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Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits

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ABSTRACT

In this study we assess multiple benefits (environmental, social and economic) provided by a multi-purpose green infrastructure (a series of constructed wetlands surrounded by a park) in a peri-urban area, and compare it with the alternative grey infrastructure and with the previous situation (a poplar plantation). We apply a multi-criteria analysis as a basis for integrated valuation. We address specific policy needs (strategic objectives) for the local territorial planning in the implementation of the EU Water Framework Directive. The analysis is used retrospectively (*ex post* evaluation) but our results could also be used prospectively to appraise new proposals of constructed wetlands under similar circumstances.

The results reflect that the green infrastructure performs equal or even better than the grey infrastructure alternative for water purification and flood protection, it has a similar cost, and it provides additional benefits (like wildlife support and recreation). The most preferred alternative is the green infrastructure, followed by the grey infrastructure and the poplar plantation.

This study demonstrates (a) the effectiveness of investments on nature-based solutions, (b) the potential of green infrastructures for delivering a broad range of ecosystem services, and (c) the utility of integrating different value systems and stakeholders' viewpoints to support environmental decision-making.

1. Introduction

Natural ecosystems are hypothesized to provide viable (cost-efficient and effective) solutions to tackle numerous societal challenges such as climate change, disaster prevention, sustainable cities and water resource management. In the present EU policy context, the use of natural ecosystems as smart solutions is promoted by several strategies. The EU Biodiversity Strategy[1] have set specific policy targets for maintaining and enhancing ecosystems and their services by establishing green infrastructures and restoring degraded ecosystems. Green infrastructures[2] are considered to provide multiple benefits contributing to achieve the objectives of several policies, including climate change and environmental policies, disaster risk management, health and consumer policies and the Common Agricultural Policy. Specifically for water policy, the recent Blueprint to safeguard Europe's water resources[3] indicated that green infrastructures and nature-based solutions, such as natural water retention measures, can greatly contribute to the provisioning of ecosystem services and should be adopted as measures in the implementation of the Water Framework Directive and the Flood Directive through the territorial planning. Therefore there is a great interest in investing in nature-based solutions assuring multiple ecosystem services. But how to measure the effectiveness of these measures and how to account for the multiple benefits they provide? These are the two key questions we want to address in the present study, based on a real case application.

Nature-based solutions are defined as actions inspired by, supported by or copied from nature that help societies address a variety of environmental, social and economic challenges in sustainable ways (DG Research and Innovation, 2015). Other definitions highlight the contribution of well-managed and diverse ecosystems to enhance human resilience and sustainable development, thus focusing on ecosystem services. For instance, Maes and Jacobs (2015) define nature-based solutions as *any transition to a use of ecosystem services with decreased input of non-renewable natural capital and increased investment in renewable natural processes*. Eggermont et al. (2015) differentiate three types of nature-based solutions that share the aim of

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[1] European Commission, 2011 COM(2011) 244 final.
[2] European Commission, 2013 COM(2013) 249 final.
[3] European Commission, 2012 COM(2012) 673 final.

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improving the delivery of a range of ecosystem services: solutions of no or minimal intervention in ecosystems, interventions in managed ecosystems and landscapes that look for sustainability and multi-functionality, and creation or deep modification of ecosystems usually to build green or blue infrastructures. The case study shown in this paper corresponds to the third type. Any of these visions implies that maintaining and enhancing natural capital and ecosystem services is of crucial importance. In Europe, investing in nature-based solutions can lead to wide socio-economic benefits, provision of jobs, and low-carbon technology innovations, that is, to sustainable economy and development as envisaged by the EU Horizon 2020 vision (Maes and Jacobs, 2015). Some of the nature-based engineered solutions already used in urban planning and water management (e.g. green roofs, bio-infiltration rain gardens, vegetation in street canyons) have demonstrated to be more efficient, cost-effective, adaptable, multi-purpose and long-lasting than the so-called 'grey infrastructure' alternatives (e.g. Gill et al., 2007; Pugh et al., 2012; Ellis, 2013; Flynn and Traver, 2013; Raje et al., 2013).

In order to support the implementation of innovative nature-based solutions in environmental management and land use planning, valuation becomes essential. Valuation can refer to monetisation (assessing a monetary value) or to an estimation of worth or importance (Dendoncker et al., 2014). In this case, valuing for sustainability and for environmental decision-making requires to account for ecological, social and economic aspects, which are considered the three pillars of integrated valuation (Boeraeve et al., 2014; Dendoncker et al., 2014; Gómez-Baggethun et al., 2014). One of the possible methodologies to achieve value integration is multi-criteria analyses (MCA). MCA is a framework for exploring and ranking the performance of alternative decision options according to multiple objectives (Belton and Stewart, 2002; Hajkowicz and Collins 2007). It can combine a wide assortment of information (e.g. qualitative and quantitative) and opinions. The approach has been largely applied for water resource management (Hajkowicz and Collins, 2007). MCA establishes preferences between options (usually identifying the most preferred option) by reference to an explicit set of objectives for which it has established measurable criteria (Department for Communities and Local Government, 2009). Their aim is to simplify handling complex information to take difficult decisions in a consistent way.

In this study we assess the benefits of a multi-purpose nature-based solution for water pollution control in a peri-urban area located in Gorla Maggiore (northern Italy), using an ecosystem service approach and applying an integrated valuation based on MCA for local water management. This solution is compared with the alternatives "doing nothing" and with the construction of a conventional grey infrastructure. This case study gives an example of integrating different value systems and stakeholders' viewpoints, thus providing hands-on guidance for integrated valuation in ecosystem service assessments linked to (water) decision-making.

2. Study area: the alternatives

The study area is located in Gorla Maggiore, a small municipality in northern Italy (Fig. 1). Gorla Maggiore is one of the case studies of the EU FP7 project OpenNESS (http://www.openness-project.eu/). This project has 27 case studies across Europe to test practical solutions that integrate the concepts of natural capital and ecosystem services into land, water and urban management. In particular, the main objectives of the Gorla Maggiore case are:

- To investigate all the benefits that a neo-ecosystem could provide in terms of ecosystem services (water purification, flood regulation, natural habitat, recreation).
- To compare the green infrastructure (water park) with other conventional grey infrastructures and with the previous situation (a private poplar plantation).
- To integrate the ecosystem service approach in the decision-making process and in river basin management plans, through the direct

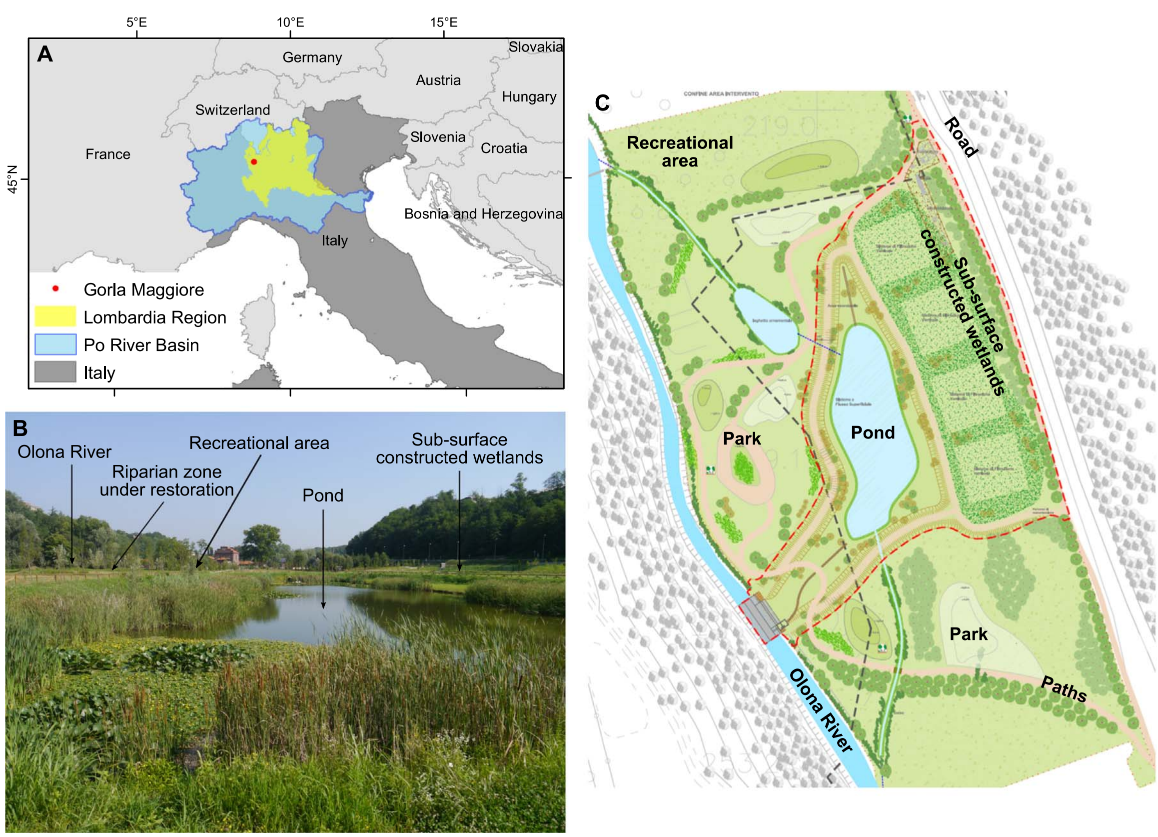

Fig. 1. Location, illustration and map of the study area with the present nature-based solution.

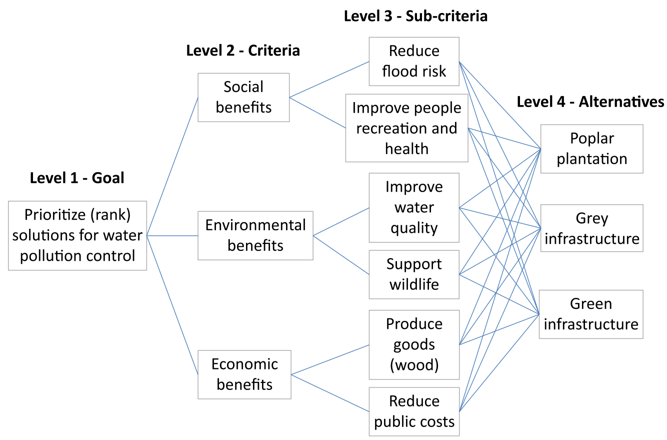

Fig. 2. The four levels of hierarchical structure used in this case study. Note that five of the six sub-criteria are ecosystem services.

involvement of the stakeholders.

Gorla Maggiore hosts an innovative nature-based solution to treat water pollution from the adjacent urban area. It consists of a green infrastructure that was specifically designed to treat the water discharged into the Olona River by the Combined Sewer Overflow (CSO), i.e. the excess flow of mixed sewage and rainwater that cannot be treated in the waste-water treatment plant during heavy rain events. These overflows are relatively common in the site (70 events were registered between March and August 2014, Masi et al., 2016) and contain not only storm water but also untreated human and industrial waste, toxic materials, and solids.

Since constructed wetlands are starting to be considered as an eco-suitable technology to treat CSO (Meyer et al., 2013), the construction of the Gorla Maggiore water park has been funded by the regional government and a private foundation (Regione Lombardia and Fondazione Cariplo) as a trial to test the feasibility of constructed wetlands to treat the CSO. The treatment of the overflows during rainy events is a critical issue in the Lombardy Region, since there are several thousands of CSOs that contribute significantly to the overall pollution load to surface water. To tackle the problem a regional law (R.R. n.3 from 24 March 2006), compliant with the EU Water Framework Directive, limits the pollutant load discharged by the CSO.

In this paper we compare and value the benefits provided by three different alternatives in Gorla Maggiore. The alternatives represent the most realistic options for water pollution control in the site facing the pressure from the urban area:

1. The present Gorla Maggiore water park, called here the green infrastructure. The water park is a constructed ecosystem of about 9 ha built on the Olona River bank during 2011–2012. It includes (a) a pollutant removal area composed of a grid, a sedimentation tank and four vertical sub-surface flow constructed wetlands; (b) a multipurpose area with a surface flow constructed wetland or pond with multiple roles, such as pollution retention (secondary and tertiary treatment), buffer tank for flood events, maintenance of biodiversity and recreational area; and (c) a recreational park with restored riparian trees, green open space, walking and cycling paths and some services (e.g. picnic table, toilets, bar) maintained by a voluntary association (http://www.calimali.org/).
2. The standard solution used to treat waters from CSOs: a first-flush and a buffer tank, called here grey infrastructure. It comprises an underground first flush storage tank of over 1000 m^3, from which the water can be pumped to the wastewater treatment plant within the 48 h after moderate rainfalls; and a dry retention pond for second flush (open-air), where the excess water during heavy rainfall can be stored until naturally drained. The size and technical characteristics of the grey infrastructure correspond to the legal requirements in Regione Lombardia.
3. Keeping the previous situation or "doing nothing": the poplar plantation. It replicates the previous private use of 4.2 ha for productive forestry, in particular for young poplars that are relatively common along the Po valley.

Table 1
Criteria, sub-criteria and indicators selected for this case study. For a complete description of the indicators see Section 3.2.

Criteria	Sub-criteria	Indicators
Social benefits	Reduce flood risk	Peak flow reduction Reduction of flooding downstream
	Improve people recreation and health	• No. of visitors/users • Frequency of visits
Environmental benefits	Improve water quality	• Load reduction of dissolved organic carbon • Load reduction of nitrogen
	Support wildlife	• Expert judgment about biodiversity • Landscape diversity
Economic benefits	Produce market goods	• Value of wood production
	Reduce public costs	• Total construction costs • Total maintenance costs

3. Materials and methods

We applied a multi-criteria analysis (MCA) based on the analytic hierarchy process (AHP), a well-established methodology developed in the 1970's (Saaty, 1980) that deals with multi-criteria decision-making and allows for the participation of multiple stakeholders (including individual and group preferences). We combine the MCA with an ecosystem services approach since most of the criteria identified are actually ecosystem services. AHP is a useful tool based on mathematical and psychological fundamentals to analyse complex decisions, involving multiple stakeholders and multiple alternatives. It applies a hierarchical structure that facilitates the definition of priorities and preferences in decision-making (Saaty, 1980). The application of the AHP to get a functional MCA for Gorla Maggiore involved the following steps: 1) identify the problem and structure it as a hierarchy; 2) assess the different alternatives; 3) pairwise compare and judge the elements of the hierarchy; 4) estimate the overall priority values to rank the alternatives; and 5) run a sensitivity analysis of weights.

3.1. Structure the problem

3.1.1. Stakeholders

To structure the problem the view of different stakeholders is fundamental. Stakeholders are actors (individuals, groups or organizations) whose interests may be affected, positively or negatively, by a specific public decision or policy. Three main groups of stakeholder associated with the problem and defined in the preliminary research were involved in this study case, totalling 19 participants:

- water management institutions (local & regional governments, environmental regulators and water management authorities).[4] These managers or representatives from institutions are responsible for the implementation of environmental or water regulations at river basin, regional or local scales.

[4] Stakeholders come from Regione Lombardia, ARPA Lombardia, ATO Varese, Autorita del Bacino del Po, Fondazione Cariplo.

Table 2
Scale to represent the intensity of preference.

Intensity of importance	Definition (verbal scale)	Explanation
1	Equal importance	Two sub-criteria contribute equally to the objective
2	Slightly preferred	Experience and judgment slightly favor one sub-criteria over another
3	Preferred	Experience and judgment strongly favor one sub-criteria over another
4	Strongly preferred	A sub-criteria is favored very strongly over another; its dominance is demonstrated in practise
5	Extremely more important	The evidence favoring one sub-criteria over another is of the highest possible order of affirmation

Table 3
Assessment of alternatives, also called performance matrix. The percentage of change between alternatives is calculated with respect to the maximum value per indicator, with a negative sign indicating a decrease from the original situation to the new one.

	Alternatives			Changes between alternatives (%)	
Indicators	Poplar	Grey	Green	From poplar to grey	From poplar to green
Peak flow reduction (%), return time of 10yr	0	80	86	93	100
Reduction of flooding downstream (m3), return time of 10yr	0	8100	8900	91	100
Load reduction of dissolved organic carbon (t/yr)	0	9.5	11.7	81	100
Load reduction of nitrogen (t/yr)	0	0.2	0.4	50	100
Expert judgment about biodiversity	low	low	high	0	50
Landscape diversity (Shannon's diversity index)	1.89	1.85	2	−2	6
No. of visitors/users	very low	medium	high	50	75
Frequency of visits	very low	medium	high	50	75
Value of wood production (profit from harvest in EUR)	21420	0	0	−100	−100
Total construction costs (EUR)	0	844750	900000	94	100
Total maintenance costs per 20yr expected lifespan (EUR)	0	27824	29590	94	100

Table 4
Descriptive statistics of the weights assigned to each sub-criteria by the stakeholders (%).

	Individual scores or weights				
Sub-criteria	Minimum	Maximum	Mean	Median	St. Dev.
Flooding	7.1	36.5	22.1	22.0	12.9
Pollution	8.7	38.3	26.9	26.4	20.3
Wildlife	10.8	35.3	21.4	20.7	14.3
Recreation	6.2	33.2	13.7	11.8	7.1
Wood	3.2	6.8	4.8	4.4	3.6
Costs	4.5	26.6	11.2	8.4	5.9

- scientific & technical experts (university professors, consultants & SMEs, scientists).[5] These technicians are some researchers involved in the Openness project, the SME in charge of building and monitoring the green infrastructure or other university professors and consultants specialised in grey infrastructures.
- local actors & NGOs (local experts, citizens' associations, environmental associations, municipalities).[6] These local stakeholders are assumed to represent the local views.

The choice of stakeholders was designed to cover all groups that may be affected by or involved in the project and those who can take decisions to implement such a project. Thus, the stakeholders cover: (1) the key water managers or decision-makers according to the Italian administrative framework (they have high influence and from low to high interest); (2) experts of both conventional grey infrastructures and green infrastructures to treat CSO that may support and evaluate the different alternatives, together with economic, environmental and statistical experts able to assess the project (in general they have high interest and low influence); and (3) representatives of social groups affected by the project decision and potential users of the area (in this case study they have low influence and high interest, those with low interest refused the invitation to take part of the study).

3.1.2. Problem hierarchy

The first step in an AHP is to structure the problem as a hierarchy. At the uppermost level is the goal(s) or objective(s) to be achieved, followed by a series of criteria and sub-criteria that contribute to attain the main goal. At the bottom level we find a number of alternatives that should be evaluated with respect to the criteria and sub-criteria. Choosing the appropriate criteria and sub-criteria is the main challenge in a MCA. They are site and context specific, and they should be designated by all the involved stakeholders (Garfì et al. 2011).

Fig. 2 illustrates the final AHP hierarchy defined in Gorla Maggiore. It is the result of some literature review (e.g. Ellis, 1998, Ananda and Herath, 2003, Martin et al., 2007, Chávez et al., 2012, Xu et al., 2014, Kukrety et al., 2013, Kurka and Blackwood, 2013, Petrini et al., 2016), a detailed analysis of the case study, two dedicated meetings with the stakeholders, and further bilateral dialogues with some of the stakeholders (in particular with the technical responsible for the infrastructure in the town hall, a local expert and the regional environmental agency). See Section 3.1.1 for a complete description of the stakeholders involved.

The social process followed to build the hierarchy included the following steps:

- The main goal of the study was planned by the authors and the regional government (the main funder of the infrastructure) and shared by the rest of stakeholders since the beginning of the project.
- The sub-criteria (basically, the ecosystem services) included in the analysis were selected by all the stakeholders through a dedicated meeting in October 2013 and, hence, they represent the main interests of the stakeholder group. Naming and classification of the sub-criteria were further elaborated by the authors (in an inclusive manner) to avoid ambiguity and double-counting. Then, they were approved by the rest of stakeholders through bilateral discussions and during another meeting in January 2015.
- The selection of and grouping by criteria was an academic exercise performed by the authors. They covered the three pillars of an integrated valuation, but they were neither planned nor discussed within the stakeholders group. That is, the main interests expressed by the stakeholder group naturally covered ecological, social and economic aspects.
- The alternatives were suggested by the authors based on tangible scenarios under the case study context. Their main narratives were

[5] Stakeholders come from Universita di Pavia, Politecnico di Milano, IRIDRA s.r.l., EC Joint Research Centre.
[6] Stakeholders come from Comune di Gorla Maggiore, Legambiente, Associazione Calimali, local naturalist.

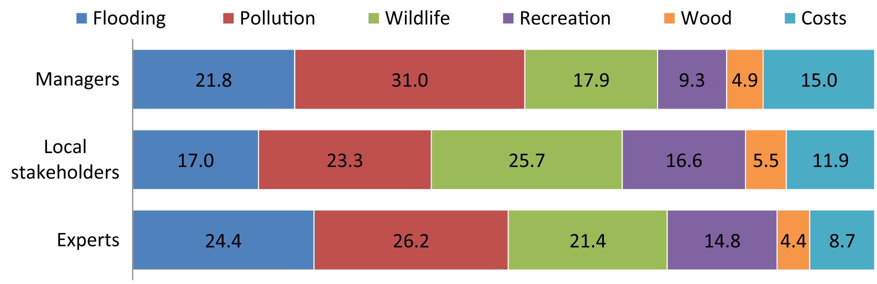

Fig. 3. Preference elicitation of the sub-criteria by stakeholders' groups (%). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

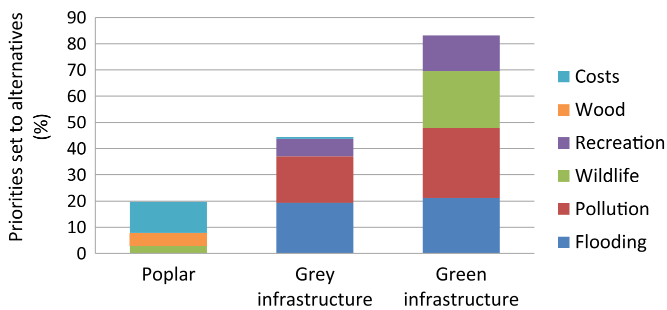

Fig. 4. Comparison of alternatives based on the results of the MCA (score in %). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

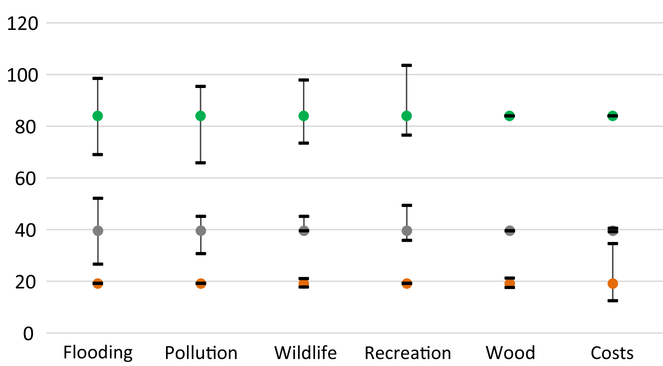

Fig. 5. Variation of the final alternative priority (score in %) depending on each single sub-criterion. The central values (green circles for the green infrastructure, grey circles for the grey infrastructure and orange circles for the poplar plantation) point to the global score shown in Fig. 4. Error bars represent the influence of minimum and maximum weights. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

shared and accepted by the all the stakeholders during the meeting of October 2013. The technical descriptions were further itemized and modified to include all stakeholders comments after the meeting of January 2015. Similarly, the indicators were proposed by the authors based on suitability and feasibility, and they were revised and in some cases adjusted after the discussion of January 2015. Some of the stakeholders, notably the regional government, the water agency, the municipality and the experts, contributed actively to the design and measurement of indicators and alternatives.

In this case the goal represents the main objective to construct the site, water pollution control, and how to select the best option. The second level includes broader priorities for public policies, actually integrating the concepts of natural capital and ecosystem services into water and urban management. It refers to criteria dealing with the environmental, social and economic benefits. The third level of the hierarchy had originally 11 sub-criteria that were further discussed and grouped into the final 6 sub-criteria of Fig. 2 which represent the main areas of concern. It is recommended that the number of elements in a level do not exceed 10 (Kukrety et al., 2013). Keeping a reduced number of sub-criteria helps avoiding confusion due to a large number of comparisons and, consequently, decreases the uncertainty of the process. Five of the six sub-criteria are benefits or ecosystem services provided by the Gorla Maggiore water park (water purification, flood protection, maintenance of natural habitats, recreation and wood extraction) while the sixth one is an analysis of public costs. Each of the sub-criteria is then measured against a number of indicators shown in Table 1.

Finally, the fourth and bottom level of the hierarchy includes the alternatives, in terms of water pollution control implementations, that might be more adequate for the success of the public policies. The alternatives, already described in Section 2, represent the previous situation or "doing nothing" (a poplar plantation), the conventional

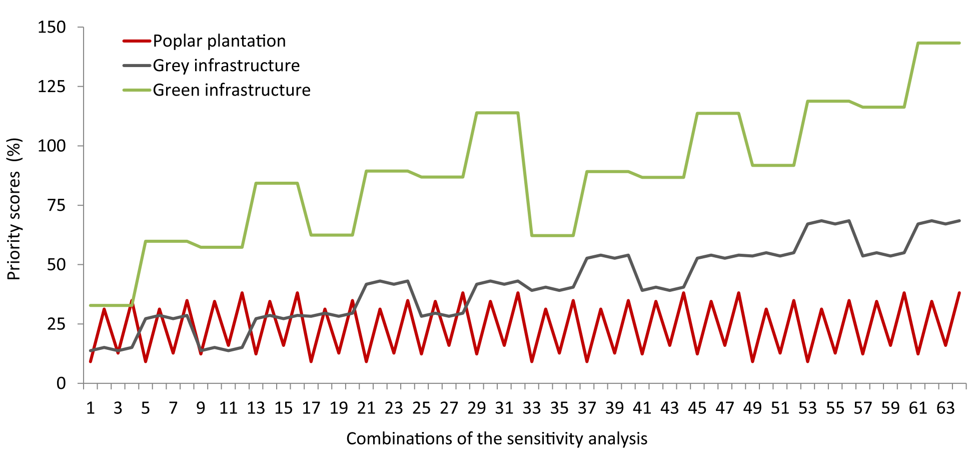

Fig. 6. Ranking of alternatives under the 64 combinations of a high dimension sensitivity analysis. The priority scores set the priorities of the three alternatives in each combination of values of sub-criteria. Combination 1 assigns the weights of all the sub-criteria to their minimum value while combination 64 assigns all weights to their maximum value. The scores show a rising trend with the increasing weights (especially for flood protection, water quality, recreation and wildlife support). This rising trend is greater for the green alternative. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

solution used to treat waters from CSOs (the grey infrastructure), and the present Gorla Maggiore water park (the green infrastructure).

3.2. Alternatives assessment

The performance of each alternative under the six sub-criteria was assessed based on the indicators of Table 1. As already explained in Section 3.1.2 (the steps of the social process), the indicators were proposed by the authors based on their relevance and feasibility to be measured under the three alternatives, and they were further refined through an iterative process with the stakeholders. Actually, some of the stakeholders were instrumental to monitor the site and perform the assessments, or to provide feedback on the measured data. Some of the indicators are evaluated with a quantitative scale (e.g. cost) and other with a qualitative scale (e.g. expert judgment about biodiversity).

The assessment of alternatives took one year of monitoring and research (roughly the year 2014). Due to the small scale and the specificity of the case study, each of the indicators has a specific quantification method, as follows:

- Peak flow reduction (%): this indicator estimates the reduction of the maximum peak flow of the hydrograph generated by a rain event with return time of 10 years. The hydrograph is derived from the design data of the CSO-constructed wetland with a runoff model. The value for the grey infrastructure was calculated according to the Lombardia Region guidelines for buffer tanks. The green infrastructure value was estimated from the modelling simulations performed in Rizzo et al. (2015), which account both the pond (buffer tank) and the vertical flow bed lamination effects. No lamination capacity has been assumed for the poplar plantation since the CSO was directly discharged to the river before the construction of artificial wetlands.
- Reduction of flooding downstream (m^3): reduction of the water volume flowing downstream from a rain event with return time of 10 years. The methodology followed to measure this indicator is the same of the previous one.
- Load reduction of dissolved organic carbon (t/yr): amount of dissolved organic carbon avoided to be discharged in the river, contributing to the improvement of the river water quality. The load reduction for the green infrastructure was directly measured in 68 registered CSO events from February 2014 to February 2015 using a mass balance approach (Masi et al., 2016). The load reduction for the grey infrastructure is derived from the same mass balance approach based on the first flush volume requested by the Lombardia region law, equal to 989 m^3 for the CSO of Gorla Maggiore, and assuming no load reduction capability of the buffer tank. No removal efficiency has been assumed for the poplar plantation, since the CSO was directly discharged to the river in the years before the construction of artificial wetlands.
- Load reduction of nitrogen (t/yr): amount of nitrogen avoided to be discharged in the river, contributing to the improvement of the river water quality. The value is expressed in tonnes of $N\text{-}NH_4^+$ per year. The methodology followed to measure this indicator is the same of the previous one.
- Expert judgment about biodiversity: a biologist and an ecologist assessed qualitatively the expected community diversity and richness in a monoculture plantation with standard farming procedures (for the poplar plantation), in a managed grassland (for the grey infrastructure), and in the set of constructed wetlands (green infrastructure). Biological sampling of the site (macroinvertebrates, macrophytes, birds and amphibians) supported the assessment of the green infrastructure. This indicator has 5 categories: very low, low, medium, high and very high.
- Landscape diversity: This is the Shannon's diversity index of the habitats of each alternative estimated with the software ArcGIS and Fragstat. For the poplar plantation and the green infrastructure, habitat mapping was based on existing satellite images of the site. Habitats of the grey infrastructure were inferred from similar infrastructures and adapted to the site.
- No. of visitors/users and frequency of visits: The number and frequency of local visits in the water park was estimated through a mail survey distributed in Gorla Maggiore that got 71 responses. It is considered that there is no access to the private land under the poplar plantation scenario. The grey infrastructure is assumed to have less visits than the green infrastructure due to the lack of biodiversity and related educational facilities, but the surrounding recreational park can still attract visits. These indicators have 5 categories from very low to very high.
- Value of wood production: The area of poplar plantation was mapped from satellite images while the average regional plant density, productivity, mass volume, wood price and investment costs were derived from the literature (e.g. Istituto di Sperimentazione per la Pioppicoltura, 2001; Fondazione Lombardia per l'Ambiente, 2008; Nervo et al., 2011). We estimated the net profit from the wood harvest being ca. 255 euro per ha and year, and assumed a 20 years rotation period. The other alternatives have no wood production.
- Total construction costs and total maintenance costs: The actual construction and maintenance costs (for a 20 years lifespan) of the green infrastructure were reported by the funders, the town hall and the construction company. The costs of the grey infrastructure were estimated from other existing infrastructures by the construction company. For this study the poplar plantation has no public costs, even if under the regional legislation "doing nothing" to treat the CSO would lead to an infraction and a fine for the municipality.

3.3. Pairwise comparisons

A crucial step in the AHP methodology is the pairwise comparison judgments among the elements at one level of the hierarchy. The AHP comparison is usually performed in each level of the hierarchy (e.g. sub-criteria) linked to the previous level (e.g. criteria), but due to time-constraints during the meetings and taking advantage of the clarity of the attributes, we preferred to compare only the sub-criteria of level 3. The question posed was: Regarding the implementation of water pollution control solutions, which sub-criteria do you think should be given more importance? How much more?

The pairwise comparison survey was carried out during the meeting in January 2015 in the headquarters of the regional government (Regione Lombardia), Milan (Italy). The sub-criteria, indicators and alternatives were technically described to the participants. Then each participant was asked to indicate the relative preference of each sub-criteria over another, based on either the point of view of the public or private institution they were representing, or on their personal judgment (perception). Qualitative (verbal) comparisons among the 15 combinations (all possible discrete combinations of 6 sub-criteria) were converted into quantitative values by using a numerical scale of integers ranging from 1 to 5 (Table 2).

Each one of the comparison or judgment matrices assumes the form:

$$A = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ a_{n1} & a_{n1} & \dots & a_{nn} \end{bmatrix}$$

where a_{ij} represents the pairwise comparison rating for attribute i and attribute j. Given the reciprocal property of the matrix, if $a_{ij}=x$, then $a_{ji}=1/x$ where $x \neq 0$ (i.e. if sub-criteria i has one of the above numbers assigned to it when compared with sub-criteria j, then j has the reciprocal value when compared with i). Mathematically, the principal eigenvector for each matrix, when normalised, becomes the vector of priorities for that matrix (Saaty, 1980). This method also allows controlling potential inconsistent responses (Kukrety et al., 2013).

The consistency ratio (CR) is calculated based on properties of reciprocal matrices (Saaty, 1980). Values of CR≤0.1 are considered as acceptable. The consistency ratio equal or below 0.1 was checked for all judgments, getting 18 valid responses from the 19 stakeholders present in the exercise. This means that one response out of 19 was considered inconsistent and was discarded. The individual judgments (decision matrices shown in the supplementary material of this paper) were then aggregated by stakeholders' group and all together, calculating the geometric means (Saaty and Vargas, 2012).

3.4. Synthesizing priorities

The pairwise comparison judgments are used together with the alternatives assessment to develop overall priorities for ranking the alternatives. The overall priority values are calculated by multiplying the priority of an element (in this case the sub-criteria weights) by the value(s) attributed to it (in this case a normalised average of their indicators). The products are then summed across each branch of the hierarchy using a simple additive function.

To integrate all these values some normalisation and weights are necessary. First, the input data for each alternative (indicators) must be transformed to a comparable scale, since they measure attributes in different scales, intensities and type of data (both numeric and categorical). All indicators are transformed to relative scale using an "ideal" mode, where the "ideal" alternative (or maximum score) is the best performant value of each indicator. The scores range from zero to one. We assume a linear distribution of values for this normalisation (minimum-maximum). When two indicators exist per sub-criteria, both are weighted equally (50%) to estimate an average score per sub-criteria. This decision is based on expert opinion, considering that all indicators have similar representativeness and it would be less biased to consider them equally. The attributes were considered too technical to ask for weights of indicators to the stakeholders. The only exception is the sub-criteria 'public costs' where, based on their magnitude, the weight of the indicators 'construction costs' and 'maintenance costs' was 95% and 5% respectively.

The preliminary results were calculated in the stakeholders meeting of January 2015 and were shown to all participants. These global priorities helped synthetize information, rank alternatives and challenge thinking in the case study.

3.5. Sensitivity analysis

In the context of the MCA presented in this study, sensitivity analysis reveals which criteria weights are most likely to change the outcome in selecting an alternative water pollution control, to investigate the extent to which disagreements between people may affect the final overall decision. Sensitivity analyses are typical run by holding all the variables (weights in this case) constant in a model, except for the one being tested, and varying that variable over its likely range of values. Such tests are referred to as one-way or one-at-a-time sensitivity analyses. In this case, since the weights have a linear relationship with the final scores of each alternative, a simple and very effective approach is iteratively combine the extreme weighs (maximum and minimum) proposed by the stakeholders and analyse what would be the final performance of each alternative under the new weights combination. Considering six sub-criteria, the number of combinations is 2^6=64.

Another possible source of uncertainty is the impact of changes on the value of indicators (i.e. on the assessment of alternatives). However, the level of uncertainty of the assessment is considered very low, since one of the key characteristics of this study is that the infrastructures were already built (i.e. this is an *ex post* assessment) and most of the indicators could be quantified based on existing data. In particular, the poplar plantation existed before, the green infrastructure could be monitored and the grey infrastructure could be observed and extrapolated from other sites.

4. Results and discussion

4.1. Integrated valuation of alternatives

The three alternatives envisaged for the MCA and described in Section 2 (i.e. the poplar plantation or "doing nothing", the conventional grey infrastructure, and the presently existing green infrastructure) are scored according to the establish criteria, sub-criteria and indicators of Fig. 2 and Table 1. In general, the poplar plantation has the lowest values in all sub-criteria but the wood exploitation (Table 3), where the net benefits would be private. Still it has more habitats' diversity than the grey infrastructure. One may argue that the poplar may reduce flooding and pollution to a certain extent, but the magnitude would be negligible compared with ad-hoc infrastructures, especially because the CSO would not flow to the poplar. This option involves "doing nothing" to treat the CSO, which may actually have negative public cost effects (in the form of penalties) in the near future linked to the non-compliance with the regional water legislation. We did not include it in the public cost scores due to lack of available quantifications.

The grey and the green infrastructures have a similar performance in the water-related indicators, with a slight advance of the green infrastructure, more important for pollution reduction indicators where the green option performs significantly better than the grey one (Masi et al., 2016). Construction and maintenance costs are quite similar, in this case resulting slightly more expensive in the green option. All these data come from the existing experience either in Gorla Maggiore or in similar conditions and, thus, can be considered as precise estimations. The foremost difference among the two infrastructures is their performance in terms of wildlife support and recreation. The green infrastructure provides substantially larger benefits as natural habitat and green space for recreation. The surface area of the grey infrastructure could be covered by managed grass, which is not a very diverse habitat, and it could retain muddy sediments and odours after the heavy rains.

The weighting of sub-criteria provided by the stakeholders' group (Table 4) was relatively homogeneous, but still we can appreciate some patterns. Based on the personal weighting factors attributed to each sub-criteria during the pairwise comparison, there seems to be three main interest groups: managers/institutions, technicians, and local stakeholders (see Section 3.1.1).

Managers tend give more importance to the costs (even if to a moderate extent) and to water-related benefits, especially pollution control for which the infrastructure was build, while they give less importance to recreation (Fig. 3). Technicians value similarly flood protection and pollution control and provide the less weight to wood production and public costs. Surprisingly, local stakeholders put the highest relevance in wildlife support. They are also the ones attaching the highest weight to recreation (Fig. 3).

We have tested the MCA model with the three groups of stakeholders, getting very similar results for the prioritisation of options. Here we just present the integrated results from all the participants. In general, the higher weight was assigned to the criteria of water pollution control, as it is the general scope of the infrastructure. Reducing the flooding risk and providing natural habitat scored very similar as second most important criteria. Then, in decreasing order, the stakeholders considered important recreation, the reduction of public costs and wood exploitation.

The best option under the MCA is the green infrastructure, followed by far by the grey infrastructure and finally the poplar plantation (Fig. 4). The combination of weights and scores highlights that the largest differences between options are linked to pollution control and natural habitat.

4.2. Results of the sensitivity analysis

The results of the one-at-a-time sensitivity analysis performed for the global weights proposed by the stakeholders are shown in Fig. 5 and in Supplementary material. It shows how the final score of each of the alternatives varies according to changes in the weights of each of the sub-criteria considered, using the minimum and maximum weights given by all stakeholders. For example, it is observed that the final score of the poplar alternative has almost no variation related to safety, water quality or recreation. This is due to the zero or near-zero utility value of this alternative in relation to those sub-criteria. Something similar happens with the green alternative and the sub-criteria wood production and public costs. These sub-criteria have little effect on the final score of the alternative because it is the most expensive or the less (wood) productive one.

Regarding a higher dimension sensitivity analysis (more than one variable at a time), we compared the maximum and minimum scores for the three alternatives changing a single sub-criterion at a time while keeping the rest stable. Fig. 6 shows the final score of each alternative under the 64 combinations generated. We observe that the best alternative is always the green infrastructure. Its minimal score (65.8, referring to changes in the weight of water quality) remains significantly higher than the maximum score of the grey infrastructure (52.2, varying the importance of flood protection). Only once (see the combination 4 of Fig. 6), when taking the public costs as the most relevant factor, the poplar plantation beat the green infrastructure as the best option. This result is logical if we analyse the values of the performance matrix, where the green infrastructure has systematically (with two little exceptions) the highest punctuation regardless of the weights assigned to the criteria. The total score of the poplar alternative varies following a saw tooth form which depends on the value weight of the public costs sub-criterion. These peaks are not revealed in the grey and green alternatives where this sub-criterion has a minor influence.

4.3. Benefits from the green infrastructure

Since the green infrastructure (i.e. the constructed wetlands and wet retention pond with a surrounding riparian park) is consistently identified as the best option for the case study, we deepen on the analysis of the socio-economic and environmental benefits it provides. The Gorla Maggiore water park is here analysed under an ecosystem service approach which, together with the MCA, allows evaluating its multiple benefits. In particular the ecosystem services quantified are water purification, flood regulation, natural habitat and recreation.

To analyse the actual water purification, two automatic sampling stations allowed to measure the pollution (organic matter, through the chemical oxygen demand, and ammonia concentration) entering and leaving the constructed wetlands during each CSO event. The system shows average removal efficiencies of 72–96% which confirms a satisfactory performance for water pollution control of CSO, especially in the vertical sub-surface flow constructed wetlands (Masi et al., 2016). The average load reduction is shown in Table 3.

Related to flood control, the mathematical model simulates the unsaturated water flow in the vertical sub-surface constructed wetlands' beds (Richards equation), the height of the ponding layer above those wetlands, and the height of the free water surface constructed wetland (mass balance equations). Modelling results show that the pond multipurpose area acts as a buffer tank with good lamination also obtained at high return time (return time 10 years, maximum flow rate 3.4 m^3s^{-1}, volume 11,497 m^3s^{-1}, duration 4.8 h). The free water surface constructed wetland works as a buffer tank to store 71% of the influent volume, with a less but not negligible role in lamination of vertical sub-surface flow beds (11%). Also the peak flow (86.2% of reduction) and the outflow duration (27.3 times higher than the CSO event duration) are satisfactorily managed during the 10 year return time events. The system is an effective bio-retention technology to manage the urban runoff towards the river (Rizzo et al., 2015). Regarding downstream flood protection, the effect of the Gorla Maggiore water park seems negligible at the catchment level (at large scale) due to the relative small volume of the infrastructure related to the Olona water discharge. Still, the combined effect of multiple similar infrastructures along the Olona River should be investigated, since the accumulated retention could be important.

The maintenance of healthy biota populations and habitats, usually acting as nursery or shelter areas, is crucial for wildlife support. Two field surveys run during 2014 indicate a high capacity of the constructed wetlands and surrounding park to provide wildlife support. Numerous macroinvertebrate taxa were identified in the pond, among which some Odonata (dragonflies and damselflies) that could be part of the Red List of Threatened Species. The pond also seems to play a crucial role in the survival of local amphibian and to support bird populations. One priority species for the EU Birds Directive was identified on the site. The littoral zone of the pond is characterized by dense beds of emergent macrophytes covering ca. 10% of the surface. Attached to them, floating-leaved species cover ca. 15%. These introduced plants contribute to the further purification of the water outflowing from the reed bed system and provide substantial benefits in relation to microhabitats for fauna and an aesthetic appearance to the whole system.

In terms of recreation, the water park has several facilities such as information panels, well-maintained paths and toilets. The accessibility from the town is excellent and it is the only green open space in Gorla Maggiore. People can practise a wide range of activities including educational, sportive and leisure activities. According to the responses collected in our questionnaire from the local residents, the park is highly visited by people living at close distance (less than 1.5 km) and it is primarily used for walking/dog walking or for sightseeing/enjoying nature. On average, each respondent has visited the park twice per month, usually accompanied by 1–2 persons. Other less practised activities in decreasing importance are running or biking, watching wildlife, educating children to nature, playing with kids, sunbathing and picnicking (Reynaud et al., 2016). The level of appreciation of the users of the park is between moderate and high.

4.4. Impacts and transferability of the results

The ecosystem services delivered by wetlands have been recognized and valued as a nature-based solution for watershed management issues (ten Brink et al., 2012). The main finding from this research is that the green infrastructure (constructed wetlands and park) performs equal or even better than the grey alternative for water purification and flood protection, it has a similar cost, and it provides additional benefits (wildlife support and recreation) specially valued by the local residents and stakeholders. This is relevant for regional water management, where biodiversity and recreation are not usually taken into account for water resources decision-making. This is in line with a similar study that analyses nature-based and collaborative solutions to future water scarcity (Reddy et al., 2015). They also find, with the use of ecosystem service valuation methods and MCA, that nature-based solutions may be cost-effective and cost-competitive for businesses, while providing public and ecosystem benefits (Reddy et al., 2015).

In this case study the MCA is used retrospectively, to evaluate an already built infrastructure (*ex post* evaluation) but our results could also be used prospectively to appraise new proposals of constructed wetlands under similar circumstances. In particular, AHP is a tool that can help decision-makers translate stakeholders' desires and expectations into beneficial public policies or decisions. Our findings can be particularly useful for similar situations: small municipalities aiming to treat their CSO as requested, for instance, by the EU Water Framework Directive. New alternatives (variants of green and grey infrastructures) can be explored based on this experience to more accurately choose the type of installation convenient in each context. Our methods and results could offer practical tools to use the concept of ecosystem services, to select the best option between a multi-purpose green infrastructure and grey alternatives, to apply a cost-benefit analysis (with further economic analysis), and to communicate with the stakeholders and local community, increasing the awareness about the benefits provided by new or restored ecosystems.

In this case study, the environmental quality of the Olona river falls under the Po river basin management plan responsibility of the "Autorita di Bacino del Fiume Po". However, the land and water resource planning is under the authority of the "Regione Lombardia". This regional government has adopted River Contracts as local strategic planning instruments in different sub-basins, among which the Olona-Bozzente-Lura,[7] involving local authorities and institutional stakeholders most of which are represented in our stakeholders group. The most recent programme of actions was adopted in 2014.[8] The strategic objectives of the River Contract are: 1) reduction of water pollution; 2) reduction of flood risk; 3) restoration of landscape, environmental and urban systems relative to river corridors; and 4) sharing of information and knowledge on water. Thus, the ecosystem services approach and the MCA developed in this study address the policy needs (strategic objectives) for the local territorial planning in the implementation of the Water Framework Directive.

5. Conclusions

Water-related projects usually tackle complex problems and provide a series of "unmeasurable" benefits, most of which can be assessed from an ecosystem service perspective. They also involve multiple interested actors, from governments to NGOs or lay citizens. MCA allows to evaluate and integrate, both quantitative and qualitatively, a set of crucial criteria with or without monetary value attached. The use of an ecosystem services' approach linked to a MCA for water projects (like the one shown in this paper) may lead to more informed and better decisions. In particular, the case study shown in this article contributed to raise the awareness of the stakeholders on the significance of aquatic habitats and encourage them to promote or implement policies that protect freshwater ecosystems together with people's wellbeing.

In general, the nature-based solution constructed in Gorla Maggiore contributes to: (1) mitigate some water-related issues of the municipality, potentially increasing the ecological status of the Olona River; (2) maintain and even improve biodiversity in the area; and (3) contribute to the residents' livelihood through recreational and educational services.

The application of the *ex post* MCA led to the identification of the green infrastructure as the best among three alternatives. The costs of the works are significant, but do not exceed those of a traditional grey infrastructure.

More broadly, the MCA highlighted the multi-functionality of the green infrastructure, accounting for multiple benefits of interest for the stakeholders. The involved actors learnt about a possible way to structure the decision process and about their own and others' perspectives. Hence, MCA brings a degree of structure, analysis and openness to complex decision that go beyond the practical reach of cost-benefit analysis.

At the same time, by integrating several criteria in the decision analysis (ecological, social and economic), the approach allowed the integration of different policies relevant to the territorial planning. This is of great interest for the regional authorities that are involved in the development and implementation of the River Basin Management Plans under the EU Water Framework Directive.

This study illustrates the effectiveness and multi-functionality of constructed wetlands and restored riparian zones for watershed management, and its capacity to deliver a broad range of ecosystem services. It also demonstrates the utility of integrating different value types (environmental, social and economic) and stakeholders' viewpoints to support environmental decision-making.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ecoser.2016.09.011.

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