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ARTICLE

Integrating Environmental Value into Strategic Environmental Assessment: An Empirical Application to a Multipurpose Rural Water Development Project in South Korea

Hyun No Kim **,** ***Hwanhee Ryu*** *

Division for Green Transition, Korea Environment Institute, Bldg B, 370 Sicheong-daero, Sejong 30147, South Korea

ABSTRACT

This study examines the empirical feasibility of quantitatively integrating environmental value information into Strategic Environmental Assessment (SEA). An analytical framework was established to incorporate environmental cost estimates into the SEA process by utilizing ecosystem service unit values provided by the Environmental Valuation Information System (EVIS), a national platform developed to support the evaluation of policies and projects. The framework was applied to a case study involving a multipurpose rural water development project in South Korea. Ecosystem service losses resulting from the project were quantified using biophysical indicators, such as vegetation biomass, forest area, and hydrological functions, and subsequently monetized through the application of the market price method, replacement cost method, and contingent valuation method. The total annual environmental cost was estimated to be approximately KRW 56.18 billion, with the majority attributable to losses in forest conservation and climate regulation services. These findings demonstrate that quantified environmental data can serve as a robust basis for alternative comparison and site evaluation within SEA. The study provides empirical evidence supporting the advancement of SEA from a predominantly procedural tool focused on environmental protection to a more comprehensive sustainability assessment framework that integrates environmental, economic, and social considerations. Furthermore, the results suggest that EVIS-based

*CORRESPONDING AUTHOR:

Hwanhee Ryu, Division for Green Transition, Korea Environment Institute, Bldg B, 370 Sicheong-daero, Sejong 30147, South Korea; Email: ryuhh@kei.re.kr

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quantitative information holds potential for broader application in other national evaluation systems, such as preliminary feasibility studies and regulatory impact assessments.

Keywords: Environmental Valuation Information System (EVIS); Strategic Environmental Assessment (SEA); Sustainability Assessment; Ecosystem Services; Environmental Decision-Making

1. Introduction

The role of Strategic Environmental Assessment (SEA) as a policy instrument for integrating environmental, social, and economic considerations at the early stages of planning and decision-making is gaining increasing attention [1,2]. As sustainable development emerges as a central policy goal, there is a growing demand to move beyond basic environmental screening toward evaluation frameworks that can quantify multiple value dimensions and assess the relative appropriateness of policy alternatives [3–5].

In South Korea, SEA is implemented under the Environmental Impact Assessment Act and primarily focuses on assessing the environmental feasibility of plans and site suitability [6]. However, social and economic impacts are often limited to qualitative descriptions, and environmental values—particularly those derived from ecosystem services—are rarely quantified or systematically incorporated into the assessment process [7,8].

Existing studies have highlighted the lack of quantitative integration of environmental values in SEA [9–12]. Recent studies have demonstrated the long-term impacts of land-use change on ecosystem service values, emphasizing the need for spatial-temporal integration in environmental assessment. Schirpke et al. [13] examined land-use changes from 1860 to 2100 and revealed substantial shifts in ecosystem service values over time. Zhang et al. [14] used the Markov–FLUS model to simulate future land-use scenarios and quantify associated changes. These findings indicate the importance of incorporating dynamic land-use patterns and simulation models into SEA to enhance predictive power and policy relevance. While some research has emphasized that applying an ecosystem services framework can enhance the objectivity and validity of policy evaluation [15,16], institutional integration and practical applications remain insufficient. In particular, few attempts have been made to link ecosystem service-based value information to SEA systematically and operationally.

One promising tool in this regard is the Environmental Valuation Information System [17], a national-level platform designed to support the integration of environmental costs and benefits into policy and project evaluation. EVIS provides standardized unit values for a range of ecosystem services, based on market price, replacement cost, and stated preference methods. Despite its potential, EVIS has not yet been meaningfully incorporated into the SEA process, and empirical applications remain rare, especially in the context of strategic-level environmental assessments [7].

This study aims to explore the institutional potential for advancing SEA into a more sustainability-oriented assessment framework by empirically linking environmental value information to the SEA process. Specifically, we develop a quantitative assessment approach using EVIS unit values and apply it to a case study of a Multipurpose Rural Water Development Project in South Korea. By quantifying the physical impacts on ecosystem services and monetizing the resulting environmental costs, we examine how such information can be utilized in alternative comparisons within SEA. This study aims to develop and test a practical approach for integrating environmental value information into SEA, with a particular focus on utilizing the EVIS as a key analytical tool. It contributes in three main respects: first, by establishing a valuation framework based on ecosystem service unit values; second, by applying this framework to an actual development case in South Korea; and third, by offering policy-level insights for embedding quantitative evaluation more systematically within SEA procedures. This study aims to enhance the quantitative foundation of SEA and provide practical insights for integrating environmental values into sustainability assessments. It also provides a basis for expanding the use of EVIS-based data in other national evaluation systems, such as preliminary feasibility studies and regulatory impact assessments.

2. Conceptual Framework

2.1. Strategic Environmental Assessment (SEA)

SEA is a policy instrument designed to promote sustainable decision-making by systematically evaluating environmental considerations at the stage of formulating policies, plans, and programs (PPPs)[18]. Distinct from Environmental Impact Assessment (EIA), which focuses on mitigating impacts at the project implementation stage, SEA is applied at earlier stages to inform the development of planning directions and to support the comparative assessment of alternatives[19,20].

In South Korea, SEA was institutionalized in 2012 through a major revision of the Environmental Impact Assessment Act, which integrated and expanded the previous Prior Environmental Review system. According to Article 2 of the Act, SEA is defined as the process of reviewing the environmental appropriateness and locational suitability of proposed plans by assessing their conformity with environmental conservation objectives and analyzing alternatives, thereby contributing to sustainable national development. SEA is applied to long-term master plans and policy-level frameworks in sectors such as land use, urban development, and water resources.

The Ministry of Environment defines SEA not only as a procedure for environmental review, but also as a tool to evaluate the environmental, economic, and social dimensions of plans, thereby supporting decision-making throughout the planning process[21]. Accordingly, SEA aims to involve multiple stakeholders and government agencies at the strategic planning stage, guiding the identification of development alternatives and locations based on sustainability criteria.

Internationally, SEA is also recognized as a strategic decision-making tool for promoting sustainable development by integrating environmental, economic, and social considerations. OECD[18] and Josimović et al.[20] emphasize that effective SEA must incorporate early-stage intervention, alternative-driven analysis, and the use of quantitative data. In the United Kingdom, for instance, SEA has evolved into a broader framework known as Sustainability Appraisal, which explicitly incorporates social and economic impacts[22]. Similar approaches have been adopted in the European Union, Canada, Australia, and other countries[23].

Despite these developments, SEA in South Korea remains predominantly focused on environmental issues, with socioeconomic impacts addressed only superficially and typically in qualitative terms. Alternative analysis often relies on expert judgment or general planning data, limiting the role of quantitative environmental information in decision-making. This practice falls short of SEA's original intent and global trends toward comprehensive sustainability assessment.

To address these limitations, recent discussions highlight the need to strengthen SEA's quantitative capabilities and incorporate diverse forms of environmental value. In particular, ecosystem service-based valuation is increasingly viewed as a promising means of enhancing SEA's analytical rigor and objectivity[24]. This study examines a practical approach for integrating environmental value information—specifically, data from EVIS—into the SEA framework.

2.2. Environmental Valuation Information System (EVIS)

Environmental value refers to the worth attributed to the various benefits and services that natural ecosystems provide to human society. These values often encompass non-market goods, which are not traded in formal markets but deliver essential utility and well-being. Environmental values are typically categorized into use values (e.g., direct and indirect use) and non-use values (e.g., existence and bequest values). They are quantified through valuation techniques such as the contingent valuation method (CVM), choice experiment (CE), replacement cost method, and market price method[25,26].

To operationalize environmental valuation, the concept of ecosystem services has emerged as a practical and widely accepted framework. Ecosystem services represent the functions and benefits that ecosystems offer to human well-being and are generally classified into four major categories: provisioning, regulating, cultural, and supporting services[27,28]. This classification facilitates the identification, quantification, and monetization of environmental benefits and costs in policy and project evaluations.

The EVIS, developed and maintained by the Korea Environment Institute (KEI), provides a structured platform for integrating environmental values into decision-making processes. Based on the ecosystem services framework, EVIS compiles and offers unit value data derived from national and international studies. These values are linked to biophysical indicators and can be used to estimate environmental costs or benefits by multiplying them with user-provided data on physical changes.

Specifically, EVIS encompasses 16 ecosystem service items across the four service categories and supports monetary valuation through multiple approaches, including the replacement cost method, the avoidance cost method, and model-derived estimations. The system is designed to be applied to various national evaluation frameworks, including EIA, Preliminary Feasibility Studies, and Regulatory Impact Assessment.

However, despite its structured data and valuation capabilities, EVIS remains underutilized within institutional decision-making systems. In particular, there is no formal mechanism for incorporating EVIS-based quantitative information into SEA. Consequently, its potential contributions to policy evaluation remain largely unrealized. Nonetheless, EVIS provides a promising foundation for integrating monetized environmental values into planning and policy processes, thereby enhancing the objectivity and consistency of environmental assessments.

2.3. Integration of Environmental Value Information into SEA

SEA serves as a policy instrument designed to support sustainable decision-making by evaluating the potential environmental impacts of alternative plans and programs during the early stages of policy and planning [22–24]. However, in practice, SEA in South Korea still relies predominantly on qualitative descriptions, and the application of quantitative analyses for evaluating environmental appropriateness remains limited. In particular, there is currently no institutional mechanism for systematically incorporating quantified environmental values, such as environmental benefits and costs into SEA procedures.

Presently, environmental impacts in SEA are often compared qualitatively between alternatives or assessed based on indirect indicators, such as the presence of legally protected areas or the potential for public complaints [29]. These approaches fail to capture the actual magnitude of environmental benefits and costs, which poses a significant limitation in evaluating the sustainability of proposed development plans on a quantitative basis. This becomes especially problematic when multiple site alternatives of similar scale are presented, making it difficult for decision-makers to clearly distinguish the environmental implications of each option [30].

In contrast, the EVIS provides a practical foundation for strengthening the quantitative dimension of SEA. EVIS enables the estimation of environmental costs and benefits associated with changes in ecosystem services by applying unit values to measurable biophysical indicators. By translating ecosystem service gains or losses into monetary terms, EVIS supports more objective and transparent comparisons among policy or project alternatives. Specifically, in core SEA procedures, such as alternative analysis and site suitability assessments, EVIS can be used to quantify the external costs of development or the benefits of conservation, thereby providing policymakers with a clear and comprehensible basis for evaluation.

Moreover, SEA, as an instrument aimed at guiding sustainable territorial development, must encompass not only environmental but also economic and social considerations. Nevertheless, current SEA evaluations typically address socio-economic impacts in a descriptive and limited manner, often listing general indicators such as population, housing, or industry. This structural constraint hinders the integration of assessments that compare environmental and economic factors in a consistent manner.

By introducing quantified environmental value information, SEA can be better aligned with other national evaluation frameworks, such as preliminary feasibility studies and regulatory impact assessments. Thus, the integration of EVIS-based data into SEA is not only desirable but necessary to enhance the objectivity, consistency, and policy relevance of environmental assessments. In countries such as the UK and Canada, SEA tends to rely on qualitative tools, such as expert judgment, impact matrices, and checklist-based reviews [31]. These methods reflect a procedural approach that, while well established, often lacks quantitative rigor. In contrast, the EVIS-based approach applied in this study incorporates monetary valuation of ecosystem services, providing a more structured and transparent basis for comparing development alternatives.

3. Methods

This study conducted an empirical case analysis to examine the feasibility of quantitatively integrating environmental value information into SEA. The subject of analysis was a Multipurpose Rural Water Development Project in South Korea, for which SEA had been applied during the planning stage. Through this case, the changes in ecosystem services and associated environmental value losses resulting from development were assessed, and environmental costs were estimated by applying unit values from the EVIS.

The research was carried out in three main stages. First, the spatial and institutional characteristics of the study area, along with the details of the development plan, were reviewed to confirm its suitability as a case for SEA evaluation. Second, changes in ecosystem services caused by the project were identified, and appropriate indicators and data sources were selected for quantifying those impacts. Third, unit values were applied to the quantified changes in ecosystem services to estimate the total environmental cost, and the applicability of this information to alternative comparison and site suitability assessments within SEA was examined.

3.1. Case Description and Study Area

The subject of this study is a Multipurpose Rural Water Development Project planned in Yangnam-myeon, Gyeongju-si, Gyeongsangbuk-do, South Korea. The main features of the project are summarized in **Table 1**. The project aims to ensure a stable supply of agricultural water and enhance resilience to droughts by constructing reservoirs, irrigation canals, and related infrastructure. An SEA was carried out as part of the planning process.

This case was selected due to its expected impacts on forest ecosystems and the presence of clearly defined site alternatives and location decisions in the planning documents, making it appropriate for comparative analysis of environmental values. Key elements of the development plan, including facility scale, watershed area, and service area, were compiled based on the environmental impact statement and related spatial data. Information on site characteristics and ecosystem conditions was analyzed using data from the Environmental Impact Assessment Support System [32] and the KEI.

Table 1. Key features of the multipurpose rural water development project in the study area.

Description	
Project Name	Multipurpose Rural Water Development Project
Location	Yangnam-myeon, Gyeongju-si, Gyeongsangbuk-do, Republic of Korea
Implementing Agency	Korea Rural Community Corporation (KRC)
Planning Authority	Ministry of Agriculture, Food and Rural Affairs (MAFRA)
Overview of Major Facilities	
Major Infrastructure	Construction of one new water intake facility
Catchment Area	657 hectare
Full Water Level Area	13.55 hectare
Irrigation Area	217.2 hectare (67.0 hectare existing, 109.8 hectare improved, 40.4 hectare newly developed)
Total Storage Volume	1,284.55 thousand m³ (Effective storage: 1,203.85 thousand m³)
Irrigation Canal	3 lines totaling 9 km

3.2. Identification and Quantification of Ecosystem Service Impacts

To analyze the changes in ecosystem services resulting from the multipurpose rural water development project, we selected assessment items based on the ecosystem service classification framework provided by EVIS. The analysis focused on quantifiable items within the categories of provisioning services, regulating services, and conservation value, while excluding cultural services and items with significant functional overlap.

The selected ecosystem service items included non-timber forest product (NTFP) provisioning, carbon sequestration and storage, water retention, soil conservation, and forest conservation value. The level of impact on each service was quantified using variables, such as forest area, vegetation conservation grade, aboveground biomass, net primary productivity, and estimated soil erosion. These service categories and the expected degree of impact were summarized in **Table 2**, which classifies the evaluation targets and provides a structural foundation for subsequent quantification and monetization.

A proxy-based indicator approach was applied for quantification. Biophysical change was calculated using coefficients derived from relevant literature. For example, the carbon sequestration and storage functions were estimated by applying a biomass-to-carbon conversion factor of 0.5, as recommended by the IPCC [33], to the reductions in vegetation biomass and net primary productivity. Water retention was evaluated using an annual recharge coefficient of 1,306.98 tons per hectare, as suggested by the National Institute of Forest Science [34]. Soil conservation was assessed based on the difference in annual soil erosion between forested and non-forested land, which was estimated at 289.41 m³ per hectare.

Table 2. Anticipated impacts of the multipurpose rural water development project on ecosystem services.

Category	Subcategory	Function	Expected Impact
Provisioning Services	Food and Forage Provision	Provision of edible plants and animals	++ Edible forest products such as wild greens and mushrooms
	Energy Production	Biological or abiotic elements with potential energy utility (e.g., biomass)	++ Woody biomass used for energy (overlapping with raw materials)
	Raw Material Provision	Biological or abiotic elements with potential material use (e.g., timber, plant oils)	++ Timber from forest areas
	Medicinal/Biochemical/Genetic Resources	Maintenance of potentially useful genes for pharmaceuticals or biodiversity	– Impact depends on vegetation conservation grade (mostly Grade 3–5)
	Freshwater Provision	Ecosystem's capacity to supply freshwater	+ Forest biomass's water retention and release function (overlapping with water regulation)
Regulating Services	Air Purification	Removal of air pollutants by ecosystem functions (e.g., forest filtering capacity)	+ Function reduction due to vegetation loss from land use change
	Climate Regulation	Regulation of regional/global climate through land cover and biological processes	++ Carbon sequestration and storage
	Water Regulation	Water storage and release by ecosystems (e.g., forests as green dams)	+ Function reduction due to vegetation loss from land use change
	Water Purification	Removal/decomposition of pollutants via biotic or abiotic means	+ Function reduction due to vegetation loss from land use change
	Pollination	Pollination services for seed-bearing plants (e.g., by insects, wind, or water)	-
	Hazard Regulation	Moderation of natural hazards by ecosystems (e.g., flood or landslide control by forests)	++ Flood mitigation and landslide prevention via vegetation (overlapping with soil and water regulation)
	Biological Control	Regulation of pest populations through ecosystem dynamics	-
	Soil Stabilization and Purification	Soil formation, erosion control, and detoxification functions	++ Soil stabilization provided by forest cover
Natural Assets	Habitat Provision	Provision of habitat for flora, fauna, and other ecosystem services	+ Ecosystem quality varies by location
	Biodiversity	Genetic, species, and ecosystem diversity	- Impact depends on vegetation conservation grade (mostly Grade 3–5)
Conservation Value		Non-use values derived from maintaining natural resources	++ Loss of conservation value due to reservoir development for water supply

Note: "–" indicates negligible impact; "+" and "++" denote moderate and high anticipated impact, respectively. Shaded items indicate those selected for quantitative valuation based on available data templates.

Table 3 summarizes the spatial and ecological characteristics of the study area, encompassing key input variables used for the quantitative assessment of ecosystem services. The table includes data on vegetation conservation grade by area and proportion, elevation and slope of the inundation zone, topographic alteration metrics (e.g., disturbed area, cut-and-fill volumes), land use by cadastral classification, number of trees to be removed, beneficiary area (existing, improved, and newly served), vegetation biomass, and net primary productivity. These spatial attributes were collected and analyzed using data provided by the EIASS and the KEI.

Table 3. Site characteristics of the case study area.

• Project site address (location information) • Area and proportion by vegetation conservation grade • Area and proportion by elevation within the planned inundation zone • Slope analysis (less than 15°, 15–20°, 20–30°, over 30°) • Topographic alteration (area of disturbance, cut volume, fill volume) • Land use status by cadastral category (area by land classification within project boundary) • Number of trees to be removed • Beneficiary area (new, improved, and existing service areas in hectare) • Pre- and post-development vegetation biomass (tons) and net primary productivity (tons/year), estimated based on vegetation conservation grade and area distribution

3.3. Monetary Valuation Methods for Estimating Environmental Costs

This study employed unit values of ecosystem services provided by the EVIS and previous research to monetize environmental costs associated with the selected case. Depending on the characteristics of each service and data availability, a combination of valuation approaches was applied, including the market price method, replacement cost method, and CVM.

The market price method was used for services with observable or estimated market values, such as non-timber forest product (NTFP) supply and carbon sequestration. For instance, the carbon sequestration function was valued using the average transaction price of Korean Allowance Units (KAU21), estimated at KRW 31,907 per ton of CO_2. The value of forest products was derived by applying a unit value of KRW 9.2/m², based on the annual production value of forest products per unit forest area in the project's administrative region.

The replacement cost method estimates the hypothetical cost of restoring or replacing lost ecosystem services[28,35]. For example, the water regulation service was monetized using the equivalent annual cost of flood control capacity from the nearby Yeongju Dam, resulting in a unit value of KRW 831/ton. The soil retention function was valued at KRW 7,515/m³, based on the cost of sediment retention through check dam construction, representing the avoided cost of installing substitute infrastructure.

The CVM was applied to estimate the non-market value of forest conservation. For this purpose, the study used the findings of a previous domestic CVM-based study, which assessed the non-use value of forest ecosystems. The study adopted a unit value of KRW 20.9 million per hectare (based on 2005 values), which EVIS also references as a transferable value for policy analysis.

All unit values were adjusted to constant 2020 prices using appropriate deflators where necessary. The data sources, valuation methods, and unit conversions applied to each service are summarized in **Table 4**. The valuation covered five ecosystem service categories for which both biophysical change and monetary unit values were available. Cultural services, medicinal and genetic resources, and biodiversity were excluded due to potential double-counting, difficulties in quantification, or negligible local impact. As such, the resulting environmental cost estimate should be interpreted as a conservative lower-bound value, likely underestimating the actual total loss.

4. Results

4.1. Quantification Results

Following the ecosystem service classification provided by EVIS, this study identified key quantifiable services within the categories of provisioning, regulating, and conservation values. Using relevant data and coefficient values, biophysical changes associated with the project were estimated (**Table 4**).

First, within provisioning services, the function of food and forage provision was represented by the supply of non-timber forest products (NTFPs). The total forested area within the project site, approximately 196,806 m², was assumed to represent the service-providing area. Based on this, a complete loss of the NTFP provisioning function was assumed for the affected area.

Regarding climate regulation, the loss of carbon sequestration and storage functions was estimated due to deforestation. The reduction in vegetation biomass was calculated to be approximately 50,366 tons. Applying a biomass-to-carbon conversion factor of 0.5 [33], the total loss in carbon storage was estimated at 25,183 tC. In addition, net primary productivity (NPP) was estimated to decrease by approximately 13,938 tons per year, resulting in an annual loss of carbon sequestration equivalent to 6,969 tC per year.

For water regulation services, the decline in groundwater recharge and the moderation of surface runoff were estimated. Applying the loss coefficient of 1,306.98 tons/ha/year suggested by the Korea Forest Research Institute [34] to the forest area of 196,806 m², the annual reduction in water retention was calculated to be approximately 25,722 tons.

In the case of soil retention and purification, the key indicator was the expected increase in soil erosion following the conversion of forested land to non-forested land. Using the estimated difference in soil runoff between forested and non-forested land (289.41 m³/ha/year [34]), the increase in soil runoff was estimated at 5,696 m³ per year.

Lastly, for conservation value, the entire affected forest area (196,806 m² or approximately 19.7 hectare) was considered as the physical loss area. This area was used as the basis for estimating non-market values, including existence value, bequest value, and option value.

Table 4. Quantified changes in ecosystem services from the multipurpose rural water development project.

Category	**Sub-Category**	**Ecosystem Service Function**	**Service Type**	**Related Variable (1)**		**Measurement Indicator (2)**		**Reference For (1) →(2) Conversion**
Provisioning Services	Food and Fodder Provision	Non-timber forest product provision	Flow	Forest Area of the Project Site (m²)	196,806	Forest Area of the Project Site (m²)	196,806	–
	Raw Material Provision							
Regulating Services	Climate Regulation	Carbon Sequestration and Storage	Stock	Change in Existing Vegetation Biomass(ton)	50,366	Carbon Storage (tC)	25,183	Conversion Factor from Biomass to Carbon (CF) :0.5
			Flow	Change in Net Primary Production (ton/year)	13,938	Annual Carbon Sequestration (tC/year)	6,969	
	Water Regulation	Water Recharge Function	Flow	Forest Area of the Project Site (m²)	196,806	Total Water Retention Vol-ume(ton/year)	25,722	Reduction in Water Recharge Function Due to Forest Land Conversion :1,306.98/ha/year
	Soil Retention and Purification	Vegetation-Based Soil Stabilization	Flow	Forest Area of the Project Site (m²)	196,806	Change in Soil Erosion Volume (m³/year)	5,696	Annual Difference in Soil Erosion Between Forested and Non-Forested Areas :289.41m3/ha/year
Conservation Value		Forest ecosystem conservation	Flow	Forest Area of the Project Site (m²)	196,806	Forest Area of the Project Site (m²)	196,806	-

The quantified changes derived through this process numerically represent the extent of loss in each ecosystem service function. These values serve as foundational data for subsequent environmental valuation and cost estimation and can function as quantitative indicators for alternative assessments and site suitability analyses within the SEA process.

4.2. Valuation Results of Ecosystem Service Losses

By applying unit values to the previously quantified changes in ecosystem services, the total annual environmental cost resulting from the Multipurpose Rural Water Development Project is estimated to be approximately KRW 56.182 billion (**Table 5**). This estimate is based on unit values provided by EVIS and related prior studies and is limited to those ecosystem services for which quantification and monetization were feasible. Therefore, this value should be interpreted as a conservative lower-bound estimate, as non-quantifiable services, such as cultural services, biodiversity, and genetic resources, were excluded.

Among the service categories, the greatest cost was associated with the loss of forest conservation value. The project is expected to result in the loss of approximately 196,806 m^2 (19.7 hectare) of forested land. Applying a unit value of KRW 20.9 million per hectare from a domestic CVM-based study, the annual loss is estimated at KRW 55.297 billion, accounting for approximately 98% of the total environmental cost. This highlights the substantial non-market losses associated with the forest's existence, heritage, and option values.

The loss of climate regulation services also contributed significantly to the decline. The reduction in carbon storage was estimated at 25,183 tC, and annual carbon sequestration was estimated to decrease by 6,969 tC. Using the 2021 average trading price for carbon credits (KRW 31,907/tCO_2), the estimated annual loss was KRW 28.74 billion for storage and KRW 7.95 billion for sequestration, totaling approximately KRW 36.69 billion.

For water regulation services, the annual decrease in water retention was estimated at 25,722 tons, which, when multiplied by a unit value of KRW 831/ton, yielded a loss of approximately KRW 216 million. In terms of soil retention, an estimated increase of 5,696 m^3 in annual soil erosion was calculated. Applying a unit value of KRW 7,515/m^3 based on sediment control infrastructure costs, the corresponding environmental cost was estimated at KRW 495 million.

Lastly, the loss of provisioning services, specifically forest product supply, was relatively minor. Based on the total forest area and a unit value of KRW 9.2/m^2, the estimated annual loss was approximately KRW 18 million. This suggests that market-based provisioning services have a minimal impact compared to the substantial non-market values.

Overall, the majority of the environmental costs are attributed to losses in forest conservation and climate regulation functions. These results provide a concrete basis for integrating quantified environmental information into SEA processes, particularly for alternative comparison and site suitability assessments.

The estimated environmental cost represents a quantified measure of the externalities associated with the loss of ecosystem service functions. It can serve as a quantitative basis for alternative comparison, site suitability evaluation, and policy decision-making within the framework of SEA. By expressing the loss of each ecosystem service function in monetary terms, the analysis enables a comparative evaluation of the relative magnitude of environmental impacts across project alternatives or locations, thereby enhancing the practical utility of SEA.

Furthermore, the findings underscore the potential for expanding ecosystem service-based quantification approaches as a formal component of SEA procedures, particularly given the current absence of standardized monetary environmental cost assessments within the system. The fact that forest conservation and climate regulation account for the majority of the total cost conveys a policy-relevant implication: ecosystem service interactions and key functional values must be prioritized in future conservation strategies.

As such, incorporating quantified environmental cost data into SEA has the potential to address the current limitations of qualitative assessments and to support more balanced, evidence-based, and objective decision-making in policy formulation and strategic planning.

4.3. Applicability to Strategic Environmental Assessment (SEA)

The quantified results of this study can serve as a practical and objective basis for comparing alternatives and assessing sites within the SEA process. Conventional SEA practices in Korea have relied heavily on qualitative descriptions when evaluating environmental impacts and comparing development alternatives, limiting the ability to make scientifically grounded and objective decisions. Against this backdrop, this study presents a quantitative tool that can enhance both the credibility and effectiveness of SEA evaluations.

Table 5. Monetized results of ecosystem service losses from the multipurpose rural water development project.

Category	Subcategory	Ecosystem Service Change	Service Type	Ecosystem Service Change Indicator (2)		Unit Value (Unit, Base Year)	Environmental Value Change (3) (as of 2020)	Source of Unit Value Used for Converting (2) to (3) (Type of Valuation Method)
Provisioning Services	Food and Fodder Provision	Non-timber forest product provision	Flow	Forest Area of the Project Site (m²)	196,806	KRW 9.2 per m² (2019)	KRW 1.819 million/year	Annual timber product yield per unit area in the administrative district of the project site (Market Price Method)
	Raw Material Provision							
Regulating Services	Climate Regulation	Carbon Sequestration and Storage	Stock	Carbon Storage (tC)	25,183	KRW 31,907 per tCO_2 (2021)	KRW 2,874 million/year	Average trading price of KAU 21 (Market Price Method)
			Flow	Annual Carbon Sequestration (tC/year)	6,969		KRW 795 million/year	
	Water Regulation	Water Recharge Function	Flow	Total Water Retention Volume(ton/year)	25,722	KRW 395 per ton (2020)	KRW 10,160 thousand/year	Derived from the construction cost of the Yeongju Dam completed in 2016 (Replacement Cost Method)
	Soil Retention and Purification	Vegetation-Based Soil Stabilization	Flow	Change in Soil Erosion Volume (m3/year)	5,696	KRW 13,427 per m³ (2018)	KRW 77,135 thousand/year	Cost per m³ of sediment reduction due to decrease in forested area (Replacement Cost Method, Value Transfer)
Conservation Value	Forest ecosystem conservation	Flow	Forest Area of the Project Site (m²)	196,806	KRW 20.9 million per ha (2005)	KRW 55.297 billion/year	Estimated from a previous study on forest conservation value (CVM-derived, Value Transfer)	
Total (Annual Flow)							KRW 56.182 billion/year	–

In particular, by quantifying the extent of ecosystem service losses and monetizing these values as environmental costs for each development alternative, this approach enables objective comparisons of environmental differences among alternatives. For instance, when two site alternatives serve the same functional purpose, quantifying their respective environmental costs allows for an integrated sustainability assessment that considers environmental, economic, and social dimensions.

Moreover, the unit values used in this study, sourced from EVIS, are based on either government-approved data or systematically derived estimates from prior studies. This helps reduce the arbitrariness and interpretive variability often found in expert-based evaluations. Current SEA guidelines in Korea focus on ecological indicators and potential public complaints, with limited mechanisms for incorporating quantitative valuation. In this context, the analytical approach presented here functions as a complementary tool to enhance the measurability and objectivity of SEA procedures.

For this approach to be formally adopted into SEA procedures, several institutional and technical improvements are required. First, regular updates of unit values in EVIS, along with the development of region-specific valuation coefficients, are essential. Second, SEA guidelines should explicitly incorporate procedures for including environmental cost information. Finally, a legal foundation should be established to ensure that quantitative evaluation results are effectively used in policy formulation and approval processes. To support the institutional integration of EVIS into SEA, several measures may be considered. These include revising relevant legal frameworks to formalize the application of monetary valuation, updating SEA guidelines to incorporate procedures for using EVIS data, and providing targeted training for practitioners. Pilot applications in sectors such as land use and water resource planning can serve as testbeds for refining the methodology and promoting its broader adoption. Collectively, these efforts can contribute to building a more systematic and scalable framework for incorporating environmental values into SEA processes. In conclusion, the estimated environmental costs derived in this study can be broadly applied not only for comparing alternatives within a single development plan, but also for setting priorities among similar projects, developing long-term land-use strategies, and promoting sustainable development. This suggests that SEA has the potential to evolve beyond its current focus on environmental protection toward a more comprehensive sustainability assessment framework that integrates economic and social considerations. Effective integration of quantified environmental values into policy processes involves several key considerations. One important aspect is the introduction of legal provisions that can support the consistent use of EVIS data within SEA. Incorporating valuation outcomes into established decision-making tools—such as cost–benefit analysis and multi-criteria assessment—may further enhance their practical relevance. Presenting environmental costs in clear and accessible formats could also facilitate stakeholder understanding and engagement. In addition, regular updates to EVIS, along with pilot applications in relevant sectors, are likely to play a valuable role in refining the approach and promoting broader implementation.

5. Discussion and Conclusion

This study explored the potential for quantitatively integrating environmental value information into SEA and conducted an empirical analysis using a multipurpose rural water development project in South Korea. Based on the ecosystem services classification framework provided by the EVIS, biophysical and topographic information for the project site was used to quantify environmental impacts. Unit values were then applied to estimate monetary environmental costs, thereby empirically demonstrating the applicability of quantitative evaluation within the SEA framework.

The results indicate that EVIS-based environmental value information can serve as a robust quantitative reference in the SEA process, particularly during the stages of comparing alternatives and assessing site suitability. Traditional SEA practices have largely relied on qualitative descriptions, which limit the ability to make objective, evidence-based decisions regarding environmental trade-offs. This study addresses such limitations by presenting physical changes in ecosystem services and monetized environmental costs, thereby providing a tangible framework for incorporating quantitative criteria into SEA. Specifically, for critical services such as forest conservation and climate regulation—where quantification and monetization are feasible—the study demonstrates how loss estimates can inform more practical and evidence-driven policy decisions. This suggests that SEA can evolve from a procedure-oriented tool focused on environmental protection to a more integrated sustainability assessment framework encompassing environmental, economic, and social values.

Nonetheless, this study is subject to several limitations related to its scope and data. To maintain methodological consistency and avoid double-counting, the analysis was limited to ecosystem services that could be reliably quantified and valued. As a result, services such as cultural values, biodiversity, and genetic resources were excluded, potentially leading to a conservative estimate of total environmental costs. This limitation may bias SEA outcomes, particularly when alternatives that preserve non-market ecological values are systematically undervalued. For instance, areas rich in biodiversity or cultural significance may appear less favorable in cost–benefit comparisons, not because they lack importance, but because their value is not easily captured in monetary terms. To address this, future research should consider hybrid valuation approaches that incorporate qualitative assessments, expert judgment, and proxy indicators to enhance the comprehensiveness and fairness of SEA evaluations.

A further limitation relates to the quality and specificity of data used in the valuation process. Some coefficients, such as those for carbon conversion [33] and hydrological functions [34], were based on generalized averages rather than site-specific values. In the case of forest conservation, older CVM-based estimates were used due to the lack of updated, localized valuation data. These constraints highlight the necessity for regular updates to the EVIS database and additional research to enhance the accuracy and applicability of environmental cost assessments.

Despite these limitations, this study contributes a practical foundation for enhancing the quantitative capabilities of SEA and advancing it toward a more comprehensive sustainability assessment. It provides empirical evidence that unit values from EVIS can be used as quantitative decision-making tools in policy evaluation contexts, reinforcing SEA's potential to function as a scientifically grounded and objective support system for planning.

Future work should aim to refine this analytical framework through additional case studies across diverse policy and development contexts. Moreover, the development of interaction models between ecosystem service functions and region-specific unit values will be crucial in addressing issues of service overlap and contextual relevance. To institutionalize the integration of EVIS and SEA, clear procedural guidelines should be established within the SEA manual, along with the development of technical and legal foundations to accommodate quantitative valuation methods. Further, linking EVIS-based information to other national evaluation frameworks, such as preliminary feasibility studies, regulatory impact assessments, and EIA, could strengthen the role of SEA as a core instrument for sustainable development planning.

In conclusion, this study proposes an empirical methodology for incorporating environmental value information into SEA in a quantitative manner and demonstrates its practical application through a real-world case study. These findings offer a meaningful foundation for improving the effectiveness of SEA and overcoming the limitations of conventional qualitative approaches.

Author Contributions

Conceptualization, H.N.K.; methodology, H.N.K.; data analysis, H.N.K.; validation, H.N.K.; writing, H.N.K.; reviewing, H.N.K.; supervision, H.N.K.; investigation, H.R.; writing, H.R.; reviewing, H.R.; editing, H.R. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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