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Review

Ecosystem Services Valuation of Constructed Wetland as a Nature-Based Solution to Wastewater Treatment

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Abstract: Constructed wetlands (CWs) are nature-based solutions that utilize natural vegetation, soils, and microbes to treat domestic wastewater and industrial effluents. They are engineered treatment systems that mimic the functions of natural wetlands to capture stormwater, reduce nutrient loads, and create diverse wildlife habitats. Providing these monetary and non-monetary benefits, its implementation has grown in several applications and geographical spread. Recent studies integrate the ecosystem services of CWs in project valuation, and the critical analysis of research hotspots has not been made yet. This study employs a systematic review to analyze the literature on ecosystem services provided by CWs and how they are incorporated into the valuation of CW projects. Among the ecosystem services that have been identified are provisioning (biomass and water supply), regulating (wastewater treatment and purification, climate regulation, flood prevention, and erosion control), cultural (recreation and aesthetic, biodiversity, education, and research), and supporting (habitat formation, nutrient cycling, and hydrological cycle). In terms of valuation methods and techniques, the results identified contingent valuation, shadow pricing, cost–benefit analysis, benefits transfer, habitat evaluation procedures, replacement cost, and travel cost. The analysis results provide researchers with a concrete basis for future studies and directions for further development. This also provides policymakers and CW project planners with valuable insights on various aspects of policy support for CW adoption and project valuation.

Keywords: constructed wetlands; ecosystem services valuation; nature-based solution; wastewater treatment

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1. Introduction

Rapid urbanization, population growth, and unsustainable economic development resulted in a significant increase in wastewater generated by humans and industries that are released into the environment. Globally, water discharges from industry, municipalities, and agriculture have doubled compared to the world's population over the last century [1]. In 2020 alone, only 56% of all wastewater flow generated by households globally was collected and safely treated [2]. The world has targets to improve this by reducing water pollution through the elimination of released hazardous chemicals, halving the proportion of untreated wastewater, and increasing the recycling and safe reuse of water by 2030. Following the Sustainable Development Goal (SDG) 6.3.1, the proportion of the total, industrial, and household wastewater flows should be safely treated in compliance with national or local standards [2].

Over the last few decades, several technologies have been employed to treat wastewater. These include physical, biological, chemical, and hybrid treatment techniques for the removal of various contaminants from wastewater [3–5]. Currently, the best method has not yet been identified as these techniques have their benefits and challenges in terms of technical difficulty, environmental impact, effectiveness, economic feasibility, and cost-efficiency [3]. Yet, these technologies helped improve wastewater management not only for protecting drinking water resources from fecal contamination and waterborne diseases but also for protecting aquatic ecosystems from nutrient input and chemical/plastic pollution and for mitigating and adapting to climate change [2].

Another alternative is constructed wetlands (CWs), which is a nature-based solution (NBS) to improve the quality of water. Naturally, wetlands are being considered increasingly for wastewater treatment due to the ability of several wetland plants to absorb huge amounts of nutrients and a variety of toxic substances [6]. Major kinds of wetlands include swamps, marshes, and bogs, while these may also refer to peatlands, sloughs, muskegs, fens, potholes, and mires. On the other hand, CWs are engineered treatment systems that have been designed and constructed using natural processes consisting of wetland vegetation, soils, and their associated microbial assemblages to assist in treating wastewater [7]. The performance of CWs depends on the type, vegetation, application by hydraulic load, and media used in the bed [8]. For instance, various types of CWs are free water surface, horizontal flow, vertical flow, hybrid, aerated, and baffled sub-surface flow. These CWs combine the core structural components of natural wetland ecosystems to mimic and perform the selected functions of natural wetlands and, therefore, deliver a range of monetary and non-monetary benefits, including water quality improvement, flood protection, and the promotion of biodiversity [9,10].

Given these benefits, numerous studies have evaluated the feasibility of a CW project from environmental, economic, technical, decision-support, and socially accepting perspectives. For example, Dumax and Rozan [10] analyzed the environmental costs and benefits directly of the ecological impact of the creation of an artificial wetland. In another study, Lutterbeck, et al. [11] employed a life cycle analysis (LCA) of integrated wastewater treatment with CW in rural areas and found reductions in chemical oxygen demand, biochemical oxygen demand, Kjedahl and ammoniacal nitrogen, and total phosphorus from the wastewater. Combining environmental and economic analysis, DiMuro, et al. [12] applied replacement cost methodology and LCA for CW in industrial wastewater treatment. The study found a 282 million USD total net present value savings over the project's lifetime; lower energy and material inputs to the CW; lower potential impacts for fossil fuel use, acidification, smog formation, and ozone depletion; and lower potential impacts for global warming and marine eutrophication [12]. Meanwhile, Friedrichsen, et al. [13] considered the social and cultural variables impacting the maintenance of constructed wetlands for decentralized wastewater treatment to provide agricultural irrigation water. Their results found three themes: mental models of CW maintenance, which showed the plural valuation of ecosystem services, immediate emotional disgust or repugnance as a leverage point for decreasing social cohesion in the community, and recommendations for improving maintenance through a human-centered design of CWs [13]. Furthermore, Ilyas, et al. [14] identified the lack of developing tools for supporting the decision-making process; hence, a method was proposed to provide a sound scientific basis for multiple decision-makers on the design and operation of CWs.

Despite the usefulness of various methods for valuing CW projects, they are most of the time undervalued as they are evaluated as water treatment projects and not as an ecosystem. Looking at this perspective, CWs provide several ecosystem services, including provisioning, regulating, cultural, and supporting services. Currently, only a limited number of studies consider these ecosystem services in the evaluation of CWs. Moreover, no reviews have been conducted so far, albeit consequential in examining the state-of-the-art and identifying the gaps as bases for future research directions.

This study aims to contribute to the literature by providing an in-depth review of the current research on the valuation of ecosystem services provided by CWs as NBS to wastewater treatment. The objectives of this study are (1) to review the extant literature that incorporates ecosystem services in the valuation of CW projects; (2) to present a comprehensive overview of ecosystem services provided by CWs; (3) to analyze various valuation techniques for ecosystem services of CWs; and (4) to identify the knowledge gaps that serve as a basis for research directions. Applying a systematic review of the literature, the results provide several insights into the ecosystem services valuation of CWs that need further research and present implications that might be useful for CW project planners and policymakers.

2. Materials and Methods

A systematic review of the literature is a process of searching, appraising, and collecting all relevant evidence on a given topic that fits pre-specified eligibility criteria and has an answer to the formulated research questions [15]. Compared with other review methods, systematic reviews deliver a comprehensive overview of a given topic, help identify research gaps in a field, highlight methodological concerns that can be used to improve future work in the topic area and identify questions with clear answers meaning that further research is not necessary [16,17]. This study applied a systematic review of the literature to provide a comprehensive overview of ecosystem services and their valuation methodologies that are used in the CW literature. The sequence of steps includes (1) sample preparation and defining search criteria; (2) database selection; (3) the adjustment and refinement of research criteria; and (4) systematic analysis, as shown in Figure 1.

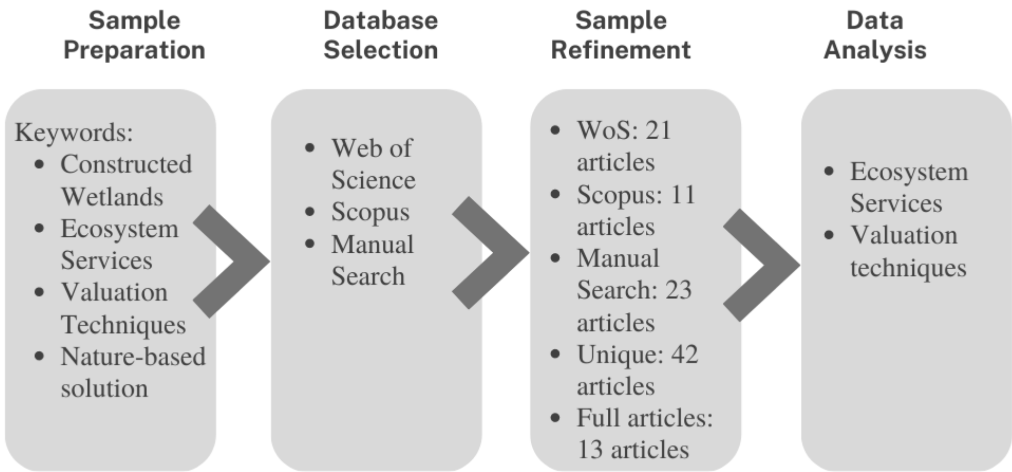

Figure 1. Systematic framework for a review of the literature.

In the sample preparation, the initial search was limited by the following criteria: (1) ecosystem services of CWs as nature-based solutions were identified, and (2) economic valuation was employed. The following combinations of keywords were used as a search criterion: "constructed wetlands" AND "nature-based solution" OR "NBS" AND "ecosystem services" AND "valuation", OR "economic valuation", OR "benefit–cost analysis" OR "cost–benefit analysis".

In the database selection, the Web of Science (WoS), being the world's leading scientific citation search and analytical information platform, was first considered as it supports a broad array of scientific tasks across diverse knowledge domains as well as providing a dataset for large-scale data-intensive studies [18]. WoS allows searching and filtered searches using several bibliographic parameters, providing easy access to the full texts of academic papers and the generation of useful information to evaluate a certain scientific area [17,19]. Another database is Scopus, which is among the largest curated abstract and citation databases with a wide global and regional coverage of scientific journals, conference proceedings, and books, which ensures the indexing of only the highest quality literature through rigorous content selection and re-evaluation by an independent board [20]. To ensure the comprehensiveness of the review, a manual search of the literature was conducted to supplement the principal source of data. While Google Scholar is considered unsuitable for primary review searches, it is considered a suitable supplementary source of evidence for its specific qualities that could retrieve additional records and further improve the evidence base [21].

The preliminary search resulted in 21 documents from WoS, 11 from Scopus, and 23 from a manual search. These three searches were combined, and the duplicates were removed. The 42 unique documents were then refined into journal articles in the English language identifying at least one ecosystem service provided by CWs using any valuation techniques. Among the excluded literature were review articles [22–26] which only provided a comprehensive review of the ecosystem services of CWs but no valuation. Additionally, a conference proceeding [27] was excluded due to the limited discussion of the ecosystem services or the valuation techniques that were crucial in the systematic review. As a result, there were 13 research articles analyzed for a systematic review of the literature. A complete list of these articles is summarized in Appendix A—Table A1. Summary of Reviewed Articles.

3. Ecosystem Services of Constructed Wetlands

A millennium ecosystem assessment (MEA) [28] defined the different types of benefits that humans could obtain from ecosystems and coined the phrase "ecosystem services" to describe them. In a broader sense, ecosystem services are the advantages that humans obtain from ecosystems that serve as a connection between human societies and the ecosystem. This results in complex ecosystem conditions and mechanisms in which the living and nonliving elements of the ecosystem produce these ecosystem services.

Constructed wetlands (CWs) are designed and built to mimic natural wetlands to treat wastewater. Today, CWs can be used as NBS to treat water from various sources and applications, including agricultural runoff [29–31], industrial effluents [32–34], stormwater runoff [35–37], and municipal wastewater [38–40]. Considering CW as an ecosystem, CWs contribute to human well-being by providing certain ecosystem services that can be classified into four distinct categories, namely: provisioning services, regulating services, supporting services, and cultural services [41]. The ecosystem services provided by CWs for wastewater treatment, as discussed in the reviewed literature, are summarized in Figure 2.

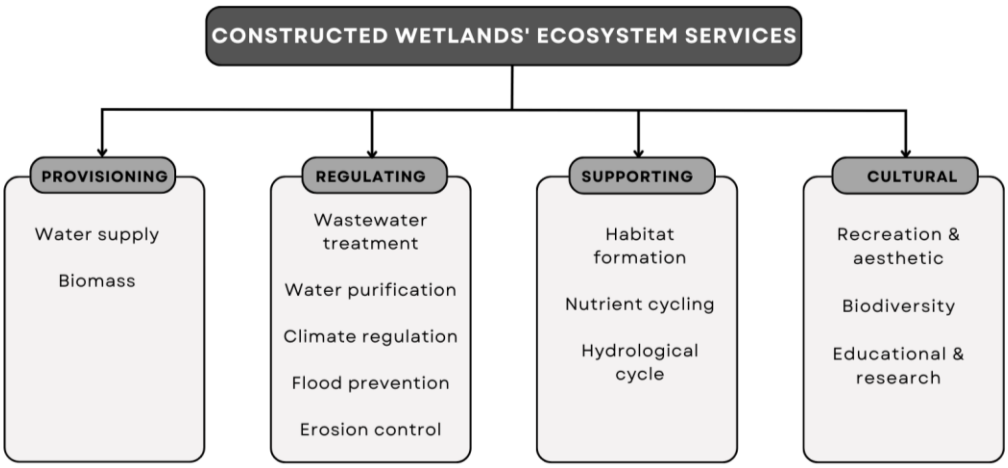

Figure 2. Summary of ecosystem services of constructed wetlands for wastewater treatment.

3.1. Provisioning Services

The tangible resources or material products that humans harvest from ecosystems are referred to as provisioning services. These are limited in quantity but have the potential to be replenished, and are capable of being directly consumed, appropriated, and exchanged [42]. The reviewed literature identified the provisioning services provided by CWs, such as sources of biomass and water supply.

- Biomass—Constructed wetlands provide biomass, which may be collected, dried, and utilized in the food and energy industries. Humans may utilize biomass as food for direct consumption, fodder for livestock, and semi-woody biomass for fueling purposes, such as directly for heating and cooking or for the creation of biogas and/or biofuel [43]. Snyder [44] investigated a case of CW in Costa Rica and found that, in the absence of wastewater treatment ecosystem services, biomass production costs ranged from 243 to 1287 USD dry Mg-1, depending on model assumptions. Considering the ecosystem services, the costs of biomass production range from 38 to −290 USD dry Mg-1, in which the negative costs indicate income, suggesting that the value of water treatment services is large enough to pay for wetland operations, and that biomass can be provisioned for free while still maintaining system profitability [44].

- Water supply—Constructed wetlands can treat several types of water, including agricultural wastewater, industrial wastewater, municipal wastewater, stormwater runoff, landfill leachate, and mining water. Treated wastewater is expected to be appropriate for reuse in a variety of settings, including construction and agricultural irrigation. Shingare et al. [45] revealed that the practice of using untreated or treated wastewater for agricultural irrigation, particularly in the least developing countries, poses a significant risk to human health due to the presence of pathogens in the water. Building a constructed wetland is one of several methods for purifying wastewater with higher enteric pathogen removal efficiency and converting it into a resource that can be used for agricultural irrigation. García-Herrero et al. [29] also described how additional agricultural benefits might come from the potential reuse of wastewater from CWs, considering it as an 'extra' income for avoided losses on production due to drought events equal to 20% on gross saleable production.

3.2. Regulating Services

Regulating services are the result of various ecological processes that contribute to the operation of an ecosystem, particularly the regulation of the environment in which humans live and work. In addition, they regulate the amount, timing, and quality of water supplies, as well as the impact of extreme weather on ecosystems and people [46]. As an NBS, regulating services of CW maintain nature's ability to provide material contributions that are usually in indirect ways. Among the identified regulating services of CWs in the literature review are wastewater treatment, water purification, climate regulation, flood prevention, and erosion control.

- Wastewater treatment—In the last five decades, CWs have developed into dependable wastewater treatment technologies. It becomes a solution for treating various forms of wastewater, such as sewage, industrial and agricultural wastewater, landfill leachate, and stormwater runoff [47]. For instance, the CW in Beijing is dominated by the ecosystem service of waste treatment, with a fraction of 63.82% corresponding to the amount of 1.31 million USD/ha/yr [48]. Pollution is cleaned in natural wetland ecosystems by mechanisms that are also present in constructed wetland ecosystems, although equivalent processes occur under more closely regulated settings in CWs [47].
- Water purification—Water purification is the process of eliminating potentially harmful impurities from water. The objective is to produce water that can be utilized for human consumption for other reasons. Wang et al. [49] analyzed the factors affecting the purification effect of CWs. They investigated zeolite characteristics, isothermal adsorption modeling, adsorption kinetics simulation, and pollutant purification. The findings demonstrate that zeolite's adsorption is greater than that of the total phosphorus suggesting that the purification process of CWs with compound substrates has increased. Irwin et al. [50] seconded that CWs provide a strategy to improve water quality via the removal of phosphorus, which may lead to an excessive algal bloom that decreases lake clarity, quality, functionality, and recreation value.
- Climate regulation—Mander et al. [51] evaluated the usefulness of constructed free-water surface (FWS) wetlands and constructed riverine wetlands (CRWs) in climate regulation. The relationship between greenhouse gas (GHG) emissions, methane emissions, and nitrous oxide (N2O) emissions and the biophysical and design factors of the systems was studied, and it was found that the current global warming potential (GWP) of FWS, CW, and CRWs was generally small, but their rapidly increasing

number should alert wetland designers and stakeholders to improve the design and management of these systems. On the contrary, Chen et al. [48] found negative ecosystem services values of −238 USD/ha/yr for GHG regulation from the CW in Beijing due to the vast GHG emission from the treated wastewater, in contrast to the positive values associated with the Sanyang and mean CWs.

- Flood prevention—CWs are cost-effective treatment systems that can be used to treat urban stormwater runoff. As CWs are generally controlled by a pit and a piped outlet, they act under the same principle as a retarding basin by discharging flood flows at a controlled rate; hence, they can be utilized to assist in flood protection in urban areas [52]. For instance, there has been a rising interest in constructed wetland projects in Korea, both as a flood control tool and for ecological reasons. Kim et al. [53] conducted hydraulic and hydrologic analyses on a wetland development plan for use as an alternative sustainable flood defense during the flood season and a wetland that could maintain the environment during non-flood seasons. They found that the CWs potentially served as an alternative instrument for flood prevention and a refuge for biodiversity. Meanwhile, in agriculture, Canning et al. [54] estimated that surrounding sugarcane farms benefited from the reduced flooding of cropland and the elevation of low-lying croplands with deposited spoil excavated from CWs' construction. Improved drainage and flow regulation increased the sugarcane yield, while elevated land increased gross margins by extending the length of the cane production cycle or enabling a switch from cattle grazing to cane production [54].
- Erosion control—Sediment stabilization is one of the many advantages of using CWs for stormwater management [55]. The major feature of stormwater wetlands (similar to other CWs) is the presence of vegetation, which plays an important part in the system's processes. They act as a protective ground cover and aid in preventing soil erosion. Its roots prevent soil from being blown or washed away by wind and water. Hence, they have the potential to slow the flow of water over land, which allows the soil to absorb a greater proportion of precipitation. Additionally, the vegetation absorbs nutrients and stabilizes the currently exposed banks of the wetlands, thus reducing the risk of erosion while also increasing resistance to water flow, thus reducing kinetic energy and promoting increased sedimentation [56].

3.3. Supporting Services

Supporting services are indirect benefits since they are ecological activities that benefit communities indirectly by maintaining one of the other three types of services [46]. As a result, supporting services constitute a subset of indirect services. They include processes and functions that provide the basis for appropriate provisioning, regulatory, and cultural services. The literature review found supporting services from CWs, such as habitat formation, nutrient cycling, and hydrological cycle.

- Habitat formation—The benefits of CW habitats extend beyond their initial design and construction standards. CWs that are utilized for wastewater treatment provide extra benefits such as habitats for local species. The habitat and refugia provision services represent the environment provided by CWs for biodiversity [48]. Scientists in several European countries as well as New Zealand, have calculated monetary estimates for the benefits gained from wetland ecosystems, including those altered by humans [22]. The conservation and restoration of natural habitats was the most highly valued ecosystem function at these locations, with monetary estimates ranging from 197 USD/ha/year in Whangamarino, New Zealand [57] to 27,678 USD/ha/year in Cheimaditida and Zazari, Greece [58].
- Nutrient cycling—Through the movement of nutrients, nutrient cycles provide a connection between living species and non-living organisms. Vegetation can minimize the quantities of elements in CWs that would otherwise be deemed pollutants because they make use of nutrients such as nitrogen and phosphorus. Additionally, they can store phytotoxic substances, such as heavy metals, in vacuolar or granular compart-

ments of their tissues. As a result, phytoremediation might be a significant part of the plants' roles in CWs [59]. Zheng et al. [60] further identified that the presence of biochar (from sewage sludge and cattail plants) in CWs not only kills pathogenic bacteria in the sludge but also promotes carbon release and nutrient cycling (P, K, Ca, Mg, etc.).

- Hydrological cycle—According to the "Sponge City" concept [61], CWs are recognized for their ability to connect the water cycle with urban development while also contributing to meeting the ongoing issues of climate change and increasing urban growth. This concept incorporates drainage, penetration, detention, storage, and purification, which make CWs an important technological answer for water purification. Within the urban hydrologic cycle, CWs may contribute to integrated urban water management by recycling the stored water volume [34].

3.4. Cultural Services

Cultural services refer to the contribution of ecosystems to the intangible benefits resulting from interactions between humans and ecosystems. One example of a cultural ecosystem function is the cultural sense of place or identity linked with the management of a particular environment [46].

- Recreation and Aesthetics—The term "recreational ecosystem services" refers to all of the benefits that humans derive from landscapes and the natural environment [62]. People benefit from an ecosystem's aesthetic and recreational components, which include physical, mental, and emotional well-being benefits [63]. Leisure activities also serve as a basis for the local economy and directly related enterprises in several cases. Ghermandi and Fichtman [64] identified 166 CW systems that support public recreational and educational activities worldwide. Yang et al. [65] suggested that while calculating the economic value of a CW, societal, cultural, and recreational components should be included as well. Since every year, primary and middle schools organize field trips to the CWs in China for their students, the CW is vital to the local community in terms of both educational and recreational purposes [65].
- Biodiversity—While CWs have shown efficiency as NBS for water treatment, Préau et al. [66] reported their ability to enhance biodiversity in various agricultural landscapes by providing suitable breeding habitats for various animal species. Hsu et al. [67] investigated the biodiversity of two free-water-surface integrated constructed wetlands in subtropical Taiwan by examining the water quality, habitat characteristics, and biotic communities of algae, macrophytes, birds, fish, and aquatic macroinvertebrates in treatment cells. The two wetlands were home to 58 birds, seven fish, and 34 aquatic macroinvertebrate species. As the most important factors impacting diversity in CWs, community structures within taxonomic groups change based on the wetland acreage, aquatic macrophyte coverage, and water quality. According to the findings of this study, well-planned and managed wetland treatment facilities can improve water quality and biodiversity.
- Educational and Research—The provision of educational opportunities is one of the many benefits to human societies that ecosystems and landscapes offer. The numerous techniques for quantifying ecosystem services hardly ever take into consideration the significance of this factor, albeit those that are important to both formal and informal learning, as well as nature-based cognitive tourism [68]. For instance, the primary and middle schools in Hangzhou organize students to visit the CW each year, creating an important role in local education and recreation [65].

4. Ecosystem Services Valuation of Constructed Wetlands

Ecosystem services are usually described as open access or pure public services. This means that they do not have producer property rights, no clear entitlement systems, and prohibitive transaction costs [69]. There is a minimal incentive for beneficiaries to manage ecosystem services sustainably because no one "owns" or has "rights" to them, and no one can prevent others from consuming or profiting from them [70]. Compensation payments from beneficiaries are difficult to obtain for redistribution among intra- and intergenerational parties who may be damaged by biodiversity loss, pollution, or the chronic deterioration and depletion of ecosystem services [69]. In reality, ecosystem services are not marketable and are thus typically overlooked in economic analyses. The value of ecosystem services is currently being established as a means of addressing the historical neglect of environmental services in policy decisions [71].

In this systematic review of the literature, various valuation methods for each ecosystem service were analyzed. Figure 3 summarizes the techniques and methods used for the valuation of ecosystem services provided by CWs. For the provisioning services, contingent valuation (CVM) and shadow price methods are used. Several methods are used in valuing regulating services, such as CVM, shadow pricing, cost–benefit analysis (CBA), benefits transfer, habitat evaluation procedure (HEP), replacement cost, and travel cost method. For support services, CVM, shadow pricing, and CBA are utilized. Lastly, cultural services apply CVM, shadow pricing, CBA, HEP, and benefit transfer methods. The applications of each method and technique in the reviewed literature are discussed below.

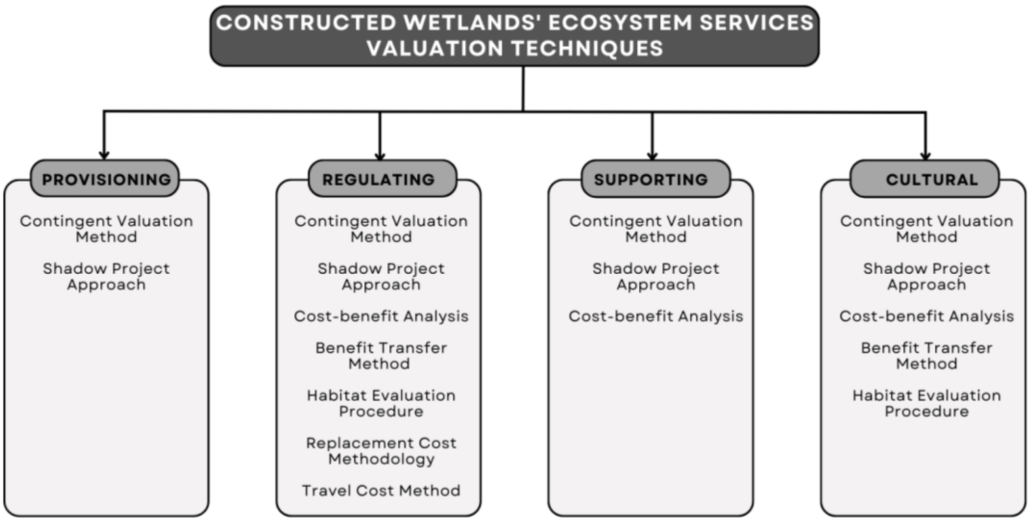

Figure 3. Summary of ecosystem service valuation techniques for constructed wetlands.

- Cost–benefit Analysis—The methodical and analytical process of comparing advantages and costs when evaluating the desirability of a project or program, frequently of a social character, is known as cost–benefit analysis [72]. It attempts to answer questions such as whether a proposed project is worthwhile, what the ideal scale of a given project is, and what the relevant limitations are. Garcia-Herrero et al. [29] evaluated the sustainability of two types of constructed wetlands in Sicily and Emilia-Romagna, Italy, using a cost–benefit analysis that incorporated both the market and non-market values of two CWs. They discovered that the benefits of both CWs outweighed their costs. In Queensland, Australia, a hybrid method was used to examine the feasibility of CWs for sugarcane profitability, freshwater biodiversity, and ecosystem services [54]. Fish ecological studies and CBA were applied. The results indicate that these services are suitable for CWs. In another study, Wang et al. [73] applied CBA employing field monitoring, social surveys, GIS geo-statistics, raster calculation methods, etc., to value the Jiuli Lake wetland: an artificial wetland derived from the restoration of a mining subsided lake in a plain area. CBA found that after ecological restoration, the ecosystem services of CW yielded positive values; the improved environment of CW has a spillover effect on the price of the surrounding land, and incomes of the ecological restoration were found to be sufficient to cover the implementation costs [73].
- Benefit Transfer Method—The benefit transfer approach assesses the economic value of ecosystem services by transferring data from earlier studies to a different location

and/or context [74]. As a result, the primary goal of benefit transfer is to estimate benefits for one situation by changing the estimates of benefits from another environment. Using value transfer mechanisms for ecosystem service monetization, Rizzo et al. [75] compared grey and green infrastructure as options for managing combined sewer overflow in Buccinasco, Italy. The results demonstrated a potential interest in the building of green infrastructure in a new urban park due to the activation of other ecosystem services of interest, such as health and recreational (cultural services) components. One advantage of this valuation method is that it allows for the valuation of ecosystem services at a low cost and effort when compared to other valuation methods.

- Habitat Evaluation Procedure—The Somerset habitat evaluation procedure (HEP) technique is used to estimate the value of a site's habitats for key species; the resulting value is then used to quantify the amount of habitat restoration required to compensate for habitat loss due to land use change [76]. The "adapted" habitat evaluation procedure (HEPa) was adopted by Dumax and Rozan [10] to better value a CW's supporting (habitat formation), regulating (water purification and flood protection), and cultural (biodiversity) ecosystem services. The HEPa directly relies on the evaluation of environmental costs and benefits on the ecological impact of the actions taken. Their findings revealed that the HEPa, which was created to analyze environmental costs, could be used to measure the advantages of creating a CW and suggested that this assessment could help decision-makers base their decisions on the genuine value of wetlands.
- Contingent Valuation Method—Contingent valuation is a survey method that asks respondents to indicate their preferences in hypothetical or contingent marketplaces, allowing researchers to assess demand for non-traded commodities or services [77]. In general, the survey gathered a sample of participants who were asked to imagine a market in which they might acquire the evaluated product or service. Individuals expressed their highest willingness to pay (WTP) for a change in the provision of an item or service, as well as their lowest compensation willingness to accept (WTA) if the change was not implemented. When provisioning ecosystem services (e.g., biomass) were evaluated using a contingent valuation method and optimistic capital cost assumptions, biomass production costs ranged from 38 to 290 USD dry Mg-1 [44]. In another study, the CVM calculated the entire economic value of the CW over 20 years to be 118 thousand USD [65]. According to the examined articles, CVM could be used to value the four types of ecosystem services.
- Shadow Project Approach—Shadow pricing is the process of assigning a monetary value to an asset, product, or service that is not typically purchased or sold in any marketplace. Shadow pricing can also be utilized to estimate social costs and benefits, such as the societal benefit of creating a public asset (e.g., public transportation, public infrastructure). It is now acknowledged that this method can be used in valuing ecosystem services. Yang et al. [65] examined the four categories of ecosystem services offered by a CW at the Hangzhou Botanical Garden in China from an economic standpoint: providing, supporting, regulating, and cultural. The contingent valuation method (CVM) and the shadow project approach (SPA) were utilized. SPA was used to justify that the sum of the annual water cost, annual electrical cost, and annual management cost was the shadow price if they continued to employ existing technologies to maintain and improve the ornamental fishpond's natural landscape. Meanwhile, the CW provided the best possible conditions for the ornamental fishpond while requiring less financial investment and using fewer resources than conventional technology. As a result, the CW's ecosystem services could be valued using the shadow price. The SPA predicted that the CW would generate 3.45 million USD in economic value in 20 years. The SPA estimates the actual market worth of the Hangzhou Botanical Garden CW more accurately than the CVM.
- Replacement Cost Methodology—The replacement cost method involves determining the value of an asset by comparing it to the current cost of replacing it with a similar

asset in the same condition in a transaction between unrelated parties. This method is based on the assumption that a buyer will not pay more than the price of a comparable object, and a seller will not accept less. The method can be used to calculate the value of a company as a whole as well as its assets. The replacement cost method is used in two studies to assess the monetary value of CWs' ecosystem-regulating service. This method was used to assess the efficacy of wastewater treatment and water purification [12,78]. Between 1990 and 2000, the value of water treatment fell from 150 USD ha-1 to 138 USD ha-1 [78]. This reduction was due to increased human and agricultural land use at the expense of forests and wetland regions. In the case of wastewater treatment, the estimated net present value savings from using the created wetland rather than the sequencing batch reactor were 282 million USD over the project's lifespan [12].

- Travel Cost Method—The willingness to pay for recreational activities is calculated by factoring in the time and money it takes to travel to these locations. Therefore, the cost of transportation is utilized as a surrogate indicator of natural resource scarcity to calculate their potential market worth. The economic value of a CW in Catalonia, Spain, was investigated by Varela et al. [79]. The travel cost method is used to calculate the costs, benefits, and externalities of the case. The opportunity costs of a trip were the only ones considered under the travel cost method because travel and recreation expenses were discounted as negligible. Private costs ranged from 0.54 to 0.59 USD/m^3, whereas positive externalities were worth 1.35 USD/m^3. These results provide empirical evidence that created wetlands in peri-urban parks can be considered a source of positive externalities when employed in environmental restoration initiatives that prioritize the reuse of treated wastewater [79].

5. Conclusions

Constructed wetlands are man-made ecosystems that are utilized as a nature-based solution to treat water for reuse covering several purposes. Due to its cost-efficiency and environment-sensitive approach, its utilization has been growing in a wide range of applications. Previous studies analyzed the feasibility of constructed wetlands from various perspectives, yet its widespread adoption has not been realized. This research extended the literature by providing an overview of the integration of ecosystem services, in addition to water treatment purposes, in the valuation of constructed wetland projects. Based on a systematic analysis, the following can be concluded:

- Constructed wetlands provide provisioning services in terms of the biomass produced from the vegetation as well as the provision of water supply.
- Regulating services include primarily wastewater treatment and purification, while constructed wetlands also serve as climate regulation, flood prevention, and erosion control.
- Indirect benefits from constructed wetlands include several cultural services such as recreation and aesthetics for nature-lovers, biodiversity for flora and fauna, education through field trips/exploration and research.
- Supporting services of constructed wetlands are habitat formation, nutrient cycling, and hydrological cycle.
- Since constructed wetlands produce less to no direct market value, several methods and techniques are utilized to value the ecosystem services they provide. These include contingent valuation, shadow pricing, cost–benefit analysis, benefit transfer, habitat evaluation procedure, replacement cost, and travel costs.

This systematic review identified several gaps in the literature, which can serve as a basis for future research directions.

- The findings show that the availability of scientific and empirical evidence on the benefits of constructed wetland projects does not translate into decision-support tools for policymakers and project implementers. Hence, future studies should carry out further research on policies and how these support the adoption of constructed wetlands as nature-based water treatment.

- Second, this review focused on the ecosystem services of constructed wetlands and the different valuation techniques applicable or suitable for assessing their values. A comparison of the advantages and disadvantages of each valuation technique may be conducted when applying them to the different categories of ecosystem services. Furthermore, a comparison may also be performed for the case of using appropriate parameters of wetlands for water treatment, such as the water quality of the treatment.
- Third, future research may explicitly consider the potential of other economic valuation methods in assessing other nature-based solutions for wastewater treatment. Additionally, other project valuation methods that incorporate, for instance, uncertainties and risks may be integrated into the valuation to better capture the investment scenarios faced by project planners.

Realizing the importance of ecosystem services provided by constructed wetlands, this review provides implications for policymakers in making policies that support constructed wetlands as a nature-based solution to wastewater treatment, as well as to project implementers in making decisions to better appreciate the valuation of the project.

- The use of constructed wetlands as nature-based wastewater treatment solutions is becoming more common in the majority of developed countries. Yet, the ecosystem services they provide are undervalued, which hinders their widespread utilization. Project planners, decision-makers, and other stakeholders involved in evaluating constructed wetland projects are recommended to consider the ecosystem services, not only the direct economic value provided by the project. Additionally, policymakers may play a crucial role in these by legislating policies and providing programs that support the adoption of nature-based solutions to address environmental issues.
- Due to the irrecoverable investment cost, little to no financial returns from the project, and the economic value of ecosystem services, they do not translate into monetary values, and project planners are encouraged to attract and seek aid programs from various international organizations and local institutions to accompany them in the implementation of constructed wetlands as a nature-based solution to wastewater treatment. Otherwise, project planners may implement appropriate payments for ecosystem service schemes to compensate for the costs of the project.

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Appendix A

Table A1. Summary of reviewed articles. [1]

Authors	Year	Country	Ecosystem Services	Valuation Method
García-Herrero, Lavrnić, Guerrieri, Toscano, Milani, Cirelli and Vittuari [29]	2022	Italy	Irrigation, support to biodiversity and habitat of an environment, recreational and socio-economic services, energy production, flood prevention and control, and retention of water and prevention of erosion	Cost–benefit analysis
Canning, Smart, Dyke, Curwen, Hasan and Waltham [54]	2022	Australia	Flood control, sugarcane profitability, and freshwater biodiversity	Cost–benefit analysis
Rizzo, Conte and Masi [75]	2021	Italy	Air quality, biodiversity, carbon reduction and sequestration, education, water quality, health, recreation, and treatment of wastewater	Adjusted value transfer method
Dumax and Rozan [10]	2021	France	Water quality, flood protection, and promotion of biodiversity	Habitat evaluation procedure
Snyder [44]	2019	Costa Rica	Biomass for bioenergy and wastewater treatment	CVM and shadow project approach
Irwin, Irwin, Martin and Aracena [50]	2018	USA	Water quality	Benefit transfer method
Wang, Wang, Yin, Cui, Liang and Wang [73]	2017	China	Spillover effect	Cost–benefit analysis
Ghermandi and Fichtman [64]	2015	Israel	Recreational and educational benefits	Value transfer method
DiMuro, Guertin, Helling, Perkins and Romer [12]	2014	USA	Wastewater treatment	Replacement cost methodology (RCM)
La Notte, Maes, Grizzetti, Bouraoui and Zulian [78]	2012	Italy	Water purification Nitrogen retention	Replacement cost methodology (RCM)
Varela, García and Alfranca [79]	2011	Spain	Externalities	Travel cost method
Chen, Chen, Chen, Zhou, Yang and Zhou [48]	2009	China	Waste treatment, food and material production, water supply, gas regulation, disturbance and water regulation, and habitat and refugia provision	avoided cost, contingent valuation, hedonic pricing, market pricing, production approach, replacement cost, and travel cost
Yang, Chang, Xu, Peng and Ge [65]	2008	China	Water, biomass, recreation, gas regulation, micro-climate regulation, groundwater recharge, education, aesthetics, cultural heritage, historical legacy, biodiversity, and habitats	CVM and shadow project approach

[1] Source: Authors' analysis.

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