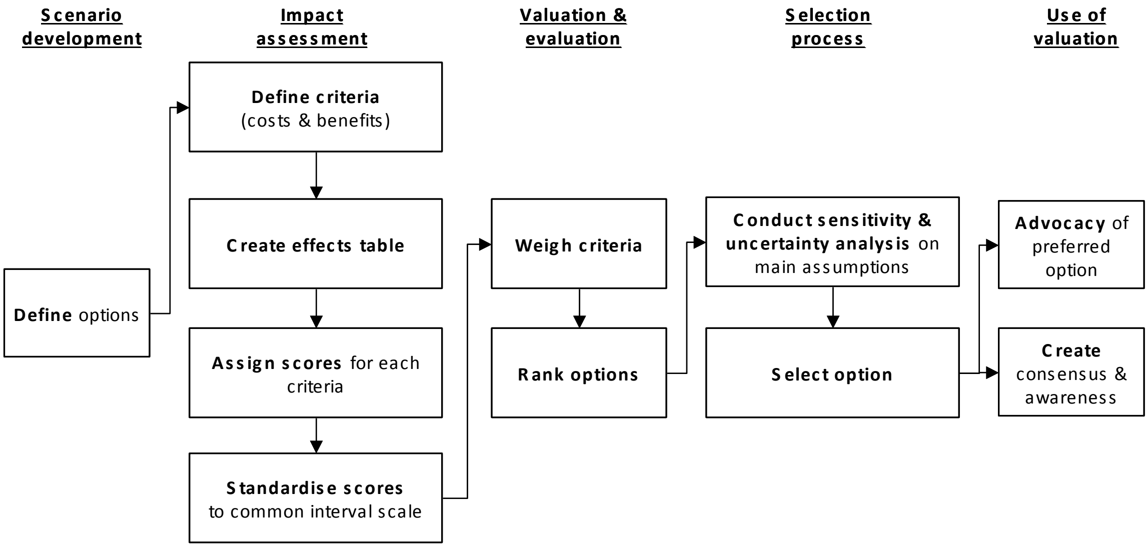


Figure 7. Methodological steps in multi-criteria analysis (source: Brander and van Beukering, 2015)

Impact assessment in a MCA involves identifying and defining all criteria that are relevant to the decision problem. These include all important categories of negative and positive effects resulting from the options under consideration. In a MCA it is possible to include criteria that are difficult to quantify and can perhaps only be assessed in qualitative terms such as political sensitivity, equity and irreversibility. The quantification of the different effects is summarised in an “effects table”, which is a matrix with the alternative options listed in the columns and the criteria listed in the rows. The effects table is completed by assigning scores to each criterion for each alternative. Information on the magnitude of each criterion can be expressed in monetary units, physical units, or simply on a qualitative scale. Data on impacts can be collected from surveys, existing data, experts, or stakeholders. In cases in which the spatial distribution of impacts is important to the decision, the data on impacts can be represented on maps. To enable the direct comparison of different criteria, standardisation of scores for each criterion to a common interval scale is conducted (usually to values between 0-100 or 0-1). There are several software packages available that can be used to help with the computations in MCA.[2]

MCA applies weighting of criteria to quantify the relative importance of each criterion in the decision process. Weights can be derived from existing information or from stakeholders by asking them to state their preferences for the various criteria. By combining the standardised scores and weights of the criteria, the alternative options can be ranked, usually through a weighted summation of criteria scores for each alternative. Similar to CBA, MCA applies sensitivity and uncertainty analysis to assess the robustness of the ranking result to changes in weights and scores. Finally, based on the ranking of options and the sensitivity of the results, a decision maker can select the most preferred option.

A key strength of MCA is that that complex and time-consuming valuation studies of all environmental impacts can be avoided, and that qualitative criteria such as political sensitivity can be included in the decision framework. MCA can therefore provide a degree of structure, analysis, and openness to decision problems that lie beyond the practical reach of CBA.

MCA is, however, heavily reliant on the judgement of the analytical team for defining alternatives and criteria, estimating the relative importance of criteria and, to some extent, in calculating and inputting data into the effects table. The subjectivity that pervades these processes can be a matter of concern. The involvement of stakeholders in defining criteria and setting weights can also be time consuming process if conducted using surveys, interviews or deliberative methods. Another important limitation of MCA is that the results do not necessarily show whether alternative options produce welfare gains or losses. Unlike CBA, there is no decision rule (such as a positive NPV, a BCR greater than 1, or an IRR greater than the market interest rate) that indicates that benefits exceed costs. In MCA, as is also the case with CEA, the analysis can only produce a ranking of alternative options and does not indicate whether the options result in a welfare improvement. It is, however, often possible to include a business-as-usual alternative in the set of options, and this can be used as a reference point to indicate whether the other options are better or worse than undertaking no action.

We provide a selection of two MCA studies that illustrate alternative approaches to integrate information from biophysical, social and economic methods. **Box 7** integrating information from different methods in a Multi-Criteria Analysis to evaluate alternative development paths for Bonaire. **Box 8** presents a good working example of how MCA can be applied to integrate different ES mapping and assessment results in order to address specifics planning and policy question in real-life is given in the Trento case study (Cortinovis & Geneletti, 2018).

[2] A number of software packages are available to structure and process information in an MCA, including: DEFINITE, HIVIEW, MACBETH, VISA and ILWIS.

Box 7. Integrating information from social, biophysical and economic methods in a Multi-Criteria Analysis to evaluate alternative development paths for Bonaire

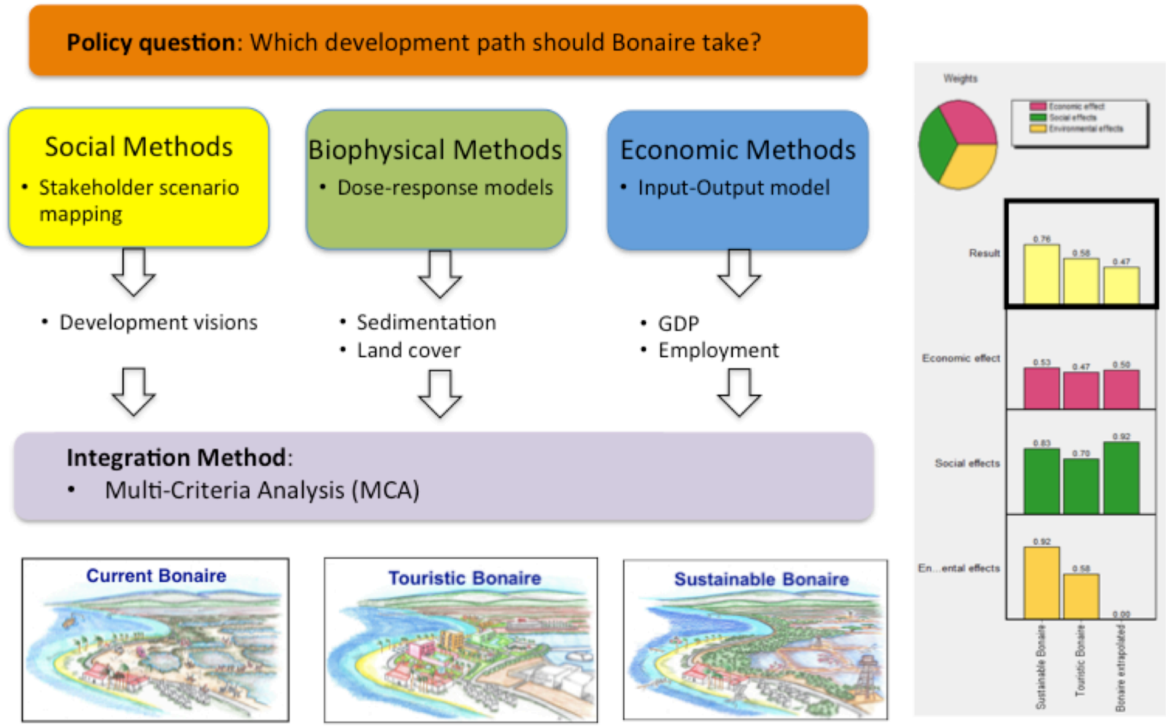


Figure Box 7. *Integrating information from different methods in a Multi-Criteria Analysis*

Box 8. Integrating information using MCA to address specifics planning and policy question in real-life in Trento (Italy)

The study explores the use of ecosystem service knowledge to support urban planning in the assessment of future scenarios. The case study concerns the prioritization of brownfield regeneration interventions in the city of Trento, a medium-sized city of around 120,000 inhabitants located along the course of the River Adige, in the eastern Italian Alps. Following is an account of the main steps of the MCA application. For a more detailed account refer to Cortinovis & Geneletti (2018).

Scenario development + Impact assessment.

In the Trento case study, alternative planning scenarios were defined considering the conversion of thirteen (13) existing brownfields into new urban parks (see. These 13 regenerated 13 brownfields thus represent the “options” to be considered while addressing the specific planning question (Figure in Box 8). The assessment of impacts focused on two ES of critical importance for the city, namely microclimate regulation and nature-based recreation. For each ES, the benefits of the different scenarios were then quantified based on the number of expected beneficiaries broken down into different vulnerability classes. According to the scheme in the Figure, the two selected ES and the different categories of beneficiaries thus represent the relevant criteria and sub-criteria, respectively.

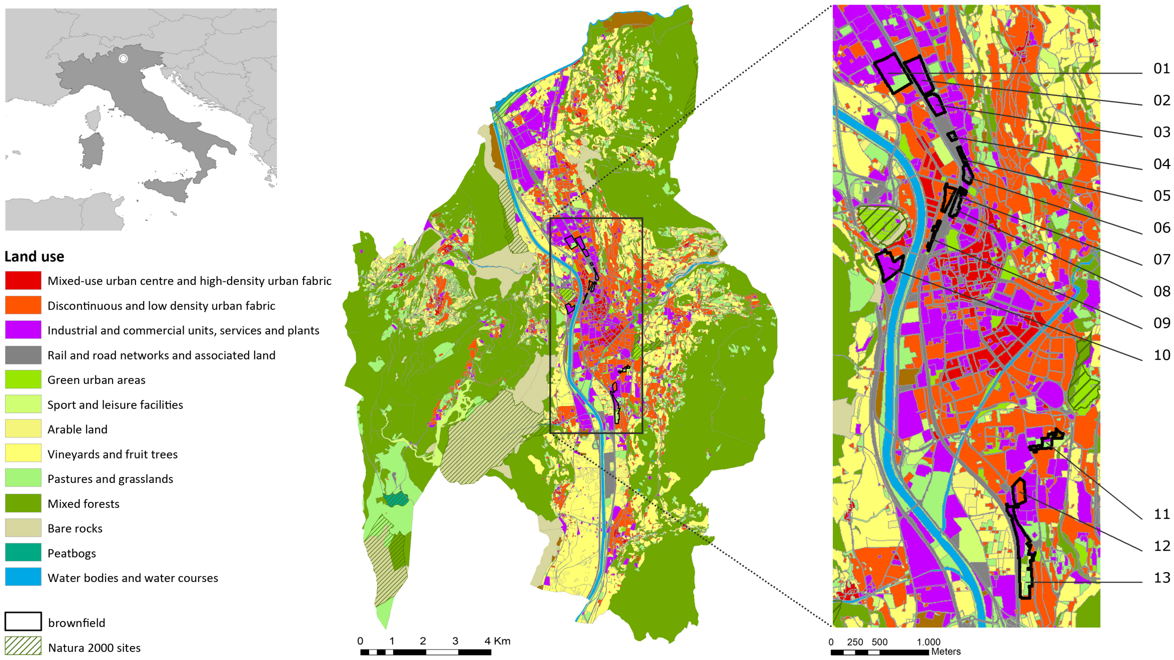


Figure Box 8. *Main land uses in Trento, Natura 2000 sites and the 13 brownfields identified by the urban plan as 'urban redevelopment sites'*

Creating the effects table and assigning scores to each criteria were the next steps. To this end, both ES were first mapped and assessed using state-of-the-art methods. To map and assess the cooling effect of urban green infrastructure, a method specifically designed to support planning and management decisions at the urban and sub-urban scale was adopted (Zardo et al., 2017). To assess the improvement in micro-climate regulation under the planning scenarios, the new urban parks obtained by the regeneration of existing brownfields were modelled as areas covered by grass, with 80% to 100% canopy coverage. Maps of the cooling effect were produced for the baseline condition and considering the conversion of each brownfield (i.e. each scenario) independently. Then, we computed the difference between each scenario and the baseline condition and intersected the resulting maps with a map of population distribution. The final indicator for each scenario was defined as the number of affected residents weighted by the intensity of change in the class of the cooling effect of their location (i.e. residents experiencing an improvement of two classes are counted twice). Young children (<5 years) and the elderly (>65 years) were selected as the most vulnerable groups, based on their higher sensitivity to heat stress and counted separately.

To map and assess the potential and opportunities for nature-based recreation in the city, we applied a locally-adjusted version of ESTIMAP-recreation. The model is part of the ESTIMAP suite, originally developed by the European Commission's Joint Research Centre for the purpose of mapping ecosystem services at the European scale (Zulian et al., 2013) and later adjusted for the application to different contexts and scales (Zulian et al., 2018). To assess the enhanced opportunities for nature-based recreation under the planning scenarios, people living within 300 m from the new parks were considered as the main beneficiaries of the transformation. Children and teenagers (<20 years) and the elderly (>65 years) were selected as the most vulnerable groups, based on the higher demand for close-to-home recreation and relaxation areas. Furthermore, we distinguished the beneficiaries already served by high-level opportunities for nature-based recreation in the baseline scenario and counted them separately

Table Box 8. *Values for each criterion and sub- criterion were normalised according to the maximum and a 'weighted summation' approach was used to calculate the overall score for each alternative, hence defining the final rankings for the three perspectives.*

CRITERIA **sub-criteria**	**Perspective 1 "balanced"**			**Perspective 2 "cool air for the elderly"**			**Perspective 3 "every child needs a park"**		
COOLING	0.50			0.80			0.20		
< 5 years		0.40			0.29			0.40	
> 65 years		0.40			0.57			0.40	
others (less vulnerable)		0.20			0.14			0.20	
RECREATION	0.50			0.20			0.80		
< 20 years		0.40			0.40			0.57	
served			-			-			0.20
not served			-			-			0.80
> 65 years		0.40			0.40			0.29	
served			-			-			0.20
not served			-			-			0.80
others (less vulnerable)		0.20			0.20			0.14	
served			-			-			0.20
not served			-			-			0.80

Valuation and evaluation + Selection process

Weighting criteria is perhaps the most crucial step to include diverse stakeholders' perspectives in the MCA process. In the case study, three illustrative combinations of weights were applied, corresponding to three hypothetical policy perspectives and related objectives (Table 1). The 'cool air for the elderly' perspective favours improvement in the cooling effect in areas with a high share of older population. The 'every child needs a park' perspective favours opportunities for recreation to people, especially children and teenagers, who are not served in the present condition. The 'balanced' perspective promotes both ES equally, but gives more weight to the most vulnerable beneficiaries (see Table 1 for details on the weights). The final rankings for the three perspectives were based on a 'weighted summation' approach, which was used to calculate the overall score for each alternative. To support the selection process, a sensitivity analysis was conducted to explore the robustness of the rankings to variations in the weights assigned to criteria and sub-criteria.

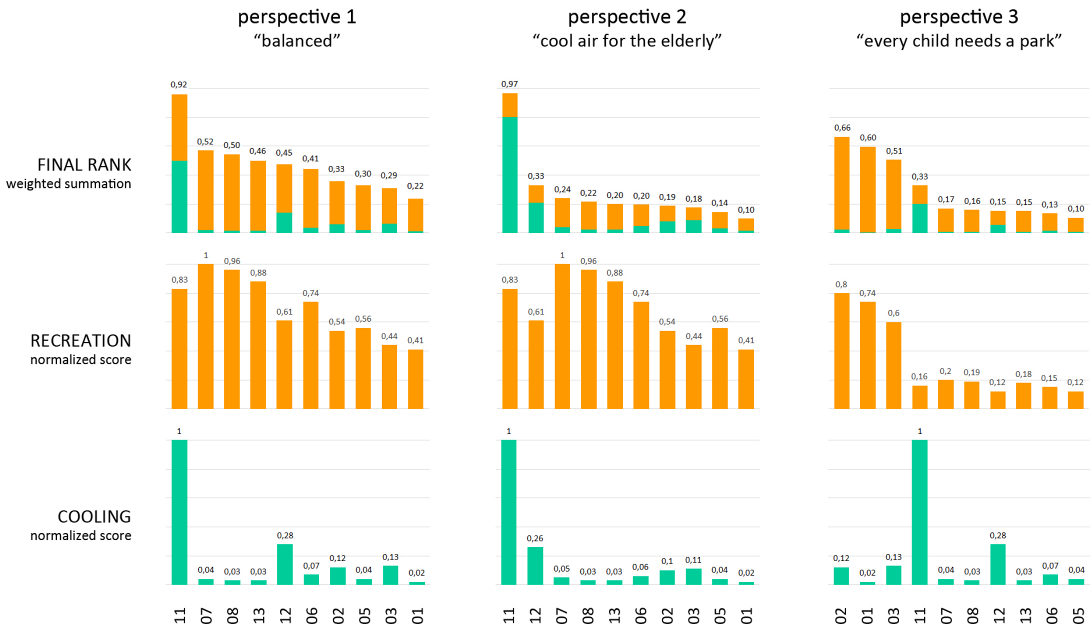


Figure Box 8. *Final rankings of the regeneration scenarios according to three perspectives considered in the multi-criteria analysis.*

Use of evaluation

The Trento case study shows one of the possible tasks that ES mapping and assessment can perform to support urban planning, i.e. the assessment of alternative planning scenarios (Barton et al. 2018). The analysis considered different brownfields in the city of Trento that could be converted to new urban parks and assessed the expected effects of the transformations in terms of ES benefits. The presence of brownfields and abandoned areas is a key issue for today's cities, with strong economic and social implications, hence their regeneration is promoted amongst the strategies for sustainable urban development (European Commission, 2016). Thus, the MCA application has great potential in terms of creating consensus and awareness.

With respect to the advocacy of a specific option, the comparison of alternatives considered three perspectives that simulate different decision-makers' orientations. In the analysis, the relative importance of different planning objectives, hence ES, is reflected by different combinations of criteria and weights. In the case of perspective 1, a balanced weighting was performed by assigning the same weight to the two ES. In the case of perspectives 2 and 3, one ES received a weight significantly higher than the other and specific vulnerable groups were identified as the main targets of policy interventions. The results clearly show how priorities change with changing policy goals. This finding highlights the need for a strategic approach to ES and for the inclusion of explicit ES-related objectives in urban plans, an aspect still mostly neglected in current planning documents. Simply providing ES knowledge as part of the information base for urban plans is not enough to guarantee that it is used to guide decisions, if it is not perceived as relevant to the problem at stake. Formulating objectives and targets for ES provision helps to identify the values against which the effectiveness of planning actions should be measured, hence also to clarify the possible role(s) of ES knowledge within the process.

Cost-Benefit analysis to integrate information from economic methods

Cost-benefit analysis (CBA) is the most commonly used economic assessment method used for integrating information to evaluate investments, projects and policies. It is important to recognise the difference between a CBA that is carried out from the perspective of society as a whole and CBA that is conducted from the perspective of an individual, group, or firm. If applied from this latter perspective, CBA is generally used to determine the financial return of private investments. This private application is commonly known as a 'financial CBA'. Alternatively, government departments apply CBA as the standard tool for evaluating investments, projects and policies from the perspective of society as a whole. This so-called 'extended CBA' is used as a method in which the societal costs and benefits of alternative options are expressed and compared in monetary terms. The extended CBA provides an indication of how much a prospective project or investment contributes to social welfare by calculating the extent to which the benefits of the project exceed the costs – essentially society's 'profit' from a project. In this application, the CBA provides a framework into which monetised ecosystem service values can be integrated.

The main steps in performing a CBA are presented in **Figure 8**. These steps are described below:

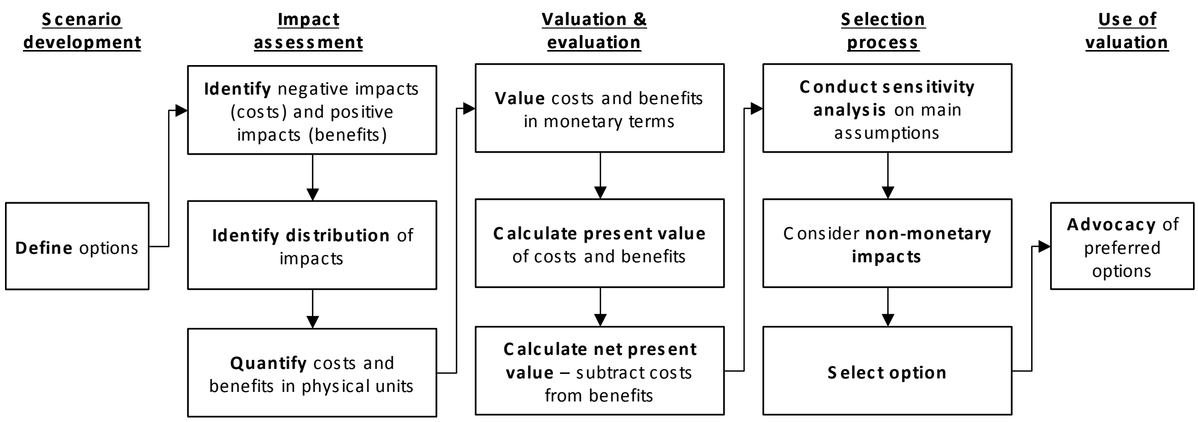


Figure 8. Methodological steps in cost-benefit analysis (source: Brander and van Beukering, 2015)

The first step in a CBA is to identify the alternative options or alternatives to be considered. The options under consideration will generally be specific to the particular problem and context, but may include investments, projects, policies, development plans etc.

The impact assessment in a CBA starts with the identification of the complete set of negative impacts (costs) and positive impacts (benefits) related to the policy or intervention options under consideration. This includes costs and benefits accruing to all affected groups and individuals (not just those involved in the project development) and costs and benefits that are incurred in the future. It is important to describe the geographical and temporal boundaries of the analysis. This is especially crucial for ecosystem services impacts since effects emerging from ecosystem change often show major variations in time and space. The final step in the impact assessment phase is to quantify each cost and benefit in relevant physical units for each year in which it occurs. Estimating changes in ecosystem services requires specific expertise and models on ecological, hydrological and climatic processes.

To conduct a CBA, all of the quantified positive and negative effects need to be expressed in monetary units. In cases where costs and benefits are not directly observable in monetary terms in well-functioning markets (as is the case for many ecosystem services), estimates need to be generated using non-market valuation methods or value transfer (see Chapter 4).

The economic performance of each alternative option can be calculated in three different ways:

1. The net present value (NPV) of each option is calculated by subtracting the present value costs from present value benefits. A positive NPV indicates that implementing a project will improve social welfare. The NPVs of alternative investments can be compared in order to identify the most beneficial project;
2. The benefit cost ratio (BCR) is the ratio of discounted total benefits and costs, and shows the extent to which project benefits exceed costs. A BCR greater than 1 indicates that the benefits of a project exceed the costs;
3. The internal rate of return (IRR) is the discount rate at which a project's NPV becomes zero. If the IRR exceeds the discount rate used in the analysis, the project generates returns in excess of other investments in the economy, and can be considered worthwhile.

A final step in a CBA is to conduct sensitivity analysis to check the robustness of the conclusions to the assumptions made. Another element is to estimate whether or not the omission of certain costs and benefits that cannot be monetised affects the decision result.

An important drawback of CBA is the requirement that all costs and benefits need to be expressed in monetary terms. Although a range of economic valuation methods are available to estimate values for marketed and non-marketed ecosystem services, there are still considerable limitations to the accuracy of estimated value in some cases. Furthermore, the application of non-market valuation techniques can be expensive and time consuming.

For these reasons it may not be possible to estimate monetary values for some costs and benefits and they cannot be entered into a CBA. In some cases the omitted impacts can be significant and therefore alternative evaluation methods are needed.

Box 9. Integrating information using CBA to develop a safety and nature restoration plan for the river Schelde (the Netherlands)
Major infrastructure works were planned in the Scheldt estuary, flowing from Belgium into the Netherlands, including the deepening of the fairway to the harbour of Antwerp and complementary measures to protect the land from storm floods coming from the North Sea. A cost-benefit analysis was carried out, taking into account ecosystem services, using different valuation methods. In addition to technical measures such as a storm surge barrier and dikes, two types of floodplains were taken into account: a system where the existing land use is maintained (mostly agriculture) and a system with controlled reduced tide that delivers a large number of ES. Regulating services were quantified through the OMES-model. This process-based ecosystem model was developed for the Scheldt estuary in order to study the possible impact of different water management strategies on the ecosystem. This model was based on a monitoring program for all major groups (plankton, benthos, avifauna, fish, and littoral vegetation), carried out by different universities and institutes, and simulated major ecosystem processes, such as the C, N and P cycles. The OMES-model makes distinctions between the impact of riverine wetlands in the fresh water, brackish and salt zone of the river. The value was estimated through replacement costs and avoided costs. The flood control service was quantified by a large hydrodynamic model. Based on land use data, damage factors and replacement values for houses, household furniture, roads, industry, crops and other damage categories the flood damages in the inundated area were estimated. A contingent valuation study was performed to value the recreational value of new floodplains. Results of the cost benefit analysis show that an intelligent combination of dikes and floodplains can offer similar safety benefits, but far more co-benefits at lower costs compared to more drastic measures as a storm surge barrier near Antwerp. The hydrodynamic modelling also indicated that floodplains are necessary to ensure safety levels in the longer term in the Scheldt basin. Merely dike heightening mainly causes a shift in flooded areas but does not suffice to importantly reduce future flood risk. Additionally, results showed that the benefits of the controlled reduced tidal areas (RTA) mostly exceed the benefits of the controlled inundation area (CIA) with agricultural use. The Dutch and Flemish government approved an integrated plan consisting of the restoration of approximately 2500 ha of intertidal and 3000 ha of non-tidal flooding areas, the reinforcements of dikes and dredging to improve the fairway to Antwerp.
CBA of the Hemmepolder: restoring marches along the Ijzer.
The first phase of the restoration of “De IJzermonding” (Belgium) was realised with the support of the European Community by the complete removal of the former Naval base. All buildings and roads were demolished, quays and landing stages were dismantled and all the

dredging sludgedumps were dug out to the original ground levels of mudflat, salt marsh and dune. All these works resulted in the expansion of these areas to many times their former size and the return of the jagged natural pattern of the transitions between each these environments.

The second phase was to investigate the salt marsh restoration and its increase in size and the feasibility of incorporating the adjacent Hemmepolder.

In a feasibility study of the Hemmepolder (Liekens et al., 2013) three scenarios for nature development in the Hemmepolder were developed and their gain of nature value, technical feasibility and financial impact were valued.

- Scenario 1: conversion of fields into meadows with relief, restoration of the creek.
- Scenario 2: like scenario 1 but periodical inlet of salt water into the creek.
- Scenario 3: building of a new dyke around the Hemmepolder: restoration of the salt marsh

Each scenario can be developed through different measures, what lead to different versions of the scenarios.

In this study a cost-benefit analysis was performed to compare the three scenarios. The cost-benefit analysis paid specific attention to the effects on agriculture, recreation and nature development. The different impacts were listed, were possible quantified and monetised.

Investments costs for construction and specific infrastructure were estimated. In addition, maintenance costs are calculated. The acquisition of the agriculture land is not included in the investment costs but is taken into account through the loss of profits for the formers.

25 ha of the area were used for intensive agriculture. In all three scenarios a more extensive use of the land for agriculture is possible (grazing), but the farmers are not very interested in rescaling. That’s why we opted to work with the total loss of agricultural use of the land. Two different methods were used to check the solidness of the results. Both methods give a comparable result: a net present value of €540 000 loss.

The new ecosystems develop some important ecological functions. These functions were translated into ecosystem services e.g. water purification, fish, reed, recreational and amenity values…To calculate the monetary value of these services, a number of different valuation methods were used: A specific contingent ranking study was performed to calculate recreational values, for regulating and production services benefit transfer was used as no specific data for the Ijzer were present at the time of the CBA. Some aspects could not be monetised but were integrated in the CBA qualitatively e.g. the important historic value of the area, the effect of salination.

We calculated the net present value of the scenarios based on three different discount rates and three different scenarios of economic growth. In addition, the payback period was calculated to rank the different scenarios.

Table Box 9. *Net present value of the different variants with mean discount rate and mean economic growth (mio € 2010).*

scenario Discount rate Economic growth	variant 3a 4% mean	variant 3b 4% mean	variant 1a 4% mean	variant 1b 4% mean	variant 1c 4% mean	variant 1d 4% mean	variant 1f 4% mean	variant 2a 4% mean	variant 2b 4% mean	variant 1e 4% mean
Costs untill 2050										
Investments	-0,97	-2,00	-0.77	-0,91	-0,99	-1,13	-2,02	-0,77	-1,30	-11,35
maintenace	-0,14	-0,53	-0.10	-0,07	-0,10	-0,23	-0,07	-0,11	-0,11	-3,97
Total costs	*-1,12*	*-2,53*	-0.87	*-0,98*	*-1,09*	*-1,36*	*-2,09*	*-0,88*	*-1,41*	*-15,32*
Effects untill 2050										
Agriculture	-0,54	-0,54	-0,54	-0,54	-0,54	-0,54	-0,54	-0,54	-0,54	-0,54
Avoided costs water threatment and nursery function	0,42	0,46	0,14	0,14	0,14	0,14	0,14	0,38	0,38	0,14
Perception value recreation	22,54	22,54	10,58	10,58	10,58	10,58	10,58	5,54	5,54	10,58
Total benefits	*22,42*	*22,46*	*10,17*	*10,17*	*10,17*	*10,17*	*10,17*	*5,37*	*5,37*	*10,17*
Net present value	**21,30**	**19,94**	**9,31**	**9,20**	**9,08**	**8,81**	**8,08**	**4,49**	**3,97**	**-5,14**
RANKING	1	2	3	4	5	6	7	8	9	10
Pay back period	5	5	5	5	5	5	6	6	7	/

Based on the best estimation of the cost and benefits, we could conclude that all three scenarios are worthwhile doing. Scenario 3 has the highest net present value and the shortest payback period.

Reasons for this conclusion are the relatively low costs, the high number of people visiting the area and their high recreation value and a potentially high contribution to improving water quality of the river. The best alternatives have a payback period of 5 to 10 years.

To check how solid the results were, we performed a sensitivity analysis were the uncertainty ranges were implemented on all the parameters. There is a small shift between ranking of the different scenarios but scenario 3a always stays the best. The results were used in further discussions with different stakeholders. Unfortunately, lobbying and local politics kept the project from being developed.

5. Tier 3. Combination of interlinked methods and use of methods for integrating information

The process of combination of interlinked methods and use of methods for integrating information requires inputs of information from many sources and methods. Conceptually it involves linking and integrating methods from social, biophysical and economic method domains, which implies not only the combination of two or more domains in the final outcome, but also the mutual linking of information from these domains. Any evaluation of alternative options for interlinking methods requires a sound understanding of individual methods and the integrating modelling approaches processes. As a basis, we need to know how the methods we select will be able to assess the biophysical functioning of ecosystems and the associated provision of services. The process of integrating alternative options also requires knowing the importance of ecosystem services in terms of social and economic methods. The final results from these more sophisticated options will be largely determined by the quality of the information we have but also requires appropriate tools for structuring that information. A policy question that requires tier 3 methods is for example the question what kind of measures and policies are most effective in avoiding further decline of coral reef ecosystems in which both financial costs (e.g. coral reef restoration costs) and social and environmental benefits (e.g. cultural values, fish abundance) are strongly interrelated. In the following section we will provide a few examples that have used this combination of methods to integrate information from different sources and methods.

5.1. Review of interlinked methods and use of methods for integrating information from case studies

Three examples of tier 3 integrated approach are presented in Boxes 10, 11 and 12. **Box 10** represent how to link biophysical and economic methods to estimate ecosystem service values and integrating the results together with social factors in an extended Cost-Benefit Analysis to evaluate investment in waste water treatment. In short, Cost-benefit analysis is based on ecological-economic models in which ecological processes and economic mechanisms are mutually linked. Feedbacks between ecosystems and the economy occur in both directions. In **Box 11**, a combination of interlinked methods and spatial multi-criteria analysis was used to inform urban development in Finland (Tiitu et al., 2018). The aim of the study was to map the most optimal residential infill sites for construction so that future urban planning could compress up and intensify the urban structure without losing the most valuable features of the green and blue areas. In **Box 12**, an integration of ecosystem condition and services in the context of nature protection management and hazard assessment is done in the town of Karlovo, Bulgaria (Nedkov et al., 2018). The integration of ecosystem condition and services is embedded in the methodological framework for mapping and assessment in Bulgaria, as both of them are assessed in the same relative scale. This allows convenient and easy interchange of data and results from different indicators of condition or services as well as methods integration and interlinkages.

Box 10. A combination of interlinked methods and use of CBA for integrating information to evaluate investment in wastewater treatment.

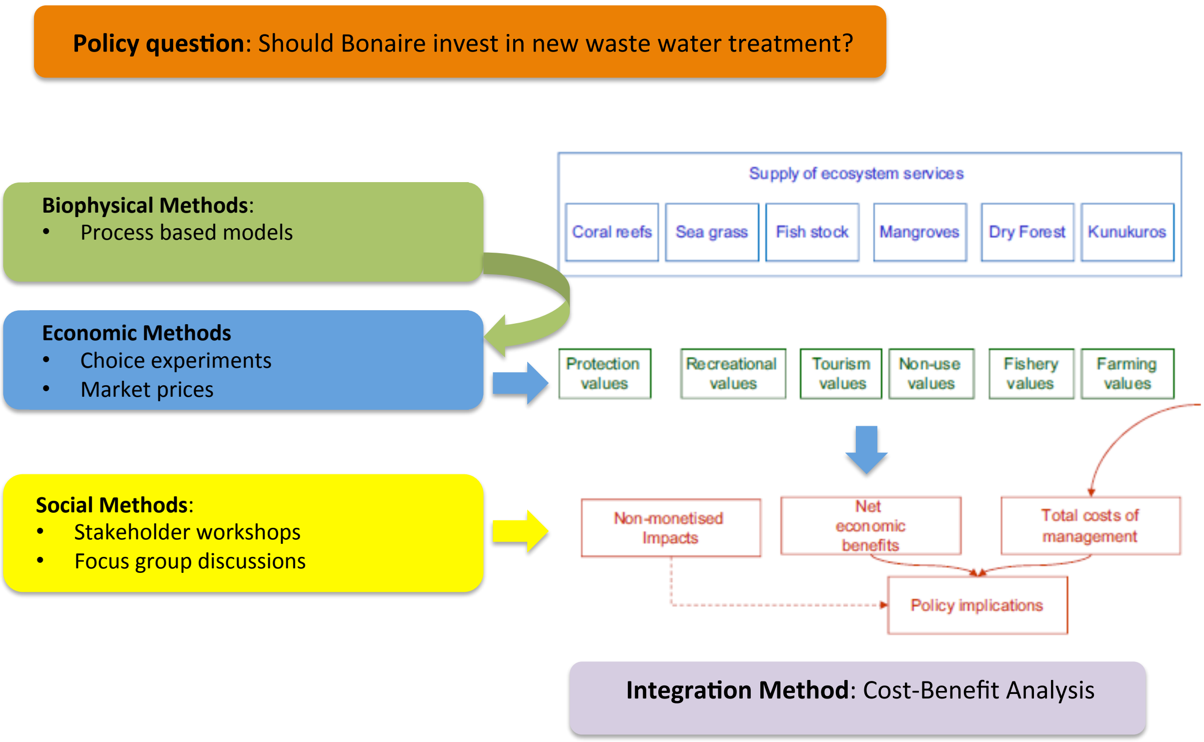


Figure Box 10: *How to link biophysical and economic methods to estimate ecosystem service values and integrating the results together with social factors in an extended Cost-Benefit Analysis to evaluate investment in waste water treatment*

Box 11. Use of interlinked methods and spatial multi-criteria analysis to inform urban development in Järvenpää, Finland (source: Tiitu et al. 2018).

The aim of the study was to map the most optimal residential infill sites for construction so that future urban planning could compress up and intensify the urban structure without losing the most valuable features of the green and blue areas. The study consisted of different phases that are presented in Figure below. First, a spatially detailed delineation and extraction of green and blue areas was conducted to map and assess of the ES supply, demand and connectivity. ES supply was mapped using GreenFrame method which is a matrix based spatial proxy method (for more detailed description of the GreenFrame method; see Vihervaara et al. (2018) for more detailed description to the spatial proxy method). Participatory GIS (social method) was used to evaluate the spatial distribution of ecosystem services demand according to the perceptions and knowledge of citizens using workshop and survey where latter one was specially tailored for schools and kindergartens. In both workshop and survey the respondents marked areas providing ES for them on a map that were later on digitized for further analyses. The connectivity of green areas was mapped by applying a graph-theory-based method using MatrixGreen and Conefor 2.6

software to quantify the importance of each green habitat to maintain overall connectivity. Analysis results were converted consistent raster format with 25 metre resolution to be used as input data for the Spatial MultiCriteria Analysis (SMCA) method. With regard to SMCDA a criteria-based decision tree was formulated using analysis results (i.e. data layers) from previous phases with additional spatial data of grey infrastructure such as urban form and transportation systems and location of and accessibility to daily services. Standardisation function was applied to make all the criteria comparable by translating the original data values common scale ranging from 0 to 1. Experts from different city sectors including: master planning, town planning, health and welfare, children and youth services, maintenance of green area, forestry and environment sector weighted the criteria individually according to the importance of the criteria's impact on optimal integration of residential infill development sites and urban green and blue spaces. The most suitable infill development sites and areas with highest green and blue values were the pixels having the highest values. Values were cross tabulated into four classes: i) low green and blue values, low infill development potential ii) high green and blue values, low infill potential iii) high green and blue values, high infill development potential, and iv) low green and blue values and high infill development potential to be presented on a map. The first class represented areas with no competing interests, and the second stood for areas preferably to be preserved as green areas. The third class described areas with possible conflicts between GI and infill development, since both values were high. The essential fourth class signified the areas with the most potential infill sites, with high construction potential but low GI values.

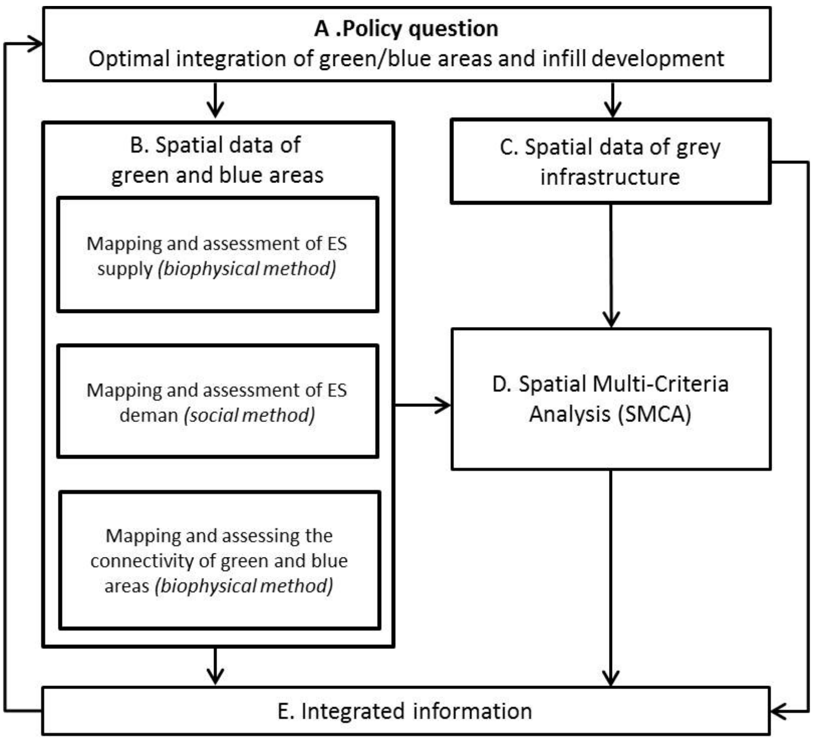
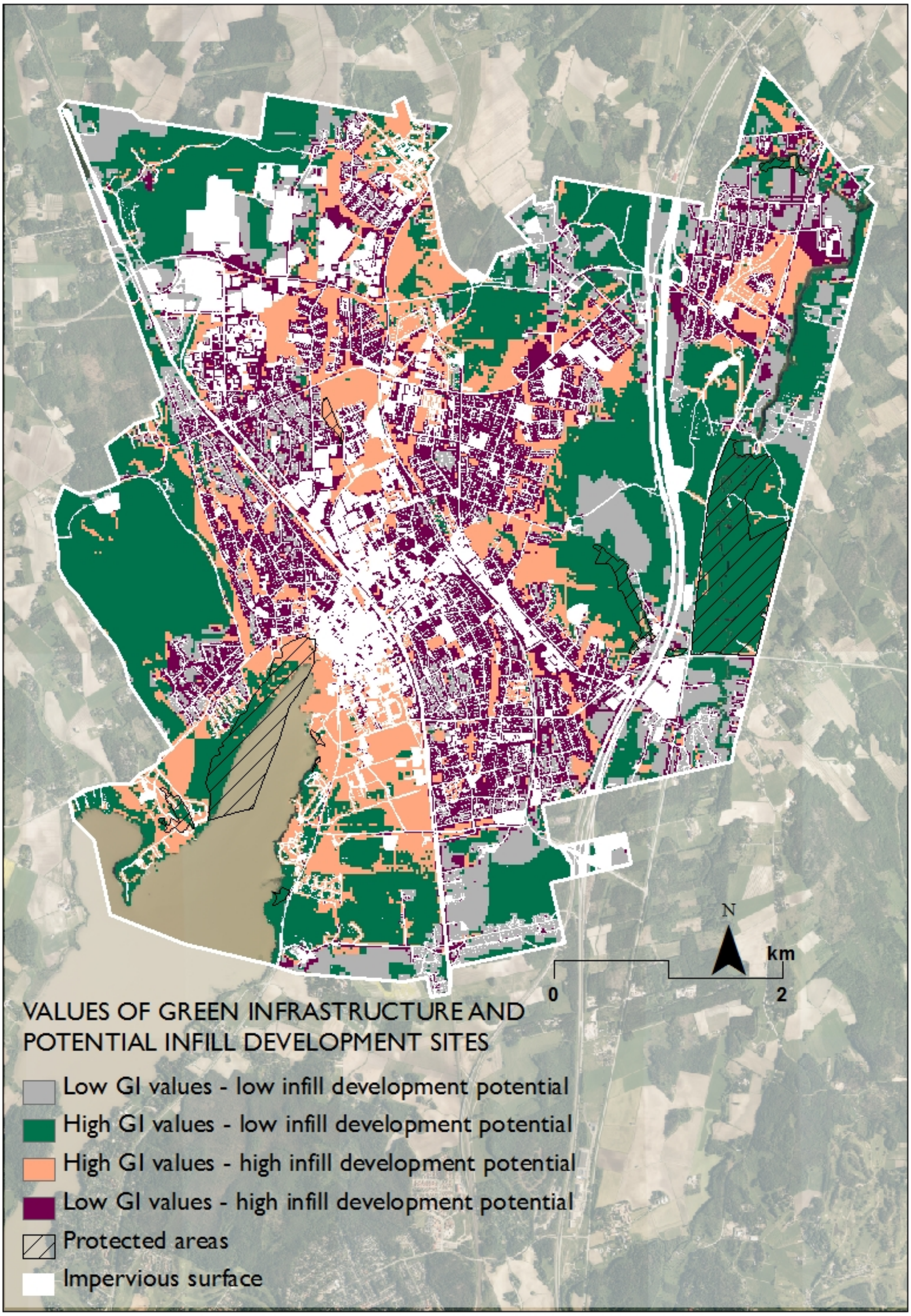


Figure Box 11: Project initiated from the policy question (A) requiring data from multiple sources (B-D) to reach information (E) to support the planning and decision making related to policy question.



Visualization of the SMCA results: a classified map with an interpretation of each class.

Box 12. Integration of ecosystem condition and services in the context of nature protection management and hazard assessment in the town of Karlovo, Bulgaria (Nedkov et al. 2018).
In the case study of Central Balkan, Bulgaria, integration of methods for mapping and assessment of ecosystem services was used in the context of nature protection management and hazard assessment (Nedkov et al., 2018). This area has been a test site for ES mapping and assessment activities carried out under the framework of several research projects at the national, regional and local scale. These studies review, evaluate and consolidate the existing datasets for the area, including the network of protected areas in the Central Balkan. The integration of ecosystem condition and services is embedded in the methodological framework for mapping and assessment in Bulgaria, as both of them are assessed in the same relative scale. This allows convenient and easy interchange of data and results from different indicators of condition or services as well as methods integration and interlinkages. The urban ecosystem condition was assessed by the integrated index of spatial structure derived by using of two indirect measurement methods (figure xxx): remote sensing and earth observation derivatives and use of statistical data. Different sources of statistical data including digital cadastre of settlements and restored property maps were used to identify and delineate the urban ecosystems (represented as vector polygons in a GIS database). Orthophoto maps were used to identify and map land cove and build types within the urban ecosystems polygons. The generation of the spatial index is a result of several repetitive procedures including GIS-based analyses and visual interpretation of orthophoto images. The integrated index of spatial structure was used to calculate the vegetation cover in the urban ecosystem for each individual polygon of the database. Furthermore, these indicators in combination of water holding capacity were used to assess the flood regulation capacity of the urban ecosystems. The assessment of water holding capacity was carried out using two soil water retention parameters (field water holding capacity and filtration rate. Spatial proxy method based on soils property maps and spatial interpolation was used to represent the soils water retention in the study area. Then the capacity of urban ecosystems to provide flood regulation ES was mapped by application of spreadsheet (matrix) method by use of a uniform relative assessment. For these purposes, the study utilises a 0 to 5 assessment scale which is applicable for both qualitative and quantitative indicators. This scale can be used for expert-based assessment, as well as with quantitative data, such as m /sec for flood regulation. The quantitative data were arranged into corresponding intervals using statistical methods in order to normalise them to the relative assessment scale. The use of a special colour scheme for all maps also facilitates the communication of the results and better supports the decision-making process.

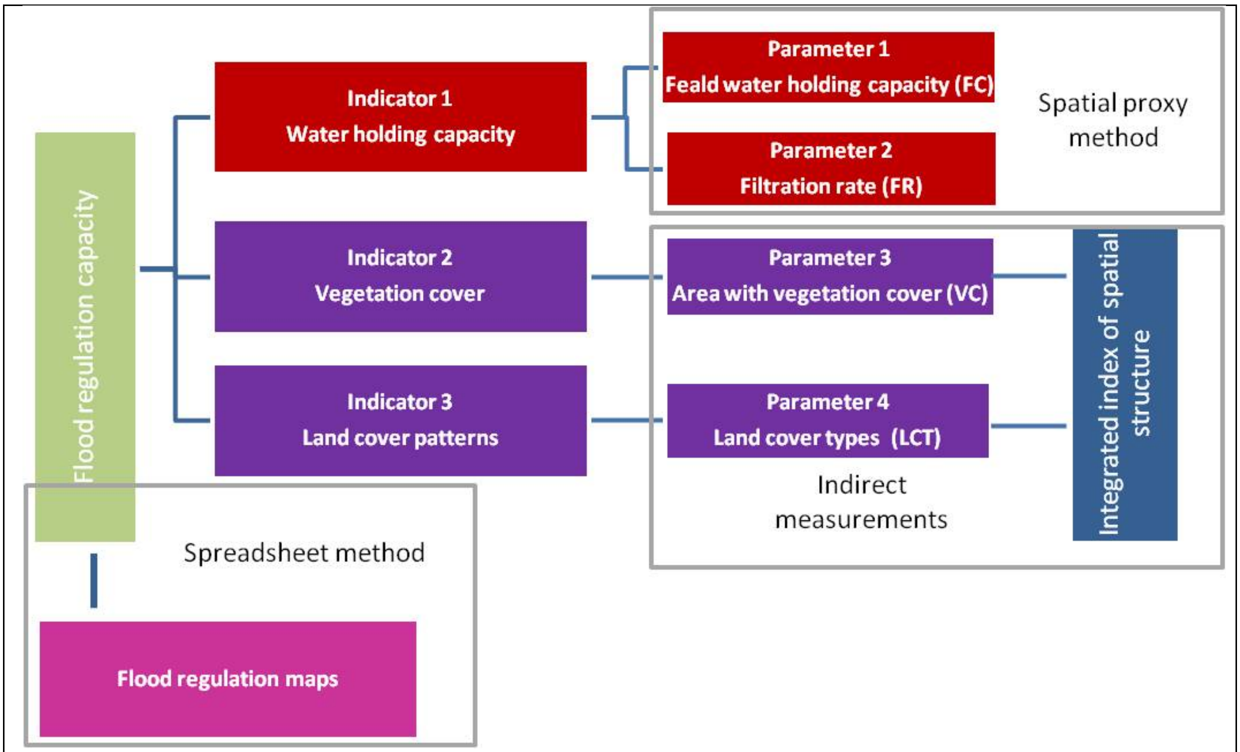


Figure Box 12. *Workflow for mapping of flood regulation provided by urban ecosystems in the town of Karlovo.*

6. Guidance recommendation for interlinked methods and use of methods for integrating information

Here we provide general guidance recommendations for a combination for interlinked and use of integrating information from different sources and methods within an ecosystem service mapping and assessment study.

- *Policy driven research design*

The selection of methods to apply and link should be based primarily on the policy question that the assessment aims to inform, and secondly by the available data and resources. Researchers may have preferences for particular methods due to their expertise, experience or academic interests. It is necessary, however, to select the methods that can be most effectively linked to deliver robust information to answer the policy question.

- *Iterative study design process*

It is often necessary to adjust the selection of methods or data to be used in an assessment after the study has started as the suitability of methods, availability of data or other limitations become known. This is particularly likely when linking methods from different disciplines. While each individual method might be well understood, there is generally less experience or understanding of how methods can be linked (in terms of units, scale, classification systems etc.). The assessment process should therefore build in flexibility to allow the study design to be modified as the links between methods are established. Be prepared to change the specification of methods (including their inputs and outputs) to enable them to be linked.

- *Multidisciplinary research teams*

The use of methods from multiple disciplines requires their implementation by multidisciplinary research teams. It is not uncommon that in order to complete assessments that use multiple methods, researchers with a particular disciplinary background attempt to implement methods from other disciplines. The results are not always successful and methodological mistakes could be avoided by involving researchers with expertise in each relevant discipline. The use of multidisciplinary teams raises the challenge of communication between researchers that have their own terminology and perspective but addressing this challenge is in itself a useful step to communicating results to a broader audience.

- *Avoid common pitfalls*

Studies that attempt to link biophysical, social and economic methods are observed to make a number of common mistakes. In general, this takes of form of overly simplified assumptions in order to establish the links between methods. Common mistakes may subsequently become established in the literature and appear to be widely accepted. One example is the frequently made link between changes in land cover (modelled using biophysical methods) and the economic value of associated changes in ecosystem services (estimated using fixed money values per hectare of each land cover class – often obtained from published summaries of the economic valuation literature). This approach misses any spatial variation in the actual provision, use or value of services. An example of another common pitfall in linking changes in biophysical ecosystem function (e.g. nitrogen filtration by wetlands) with economic value is the assumption that the cost of replacing the service with manmade infrastructure (e.g. a water filtration plant) is a valid measure of benefit irrespective of whether the function is realised as a service (i.e. used by people).

- *Match spatial scales and units across methods*

It is important that the methods that are linked in an assessment are conducted at the same spatial scales. Specific methods may be naturally better suited to implementation at certain scales due to data availability or other practical considerations. For example, many social methods that involve stakeholder participation are well suited to local scale assessment but would be challenging to implement at larger scales; whereas some biophysical methods are well suited to national scale assessment if data is available at that scale but difficult to apply if consistent regional data or fine resolution local data are not available. In order to link methods, however, there should be consistency in terms of spatial scale or an adjustment to ensure that the linked information is valid, i.e. a process of scaling up or down data to a common scale. Similarly, the units in which links between methods are made should be consistent or adjusted appropriately. For example, biophysical changes in water quality measured in concentrations of nitrogen should be matched to qualitative measures of water quality used in social and economic valuations (e.g. water quality ladder defined by what the water can be used for).

- *Consistency across tiers*

The tiered approach to selecting between assessment methods is explained in detail in Section 4 but in brief the assignment of methods to tiers is related to the resources required for implementation and the robustness of the results. When linking methods in an ecosystem service mapping and assessment study it is recommended to use methods that are of the same tier. The complexity in using multiple methods to quantify and map ecosystem services makes it difficult to quantify the overall accuracy of the final information because the uncertainties stack at each stage of the analysis. Mixing methods of different tiers risks undermining the relatively robust results of a high tier method (which required substantial input of resources) with the relatively simple results of a low tier method.

- *Dealing with different sources of uncertainty*

Most decision-making contexts involve some degree of uncertainty about the possible range of outcomes for a given option. This is also the case with integration method that deals with complex environmental systems for which the outcomes cannot be known with certainty. Uncertainty in integrated methods derives from the fact that different studies may assume different conceptual representations of reality and/or choose to focus on different variables and processes, which are portrayed in different ways within each of the three alternatives described above. There are three general sources of uncertainty in integrated modelling approaches are: (i) input data, (ii) method selected uncertainty, and (iii) estimation uncertainty. Each of these sources of uncertainty is described below:

- *Distribution of impacts across individuals and groups*

The distribution of costs and benefits across different groups in society is usually an important criterion in public decision-making and needs to be assessed as part of the evaluation process. The allocation of the benefits and costs among different groups within society may well determine the political acceptability of alternative options.

- *Distribution of costs and benefits*

In practical terms, it is important to assess the burden of costs and benefits received by local residents, as they often have a strong influence on how successful project implementation will be. If local residents stand to lose out from a particular project they are unlikely to support it. It is often the case with ecosystem conservation in small islands that simply attempting to exclude local people from accessing an environmental resource will not be successful without sharing the benefits of conservation with them. Understanding who gains and – in particular – who loses from each policy option can provide important insights into the incentives that different groups have to support or oppose each project. This approach can thus provide useful information in the design of appropriate responses. In terms of ethical considerations, the analysis of the distribution of costs and benefits is important to ensure that conservation interventions do not harm vulnerable groups within society. Recent studies show that the poor are often very dependent on natural resources for their livelihoods, and may therefore be heavily affected (positively or negatively) by changes in resource management.

- *Spatially distributed impacts*

The spatial distribution of impacts from alternative policy options may also be of interest to decision makers, particularly where different user groups are located in different areas. The analysis of the spatial distribution of impacts may be seen as an extension of the distributional analysis described in the previous section and may be a useful approach to identifying different societal groups that are impacted by a project. For example, projects that address water management at a river basin level are likely to affect upstream and downstream stakeholders differently – and this should be identified through spatial analysis. Alternative policy options will generally result, not only in different aggregate costs and benefits, but also in the spatial distribution of impacts. If these differences in spatial distribution are considered of importance, the decision problem of selecting between alternative mitigation options has a spatial element. A useful means of conducting spatial analysis of impacts and of representing spatial distributions of costs and benefits is through the use of Geographical Information Systems (GIS).

- *Temporally distributed impacts.*

Most policy options will result in impacts not only in the current year but also over a number of years into the future. Both the costs and benefits of a project will therefore have a temporal distribution. It is often the case that projects involve initial investment costs and that a stream of benefits is received over several years in the future. It is important to account for this distribution of costs and benefits over time because people tend to value a benefit or cost in the future less than a benefit or cost now. The practice of accounting for this time preference is called discounting and involves putting a higher weight on current values. There are two motivations for this higher weighting of current values. The first is that people are impatient and simply prefer to have things now rather than wait to have them in the future. The second reason is that, since capital is productive, a pound's worth of resources now will generate more than a pound's worth of goods and services in the future. Therefore, an entrepreneur is willing-to-pay more than one pound in the future to acquire one pound's worth of these resources now. In most cases, the discount rate is therefore based on the opportunity cost of capital – the prevailing rate of return on investments elsewhere in the economy, i.e. the interest rate.

7. Conclusion

This report describes three main integration alternatives that can be applied to decision-making regarding ecosystem services. These alternatives do not promise to provide the 'correct' answer for decision makers but should be seen as useful guidance recommendations for structuring information and supporting decisions. The level and extent of integration is at the users' discretion according to the level of data, time and resources they have available. In this report, we provide practical guidance on interlinking methods for mapping and assessing ecosystem services and on the methods that can be used for integrating information from different sources. Examples used in this report are inspired by the case studies of the ESMERALDA database as well as additional cases that demonstrate the nature of these methods. This report on interlinking mapping and assessment methods and methods for integrating information contributes to the development of ESMERALDA main objective to develop a flexible methodology for mapping and assessment activities in the EU.

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Appendix 1: Publications derived from the work in Task 3.4, respectively this deliverable:

Potschin-Young, M.; Burkhard, B.; Czúcz, B. and F. Santos-Martín (2018): Glossary of ecosystem services mapping and assessment terminology. OneEcosystem 3: e27110 https://doi.org/10.3897/oneeco.3.e27110

Santos-Martín, F.; Viinikka, A.; Monomen, L.; Brander, L.; Vihervaara, P.; Liekens, I. and M. Potschin-Young (2018): Creating an operational database for Ecosystems Services Mapping and Assessment Methods. One Ecosystem 3: e26719 doi: 10.3897/oneeco.3.e26719

One Ecosystem : Review Article

Print

Glossary of ecosystem services mapping and assessment terminology

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Abstract

Mapping and assessment of ecosystems and their services (MAES) is a key EU initiative to synthesize vital environmental information and facilitate balanced policy decisions. As MAES integrates across many scientific and policy domains the development of a common language and shared concepts is essential. Here we present a comprehensive MAES glossary that was compiled in the ESMERALDA project; it is based on the integration of several previous glossaries and a wide-ranging consultation process. While there are several ecosystem services glossaries available as from EU supported work such as Oppla, OpenNESS, and ecosystem services related handbooks, the new material presented here focusses on mapping and assessment of ecosystem services and therefore more directly supports the MAES process.

Keywords

Ecosystems, Ecosystem Services, Mapping, Assessment, Terminology, ESMERALDA, OpenNESS, EU Biodiversity Strategy

One Ecosystem 3: e26719
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Research Article

Creating an operational database for Ecosystems Services Mapping and Assessment Methods

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Abstract

Identifying and applying the appropriate method for ecosystem services mapping and assessment is not trivial. To provide guidance in this task, this paper describes the creation of a database for existing studies on mapping and assessing ecosystems and their services, which records relevant information to the ecosystem studies (e.g. methods used, the scale, ecosystem type, ecosystem service categories) and other relevant attributes that need to be considered. This database, therefore, forms the basis for an online ecosystem service 'methods finder'. Our results provide an overview of the database itself (883 entries until April 2018) and the consultation within the ESMERALDA consortium that shaped its development, as well as providing an overview of the final mapping and assessment methods describing their spatial distribution. This work helps identify the main gaps and opportunities for alignment and development of commonalities in analytical approach amongst the individual Member States. The results illustrate the different conditions,