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The Valuation of Ecosystem Services in the Venice Lagoon: A Multicriteria Approach

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Abstract: Coastal ecosystems are among the most economically valuable and highly threatened on Earth; they provide valuable ecosystem services (ESs) but are severely exposed to climate changes and human pressure. Although the preservation of coastal ecosystems is of the utmost importance, it is often sub-optimally pursued by Governments and Societies because of the high costs involved. We consider salt-marsh ecosystems in the Venice Lagoon as an example of a threatened landscape, calling for innovative, integrated management strategies, and propose an application-driven methodological framework to support policymakers in the identification of cost-effective incentive policies to ecosystem preservation. By combining group decision-making and Value-Focused-Thinking approaches, we provide a multiple-criteria decision model, based on pairwise comparisons, to identify which ESs are top-priority policy targets according to a cost-effective perspective. We implemented an online Delphi survey process and interviewed a pool of experts who identified "recreation and tourism", "coastal protection from flooding", "carbon storage", "biodiversity and landscape", and "nursery habitats for fisheries" as the five most relevant ESs for the Venice Lagoon taking into consideration the Environmental, Economic, and Social perspectives. Our results suggest that the Environmental perspective is the most important criteria, whereas "biodiversity and landscape" is acknowledged as the most important ES.

Keywords: Venice Lagoon; ecosystem services; salt marsh; cultural landscape; world heritage site; analytic hierarchy process; ranking; pairwise comparisons

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1. Introduction

Coastal ecosystems host important socio-economic activities worldwide, being simultaneously some of the most economically relevant and vulnerable ecosystems on Earth (e.g., [1–5]). Coastal ecosystems, such as salt marshes, seagrass meadows, and mangrove forests, provide fundamental Ecosystem Services (ESs) [1,3,6–9], that are the benefits human populations derive, directly or indirectly, from ecosystem functions [1,10]. Coastal ecosystems provide a unique natural landscape contributing to a sense of place, enhance biodiversity, support commercial fisheries, protect coastal regions against erosion and storms, provide ecotourism revenues, and act as efficient natural carbon sinks, helping to offset CO_2 emissions and fight climate change.

Unfortunately, coastal ecosystems are some of the most heavily threatened ecosystems globally (e.g., [3,4,11–13]), and their future survival is today at risk worldwide, exposed as they are to possibly irreversible transformations. Being currently threatened by climatic changes and increasing human pressure, their deterioration is intense and increasing, and several studies suggest that, depending on the type of ecosystem, between 25 and 50% of their total area worldwide has been lost in the last 100 years, as well as that between 0.5 and 3% of their current area is being lost annually [14–16]. Based on current degradation rates, between 30 and 40% of salt marshes and seagrass beds might be lost in the next century [17]. Intense marsh deterioration processes have been documented worldwide. Marsh areas decreased by 85% since 1850 in the San Francisco Bay [18]; about 4900 km^2 of wetlands have been lost in the Mississippi Delta plain since the beginning of the 20th century at rates as high as 100 km^2/year [19]; in the Greater Thames area and the Solent (UK), around 25% and 40%, respectively, of the total marsh area present at the beginning of the 1970s have been eroded [20]. In the Plum Sound and the Virginia Coast Reserve (USA), salt-marsh lateral erosion rates up to 3 m/year were observed [21], whereas, in Barnegat Bay (USA), half of the marsh area fringing the interior of the bay displayed erosion rates up to 2 m/year [20].

As an example of such an intense and increasing ecosystem deterioration, we consider the case of the Venice Lagoon, Italy (Figure 1).

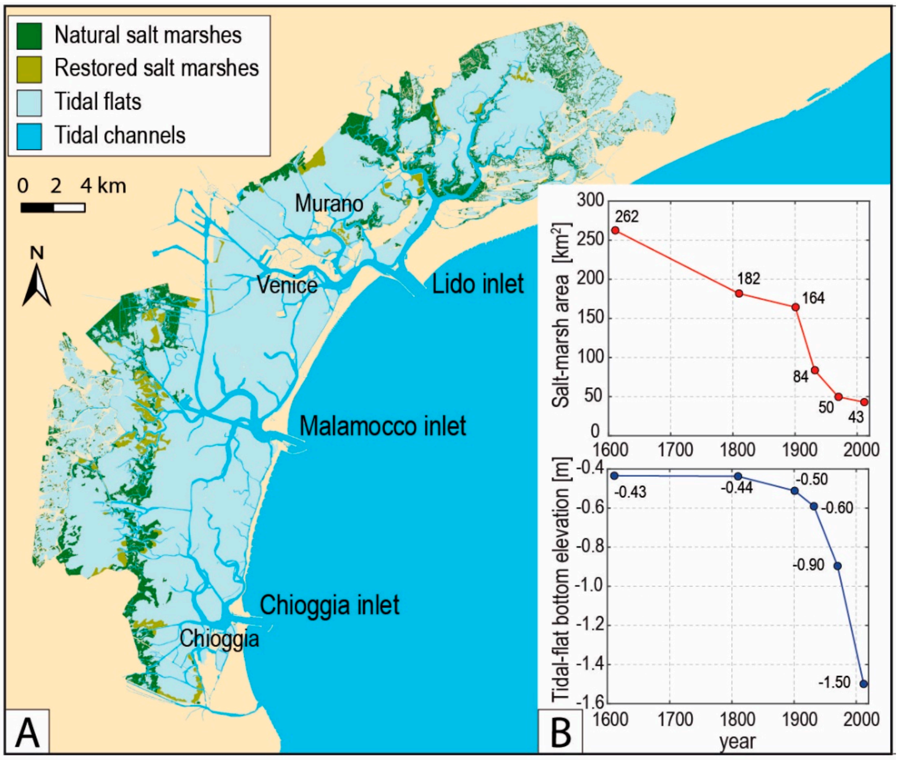

Figure 1. (**A**) The Venice Lagoon and its main morphological features: salt marshes, tidal flats, and tidal channels. (**B**) Temporal evolution of salt-marsh area (top) and of tidal-flat bottom elevations (referenced to mean sea level) between 1600 and today (adapted from Reference [22]).

The Venice Lagoon is the largest brackish water body in the Mediterranean, whose history and fate are tightly intertwined with those of the City of Venice and the other urban settlements within the Lagoon. Venice and its Lagoon have belonged to the UNESCO World Heritage Sites since 1987 and represent a unique example of coevolution of people and landscape, and of built and natural environments since the 5th century, when Venetian populations found refuge on the northern-lagoon islands when fleeing from Barbarians [23,24].

The Venice Lagoon provides a timely example of a tidal landscape currently threatened by intense degradation processes due to the intertwined effects of climate changes and human interferences [25–28]. Starting from the 15th century, the Venice Lagoon has experienced important morphological transformations due to human interventions when the Serenissima Republic of Venice (an ancient Venetian State) diverted to the Adriatic Sea the main rivers previously debouching into the lagoon to prevent the lagoon from silting up [26,29,30]. These interventions rapidly turned the silting-up issues into the current erosion problems that affect the present lagoon morphologies. The increasing anthropogenic pressure, coupled with the effects of natural processes exacerbated by climate changes, has further accelerated the morphological deterioration in the last century, due to the construction of the jetties at the inlets and the excavation of the large navigation channels, such as the Malamocco-Marghera ship canal [25–27,31]. These erosion processes led to negative consequences for salt-marsh ecosystems in the Venice Lagoon. Indeed, the salt-marsh area in the Venice Lagoon (Figure 1B) decreased from about 180 km^2 in 1810 to just 43 km^2 today, and the depth of the tidal flats hosting seagrass beds (Figure 1B) increased from 0.5 m in 1810 to 1.5 m today [22,26,32].

A general loss of morphological heterogeneity has been observed, mainly related to the flattening of the lagoonal bottom and the silting of the tidal channels [26], with important consequences on the form and function of lagoonal biogeomorphic patterns [33–37], as those reported in Figure 2. Regrettably, when degraded, coastal ecosystems stop providing services of fundamental importance to human well-being, health, livelihoods, and survival [1–5].

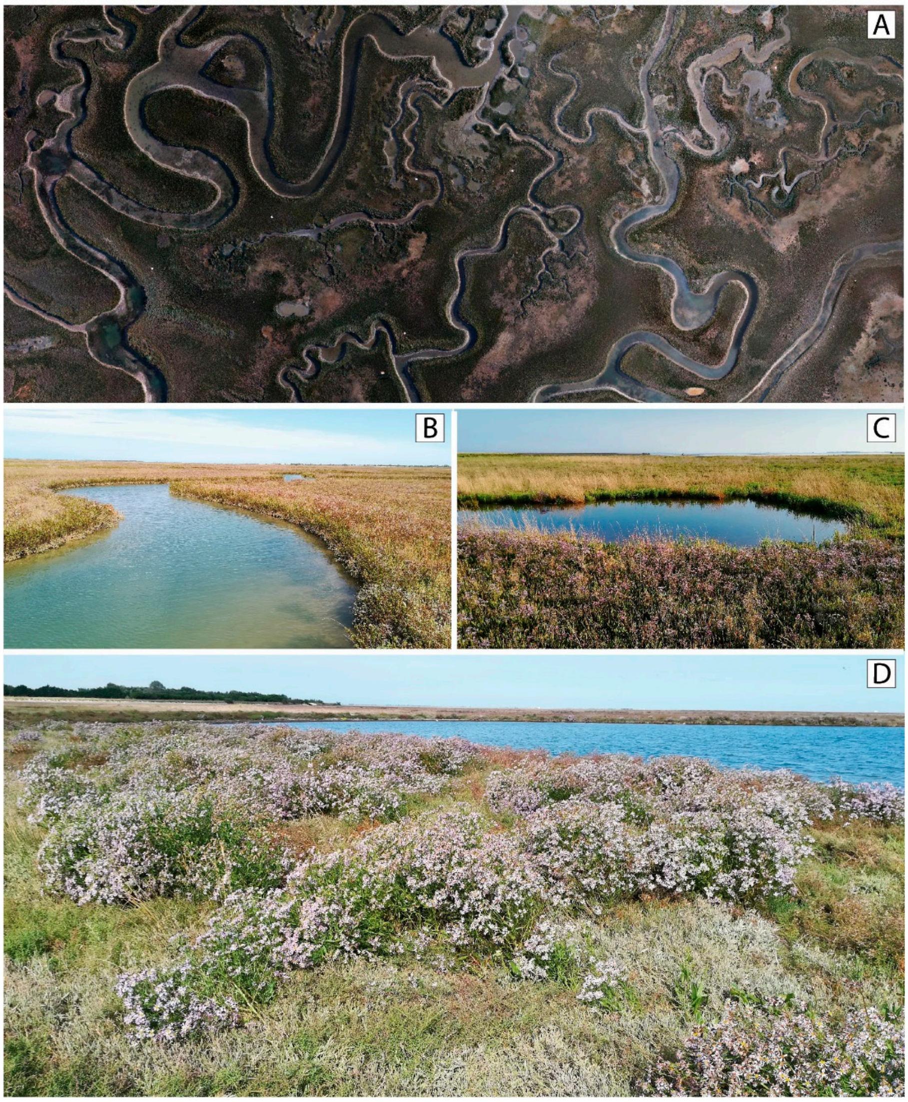

Figure 2. Biogeomorphic patterns in the Venice Lagoon. (**A**) Tidal channel network cutting through the San Felice salt marsh (Norther Venice Lagoon), providing an example of morphological diversity that is associated to biogeomorphic patterns [37]. The channel network structure influences the distribution of marsh elevations that, in turn, controls vegetation distribution. (**B**) Detail of a tidal channel meandering through the San Felice salt marsh. (**C**,**D**) zonation patterns in the Conche salt marsh (Southern Venice Lagoon), a mosaic of extensive, rather uniform vegetation patches, exhibiting sharp transitions associated to small topographic gradients [34–36]. Salt marshes are characterized by large biodiversity in terms of, e.g., different vegetation species (*Limonium narbonense*, *Salicornia veneta*, *Sarcocornia fruticosa*, *Puccinellia palustris*, and *Aster tripolium*, in the photographs, courtesy of Alice Puppin and Davide Tognin).

The preservation of tidal ecosystems, such as those analyzed herein is costly, and, because of the lack of financial resources resulting in limited investments, it is usually sub-optimally produced by Governments and Societies. This sub-optimal production is generally due to an underestimation of the true value of tidal ecosystems and related ESs, which are indeed valuable resources generating positive net benefits over time that can balance their conservation costs.

To favor the implementation of cost-effective conservation and preservation strategies, which call for innovative integrated management perspectives, policymakers must take into consideration social costs and benefits, EU targets, and environmental concerns. Although a number of studies exist that consider the ES approach as a tool for coastal management in the case of the Venice Lagoon [38–41] and in other coastal contexts worldwide (e.g., [1,3,7,9,42]), the prioritization of coastal ESs as top-priority policy targets has not received the attention it deserved so far.

Indeed, the identification of those ESs which are considered of primary importance in coastal ecosystems, in general, and in the Venice Lagoon, in the case at hand, represents a preliminary fundamental step in the design of cost-effective incentive policies, meant to preserve and restore costal and lagoon ecosystems. In a context where stakes are high, future implications are stochastic, and multiple and often conflicting objectives need to be pursued, multiple-criteria approaches provide a proper theoretical and methodological framework to address the complexity of economic, physical, social, cultural, and environmental factors, which characterize fragile environments, such as the Venice Lagoon.

Among the numerous multicriteria methods provided in the literature, the Analytic Hierarchy Process (AHP), proposed by Saaty in the Eighties [43], is widely adopted worldwide across multiple domains (e.g., social studies, environmental studies, engineering, etc.). It is widely acknowledged by academics and practitioners that, due to its ease of use and understanding, AHP facilitates structuring the complexity, measurement, and synthesis of rankings [44,45]. Nonetheless, to our knowledge, just a handful of papers in the literature exist on the implementation of the AHP to the valuation of ESs [46–50].

In this paper, we contribute to the existing literature by proposing an application-driven methodological framework to support policymakers in the identification of those ESs which are considered as of primary importance in the Venice Lagoon.

In detail, we present a novel application of the AHP in the domain of ESs assessment and develop and implement an AHP (relative) model to rank multi-criteria prioritization of ESs provided by the Venice Lagoon. Based on literature review and experts' judgments, valuation criteria and sub-criteria were identified and organized into a hierarchy, and weights were determined by pairwise comparisons of elements in the hierarchy to create a one-dimensional index for ranking top priority policy targets. This ranking will be of paramount importance in informing conservation and valorization strategies for the Venice Lagoon and will support policymakers in the design of cost-effective incentive policies. Although centered on the Venice-Lagoon case study, our contribution has wider implications for similar coastal ecosystems worldwide (e.g., [4,12]). The Venice and Venice-Lagoon issues are becoming indeed a new paradigm of the conflicts arising from the interactions among the three main pillars of sustainable development, namely economy, society, and the environment (e.g., [30]). Because Venice and its lagoon represent an "indication and a laboratory of what fate has in store for the cities of the future" [51], the proposed method can be applied to solve decision-making problems involving coastal ecosystem issues, which can derive from different contexts.

The remainder of the paper is organized as follows. Section 2 describes the methodological background; Section 3 provides the modeling framework; Section 4 discusses results, whereas Section 5 provides the main conclusions.

2. Methodological Background

The Analytic Hierarchy Process (AHP), firstly proposed by Saaty in the Eighties [43], is now considered as a well-established multi-criteria approach, widely applied by both academicians and practitioners to solve complex decision problems, in which quantitative information on the effects of actions or alternatives under evaluation is limited, as well as to cope with multiple objectives and criteria trade-offs [52–56].

The AHP permits to rank a finite number of actions A_i, by evaluating them with respect to a finite number k of attributes a_j ($j = 1, \ldots, k$), each of which is assigned a judgment score qualifying its performance, and by eliciting the relative importance of (or preference for) evaluation parameters through pairwise comparisons [43,57,58]. The AHP allows for constructing ratio scales on qualitative and quantitative factors and dimensions and evaluating them on the same preference scale [52,59].

The AHP deconstructs the decision problem into a hierarchy, characterized by unidirectional hierarchical relationships between different hierarchical levels. On the top of the hierarchy, there is the goal (i.e., the objective of the decision problem), whereas criteria and sub-criteria that contribute to the goal are listed at lower levels, and alternatives/actions to be evaluated are placed at the bottom level. By structuring the problem in subsequent disaggregation stages, a set of sub-decision problems are defined, which are easier to solve from a cognitive perspective with respect to the formulation of preference judgments. The relative importance of elements in the hierarchy (e.g., criteria, sub-criteria, alternatives, etc.) is determined through pairwise comparisons of elements at each hierarchical level with respect to their parental node [43,52]. The relative importance is expressed via semantic judgments, which are transformed into numerical values based on Saaty's fundamental scale [43,60,61]. Saaty's scale is a scale of integers ranging from 1 to 9, where 1 represents indifference between the two elements, whereas 9 denotes extreme preference (Table 1).

Table 1. Saaty's fundamental scale [43].

Importance	Definition
1	Equal importance
3	Moderate dominance
5	Strong dominance
7	Demonstrated dominance
9	Extreme dominance
2, 4, 6, 8	Intermediate values

At each decision node, a pairwise comparison matrix is compiled: coefficients a_{ij} represent the relative importance of a specific criterion, sub-criterion or action in comparison to another criterion, sub-criterion or action, and coefficients a_{ii} are equal to 1. Priorities (i.e., weights $w_1, w_2, \ldots, w_n$) are determined according to the Perron-Frobenius eigenvalue approach to pairwise comparisons [43,52].

Once the priority vectors are determined, the consistency index $\boldsymbol{CI}$ and the consistency ratio $\boldsymbol{CR}$ are computed to verify the consistency of each pairwise comparison matrix [43,62,63]:

$$\boldsymbol{CI} = \frac{\boldsymbol{\lambda_{max} - n}}{\boldsymbol{n - 1}}, \tag{1}$$

where $\boldsymbol{\lambda_{max}}$ is the maximum eigenvalue of the pairwise comparison matrix, and $\boldsymbol{n}$ is the matrix rank, and

$$\boldsymbol{CR} = \frac{\boldsymbol{CI}}{\boldsymbol{RI}}, \tag{2}$$

where $\boldsymbol{RI}$ is a random consistency index, which depends on $\boldsymbol{n}$ [43,64].

Any $\boldsymbol{CR} < 0.1$ is considered acceptable [43,65], whereas, whenever $\boldsymbol{CR} > 0.1$, experts' judgments are inconsistent, and a revision of the pairwise comparison matrix is recommended. It is worth noting that, when experts' judgments are perfectly consistent, due to the Perron-Frobenius theorem, $\boldsymbol{\lambda_{max}} = \boldsymbol{n}$, and, consequently, $\boldsymbol{CI} = 0$.

3. Model

Public policy assessment is a complex task, specifically with respect to the preservation and conservation of delicate coastal ecosystems, such as the Venice Lagoon. In such contexts, stakes are high, decisions are costly to reverse, and their effects are usually long-term effects and can affect different groups of stakeholders and actors. In addition, the support and consensus of actors and stakeholders are fundamental to the successful implementation of any public policy. Such a successful implementation depends on citizen environmental awareness, and it may involve large implementation costs, giving rise to conflicting stakeholders' objectives and viewpoints.

To design an optimal incentive policy for the preservation and valorization of the Venice Lagoon, it is of paramount importance to preliminarily evaluate the ESs it provides and identify which ESs are top-priority policy targets according to a cost-effective perspective.

To structure the decision problem and identify a list of ESs, which are relevant to the Venice Lagoon, an extensive literature review was conducted [38–40,66]. Secondly, a panel of experts, which includes academics, policymakers, business representatives, and stakeholders, were interviewed. Literature review, interviews, and the analysis of international experiences and the Italian context informed the identification of ESs to be evaluated. According to a reference-based ranking approach, inspired by Roy [67], and following D'Alpaos and Bragolusi [68], the relative importance of ES was evaluated on a qualitative basis, which was built on expert judgments provided by the panel [69].

Secondly, to identify criteria and construct the hierarchy, a group of 25 experts representing three main perspectives, such as knowledge, government, and business and society, were selected [69,70]. This panel was meant to capture as much diversity of thinking as possible and to construct consensus on the final decision by considering different and often conflicting viewpoints [71,72]. The panel was involved in a two-round Delphi process survey, during which we elicited opinions of respondents and asked elicitation questions according to a qualitative format, which did not require expertise in multiple-criteria decision-making.

Focus groups were then organized, and the Delphi survey was implemented, to identify ESs to be considered as of major relevance for the Venice Lagoon, create consensus on criteria, elicit expert judgments, and validate the final hierarchy through dynamic discussion [53,68,70]. To ensure large representability and diversity of thinking, the group of 25 experts (aged between 30 and 60 years, of which about 70% are male, 70% hold a Ph.D., and 30% have a master degree) consisted of 17 academics and researchers with proven expertise in environmental and hydraulic engineering, geology, geomorphology, ecology, environmental sciences, 3 representatives of local and regional authorities, and 5 representatives from business in the Venice Lagoon and non-profit local associations.

The panel of experts structured the hierarchy into 3 hierarchical levels, from the goal at the top of the hierarchy (i.e., ranking ESs from most to least relevant as top priority policy targets), to alternatives (i.e., ESs) at the bottom of the hierarchical structure. In addition, they identified 3 main criteria, which coincided with the 3 main pillars of the sustainability paradigm (i.e., Social, Economic, and Environmental perspectives) and 5 ESs to be investigated, which are: "recreation and tourism", "coastal protection from flooding", "carbon storage", "biodiversity and landscape", and "nursery habitats for fisheries". Figure 3 illustrates the hierarchy.

Once consensus was reached upon the hierarchy, and the latter was validated by the panel, the model was implemented on the Super Decision Software to obtain weights and priorities. In this respect, experts compiled the pairwise-comparison matrices relative to each decision node via an online interview. Subsequently, the ***CI*** for each pairwise comparison matrix was calculated to prove whether it was within the acceptability limit (i.e., $\boldsymbol{CI} < 0.1$). Finally, experts' judgments were combined, and weights were aggregated by calculating judgment geometrical mean according to group decision-making theory [73,74].

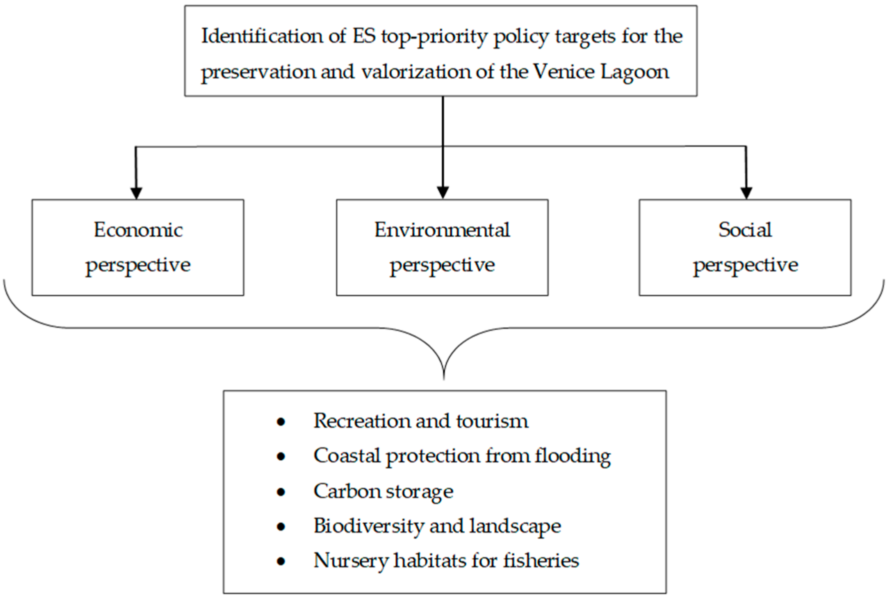

Figure 3. The hierarchy of the model, which shows how the evaluation criteria and sub-criteria are organized. The objective of the decision problem is on the top of the hierarchy, criteria and sub-criteria contributing to the goal are listed at lower levels, and alternatives to be evaluated are placed at the bottom level.

4. Results and Discussion

Table 2 shows the results of the multiple-criteria decision model, based on pairwise comparisons, that was applied to identify which ESs are top-priority policy targets in a cost-effective perspective. According to priority vectors (hereinafter pv) displayed in Table 2, it emerges that, among the considered criteria (Economic, Environmental, and Social Perspectives), the Environmental Perspective (pv = 0.67) is the most important criteria with respect to the goal, compared to the Economic (pv = 0.12) and the Social (pv = 0.22) ones. This result can be explained in light of the importance that the environment has for the panel of experts interviewed in our analysis. Experts in the panel are aware that the Venice Lagoon is currently suffering from a major environmental issue; therefore, they tend to sustain environmental issues compared to social and economic (deemed to be less important) ones. In the Venice Lagoon, indeed, the environmental perspective is of the utmost importance particularly because of the dramatic erosion and degradation trend that the Lagoon and its ecosystems have been experiencing in the last century [22,26,27]. The ESs provided by the Lagoon are at risk.

From an Environmental perspective, "biodiversity and landscape" (pv = 0.44) is the most important ES according to the experts, followed by "carbon storage" (pv = 0.21), "nursery habitats for fisheries" (pv = 0.18), "coastal protection from flooding" (pv = 0.13), and "recreation and tourism" (pv = 0.04). From an Economic Perspective, "nursery habitats for fisheries" (pv = 0.24) and "biodiversity and landscape" (pv = 0.24) are the most important ESs, followed by "coastal protection from flooding" (pv = 0.21), "carbon storage" (pv = 0.14), and "recreation and tourism" (pv = 0.17). Finally, from a Social Perspective, "biodiversity and landscape" (pv = 0.25) is the most important ecosystem service, followed by "coastal protection from flooding" (pv = 0.24), "recreation and tourism" (pv = 0.21), "nursery habitats for fisheries" (pv = 0.20), and "carbon storage" (pv = 0.10).

Table 2. Aggregation of experts' judgments on goal and criteria and final priority vector.

Goal	Priority Vector
Economic perspective	0.1185
Environmental perspective	0.6664
Social perspective	0.2151
CI	0.00115

Economic Perspective	Priority Vector
Recreation and tourism	0.1406
Coastal protection from flooding	0.2087
Carbon storage	0.1706
Biodiversity and landscape	0.2357
Nursery habitats for fisheries	0.2443
CI	0.01343

Environmental Perspective	Priority Vector
Recreation and tourism	0.0384
Coastal protection from flooding	0.1342
Carbon storage	0.2055
Biodiversity and landscape	0.4402
Nursery habitats for fisheries	0.1818
CI	0.01265

Social Perspective	Priority Vector
Recreation and tourism	0.2098
Coastal protection from flooding	0.2419
Carbon storage	0.0955
Biodiversity and landscape	0.2541
Nursery habitats for fisheries	0.1987
CI	0.01784

The results are easily interpretable, as one of the current major concerns in environmental sciences is the loss of biodiversity and preservation of natural and cultural landscapes, which are particularly delicate issues in very fragile coastal environments and ecosystems, such as the Venice Lagoon, that have been deeply modified through the centuries (relevant human interventions in the Venice Lagoon started in the 15th century, see, e.g., References [26,29]) to serve the needs of economic and social developments [30]. It is also rather intuitive that "carbon storage" is ranked as second. Indeed, growing attention at EU and national level is currently paid to both reduction in greenhouse gas (GHG) emissions and increase in carbon storage, proven by the successful development of EU Emission Trading System (ETS), which is the cornerstone in the EU policy for mitigation of climate change effects and has become the first major carbon market worldwide. General awareness of the surprisingly high capability of salt-marsh ecosystems to capture carbon from the atmosphere and store it in their soils has increased in the last years (e.g., [16,75]), attracting the attention of a diverse group of actors beyond the scientific community, devoted to marine conservation and climate change mitigation and adaptation [75]. By contrast, "recreation and tourism" plays a marginal role from an Environmental Perspective, as it is currently more strongly related to the Social perspective. Furthermore, it is still debated whether tourism (specifically mass-tourism) can contribute to endangering the Venice Lagoon environment, if not properly regulated. As to the Economic Perspective, "nursery habitats for fisheries" is ranked as first, being that fishery and aquaculture are one of the major economic activities in the Venice Lagoon, which provides convenient nursery areas or feeding grounds for many juveniles of commercial fishes [41,76]. "Biodiversity and landscape" is also ranked first from the Social perspective, thus highlighting that biodiversity not only fits within the environmental system but within a broader landscape, including social systems and perspectives. "Biodiversity and landscape", as an ecosystem service, is considered to provide high environmental and social value [77,78].

Table 3 summarizes the global priority vector and the final ranking of ESs with respect to the goal, i.e., identifying top-priority policy targets for the preservation and valorization of the Venice Lagoon. By direct inspection of Table 3, it emerges that "biodiversity and landscape" is the top priority policy target (global pv = 0.38), followed by "nursery habitats for fisheries" (global pv = 0.19) and "carbon storage" (global pv = 0.18). "Recreation and tourism" is considered as the least important in the ranking, immediately after "coastal protection from flooding".

Table 3. Global priority vector and ranking of alternatives.

Alternatives	Priority Vector
Recreation and tourism	0.0874
Coastal protection from flooding	0.1662
Carbon storage	0.1777
Biodiversity and landscape	0.3759
Nursery habitats for fisheries	0.1928

According to our findings, the rich biodiversity that salt-marsh systems support, by providing unique habitats for a wide variety of flora and fauna, is evaluated of major importance for the landscape [5]. Where salt marshes have healthy biodiversity, they provide essential services to the environment and local communities. Biodiversity in salt-marsh ecosystems can be strongly affected by climate change and human pressure [5,37,79], which might lead to changes in natural biogeomorphic patterns. Not surprisingly, biodiversity preservation is, therefore, valuated as fundamental. The results of the analysis support the view of Venice and its Lagoon as indivisible elements of a unique system, whose fate and preservation are strongly intertwined [30,38,80] and need to be considered and pursued within a holistic, integrated management strategy. "Nursery habitats for fishery" is ranked as second due to the relevant economic value of traditional fishery and aquaculture in the Venice Lagoon, which, according to recent estimates, amounts to about Eur/year 18,500,000 [41]. Nonetheless, many concerns and conflicting opinions arise in this respect and require the urgent design of management policies, on the one side, on the overexploitation of fishery, which is threatening the lagoon environment and its biological capacity, due to progressive deregulation that has impaired the sustainability of fishery in the Venice Lagoon. On the other side, there is an increasing awareness that climate change is increasing the vulnerability of artisanal fishery.

In addition, salt-marsh capability to sequester and store organic carbon in their soils for centuries, with rates up to 30–50 times larger than terrestrial forests [16,75], is also acknowledged as fundamental. As an example, Roner et al. [81] showed that salt marshes in the Northern Venice Lagoon can sequester organic carbon at rates of about 130 tons C km^{-2} $year^{-1}$. Estimates of the carbon sequestration potential of Venice marshes (43 km^2), based on Roner et al.'s [81] data for the San Felice salt marsh (Venice), suggest that they can sequester at least ~5600 tons C $year^{-1}$, whereas the topmost 1 m soil layer might retain a carbon stock of about ~2×10^6 tons C. "Protection from flooding" is evaluated as the second less important policy target, likely because most of the experts are aware that salt marshes in the Venice Lagoon cannot provide a significant reduction in the tidal amplitude and storm attenuation to the city of Venice [26,31], as they can effectively do for other coastal cities worldwide [19,82–84]. The city of Venice is very close to the Lido inlet (one of the inlets from which the tide propagates within the Venice Lagoon), whereas most of the marshes in the Lagoon are fringing marshes close to the mainland (Figure 1), which cannot significantly influence tidal propagation and water levels in Venice. Finally, the reason that "recreation and tourism" is rated as the least important may reside in that tourists are mostly attracted by the cultural heritage in the historical center of Venice as a worldwide iconic historical city, as well as are generally less interested (at least in terms of number of tourists) in visiting the lagoon environment. By contrast, residents enjoy recreational activities offered by salt marshes, tidal flats, and the network of channels that cuts through them, whose characteristic patterns are a unique features of tidal systems, such as the Venice Lagoon. This is intrinsically a form of sustainable tourism, also called eco-tourism, which generates a low impact on the surrounding environment and, consequently, is not viewed as top priority policy target for the preservation of the Venice Lagoon. Nonetheless, it is worth noting that the desirable shift from a resource-intensive tourism to a sustainable one requires putting limits on the demands individuals can make on the environment, to reduce its marked deterioration. Obviously, the implementation of education and information campaigns on the lagoon potential is a necessary step to favor the aforementioned shift. This would further increase local community and tourists' awareness of the significance of Venice Lagoon ecosystems and their importance for, e.g., migratory birds and other wildlife, as it is currently being done within the framework of the DETOURISM campaign run by the city of Venice, which proposes authentic, sustainable touristic itineraries off the beaten track, within the Venice Lagoon.

The limitations of the AHP here adopted are common to any AHP relative model and reside in the fact that results and weights are expressed in terms of relative measurements: initially, preferences on criteria are independent of the alternatives (i.e., ESs) under investigation, and then results are later rescaled according to the measurements of alternatives, which are pairwise compared according to their relative dominance with respect to each criterion [43,60]. In this respect, the best-rated ES is the best among the ESs that it is compared with. Nonetheless, it is worth noting that model results, which are grounded in experts' judgments, are consistent with a formal preference theory, and the decision model is mathematically rigorous and transparent [43,52].

Although any multicriteria model is tailored to a specific decision problem (e.g., "ranking of ESs top-priority policy targets for the preservation and valorization of the Venice Lagoon" as in the case at hand), the method here proposed can be applied to different fragile and under-protected coastal ecosystems worldwide (e.g., [3,4,12,14]). However, the hierarchy, the ESs under investigation, and their relative importance may change depending on site-specific characteristics, thus requiring the constitution of an ad hoc panel of experts.

Several studies exist that estimate the current economic value of ecosystem services to support decision-making in land use and conservation policies (e.g., [1,3,7,9,38,40,41]). Different from the existing literature, we addressed the preliminary and fundamental step in the design of cost-effective policy strategies meant to preserve and restore coastal ecosystems in general, and the Venice Lagoon for the case at hand, by identifying those ESs which are considered as top-priority policy targets.

We focused on the case of Venice and its Lagoon, inseparable elements of a unique system of such an outstanding universal value that they represent a public good of worldwide interest, which must be preserved for humanity [30,51,85]. This is an ambitious challenge, which makes the case of Venice and its Lagoon a representative example of the complex interactions among the economy, society, and the environment. Echoing Settis [51], Venice and its Lagoon offer an indication of the fate of coastal cities and ecosystems of the future [4,11,12], threatened as they are by climate change and by competing and intertwined economic, social, and environmental interests.

As Musu [85], on p. 1, clearly argued, "in the Venetian case, the problem of sustainability can be specifically defined as the problem of the relationship between economic development and the lagoon ecosystem", which goes far beyond a model of economic activities and human life in harmony with the lagoon environment. From this point of view, the proposed framework can contribute to the co-creation of sustainable management policies, furthermore contributing to overcome the typical bottom-up approach implemented in the Venice and Venice-Lagoon case and other systems worldwide (e.g., [4,11,12,42]), which make it challenging to integrating micro-interventions into coherent, integrated, and large-scale planning strategies (e.g., [86,87]).

In the case of Venice, our findings can support current management plans. As an example, the results of our analysis nicely meet the objectives of the "Morphological and environmental plan of the Venice Lagoon" [88], whose main goal is to pursue the hydrodynamic and morphological restoration of the Lagoon by counteracting the degradation of the lagoon morphology, as well as ensure an adequate level of biodiversity and intertidal habitats. The results can also help to raise managers' and policymakers' awareness of the effects of the Mo.S.E. defense system on the lagoon ecosystem. The Mo.S.E. system consists in storm-surge barriers designed to close the lagoon inlets and protect the city of Venice and other urban settlements from the increasingly frequent flooding due to high tidal levels (*acqua alta*). Recent findings by Tognin et al. [89] highlight that capping high water levels by the closing of the Mo.S.E. system might decrease sediment accumulation on marshes by about 30%, thus challenging salt-marsh future survival in the Venice Lagoon.

It clearly emerges that, today, the conflict between economic and social issues and the preservation of the lagoon ecosystem is unprecedentedly harsh. For governing the process towards sustainable development of Venice and the Venice Lagoon, thus, it is urgent to provide formal decision support tools to make emerge the trade-off between preserving an ecosystem and to consider it as an economic resource, as well as the trade-off between different urban growth scenarios and the preservation of the biogeomorphic systems.

5. Conclusions

The Venice Lagoon is a complex system where multiple environmental, economic, and social issues call for innovative integrated management perspectives. In order to design optimal incentive policy to the preservation of the Venice Lagoon, it is of paramount importance to evaluate the ecosystem services it provides and their relevance in a cost-effective perspective towards a sustainable development of the area. In this paper, we have proposed an application-driven methodological framework to support policymakers in the identification and prioritization of those ESs, which are top-priority policy targets in the preservation and valorization of the Venice Lagoon. This valuation framework is grounded in the AHP and supports policymakers in ranking ESs provided by the Venice Lagoon. We structured the decision problem by conducting an extensive literature review and interviewing a panel of 25 experts via a Delphi survey process. By combining group decision-making and Value-Focused Thinking approaches, the experts identified three main valuation criteria or perspectives (i.e., Environmental Perspective, Economic Perspective, and Social Perspective), as well as five ecosystem services considered relevant in the Venice Lagoon context (i.e., "recreation and tourism", "coastal protection from flooding", "carbon storage", "biodiversity and landscape", and "nursery habitats for fisheries"). Our results show that "biodiversity and landscape" is rated first in terms of relative importance, due to the rich biodiversity that salt marsh systems support, by providing unique habitats for a wide variety of flora and fauna. "Natural habitats for fisheries" and "Carbon storage" as ranked second and third, respectively. This is not surprising if we consider the economic value of traditional fishery and aquaculture and the potential of salt marshes to sequester organic carbon with rates up to 50 times larger than terrestrial forests.

By contrast "recreation and tourism" is ranked as the least important. This result might appear to be counterintuitive. Nonetheless, it does not refer to the mass-tourism attracted by the city of Venice and its historical heritage, but rather to the recreational and eco-touristic activities offered by salt marshes, tidal flats, and the tidal channels that dissect them, which are usually enjoyed by residents and by a relatively small number of tourists.

We have tailored our analyses to the case of Venice and its Lagoon, as it is a paradigm of current complex interactions among economics, society, and the environment worldwide, as well as a mirror of what climate change and human interferences have in store for coastal cities of the future. Indeed, by identifying those ESs which are considered as top-priority policy targets, our methodological framework addresses the preliminary and fundamental step in the design of cost-effective policy strategies for coastal ecosystem preservation and valorization and can be applied to solve decision-making problems involving coastal ecosystem issues to a broad extent. To design optimal policies, policymakers need to clearly identify their priority targets and structure their decision problem transparently and coherently. The formal model here provided contributes to improving accountability and legitimation of public decision-making and may represent the basis for participative decision processes, which are the key drivers of the successful implementation of any environmental policy.

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