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How to manage land use conflict between ecosystem and sustainable energy for low carbon transition?: Net present value analysis for ecosystem service and energy supply

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Solar energy generation has become one of the most popular renewable energy sources for achieving global carbon neutrality. This transition to land-intensive energy generates inevitable land use conflicts with existing land cover, such as forest or agricultural land. South Korea is one of the countries currently experiencing conflicts in land use between ecosystems, food and energy. In addition, various land use problems occur, such as deforestation due to developments and an increase in idle agricultural land due to a decrease in the labor force. Thus, it is important to establish future land use policies that consider these issues. This study conducted a net present value (NPV) analysis for solving land use conflict by comparing monetary value according to different land use cases. Two land use scenarios were investigated: 1) land cover maintained (forest or agricultural land) and 2) land use change for solar energy generation. These two scenarios were compared in the target areas selected in this study to determine the criteria for the solar energy generation site. The economic values from Scenario 1 were calculated primarily using ecosystem services assessment and market value, and those of Scenario 2 were calculated based on statistical data. The total suitable area for solar energy generation in Korea was 551,393 ha. As results, the NPV of forest ecosystem services was higher than that of solar energy generation in forest. In the case of idle agricultural land, agriculture caused a continuous deficit owing to carbon emissions, and accordingly, the carbon reduction effect through solar energy generation had a greater value than agricultural activities. This study attempted to resolve land use conflict by considering carbon neutrality through comparing economic values and introducing ecosystem services assessment and carbon credit price in the process of the analysis.

KEYWORDS

land use management, ecosystem services, carbon neutrality, economic evaluation, net present value, sustainable development

1 Introduction

The low-carbon transition is vital for responding to climate change and reducing greenhouse gas (GHG) emissions, and renewable energy is the main factor for achieving global low-carbon transition (Poggi et al., 2017; Dahal et al., 2018). Solar energy is the one of most popular renewable energy source because of the decreasing prices of photovoltaics and technological advancements (Campbell, 2017; Dahal et al., 2017). However, this transition to renewable energy is predicted to increase global competition for land (Rao and Sastri, 1987; Nonhebel, 2005; Scheidel and Sorman, 2012) as its land use efficiency is lower than earlier expectation (van de Ven et al., 2021). As solar energy is a land-intensive energy source, solar energy distribution is mainly concentrated in forest or agricultural land, which has low development costs (Kim et al., 2019). Accordingly, ground-based energy and terrestrial ecosystems may compete for land use (Gazheli and Di Corato, 2013).

South Korea is one of the countries struggling with the low-carbon transition. Accordingly, in 2020 the Korean government declared a '2050 Carbon Neutral Strategy' and planned to increase renewable energy generation, with solar energy accounting for 57% of the total renewable energy generation (The Government of the Republic of Korea, 2020). Inevitably, this goal is now leading the serious land use conflicts. In fact, in Korea, from 2017 to 2020, more than 5,131 ha of forest was used for solar energy (MOTIE, 2020). The public and environmental organization have raised the objections and argued that the damage from landslides and soil spills has increased due to the deforestation within a short period of time. In response to these concerns, the government started to reduce the renewable energy certificates (RECs) weight for solar energy in forest and strengthen regulations from 2018 to suppress forest damage caused by the installation of solar power facilities (MOTIE, 2020). Nevertheless, many forest owners continue to apply for solar energy business for increasing land prices and generating stable income (Kim et al., 2019). Meanwhile, in the rural area, as the number of abandoned farmland increases due to the decline of the labor force and the weakening of agricultural competitiveness, idle land and wasteland are increasing.

Land use conflict between development and ecosystem has been studied for a long time not only internationally but also for land planning in Korea. Ko et al. (2014) suggested that, despite the importance of renewable energy, the value of protecting natural ecosystems is still great. However, the evaluation results of previous studies were presented briefly only for reference and focused on conveying the contents of various pros and cons issues. Choi and Wang (2017) evaluated land use efficiency and derived the implication that negative feedback such as environmental pollution should be considered for sustainable policies, but the evaluation related to environment was only the cost of pollution caused by land development, not the opportunity cost to degrade the land due to the development. Kim et al. (2021a) recently evaluated the monetary value for economic comparison between conservation and development. However, the questionnaire-based monetary evaluation had limitation that the preference of respondents may vary depending on the time or the object of comparison, which made it difficult to directly reflect on the policy. In other words, previous studies dealing with land use conflict had limitations in that they did not directly reflect the benefits from the ecosystem or only consider them as at the level of demand-based willingness for comparison.

The evaluation of natural assets to support land use policies can be replaced or supplemented by ecosystem services assessment. Ecosystem services research has contributed greatly to highlighting and emphasizing the importance of forest conservation by suggesting the quantified value of them through scientific modeling. Song et al. (2015) quantified the water provision from forests in Korea, and Choi and Lee (2017) evaluated the carbon storage of Korean forests and evaluated the economic value. These studies needed to be improved to support land use decision-making since they respectively evaluated the single specific service of forests. Accordingly, Kim et al. (2010) conducted an important study to comprehensively evaluate the public value of forests and convert them into monetary values using alternative cost method. Similarly, Kim et al. (2021b) and Lee et al. (2018, 2020) quantified the dynamics of several ecosystem services over time and forest management. Although these studies supported forest management policies by focusing on the forest ecosystem services, they did not lead to land policy supporting through comparison with other land use values.

Therefore, in this study we attempted to address the necessity of considering ecosystem services in a net present value (NPV) analysis as a trade-off approach in the land use planning stage for sustainable balancing of food (agriculture), ecosystem (forest) and renewable energy. In this study, the area suitable for solar panel installation was detected in forest and agricultural land was set as the target area for the assessment. Focusing on land use conflict, two land use scenarios were built: 1) maintaining the original land cover and 2) changing land use for solar generation. Using geospatial and statistical datasets the NPV analysis for both scenarios in forest and agricultural land was conducted.

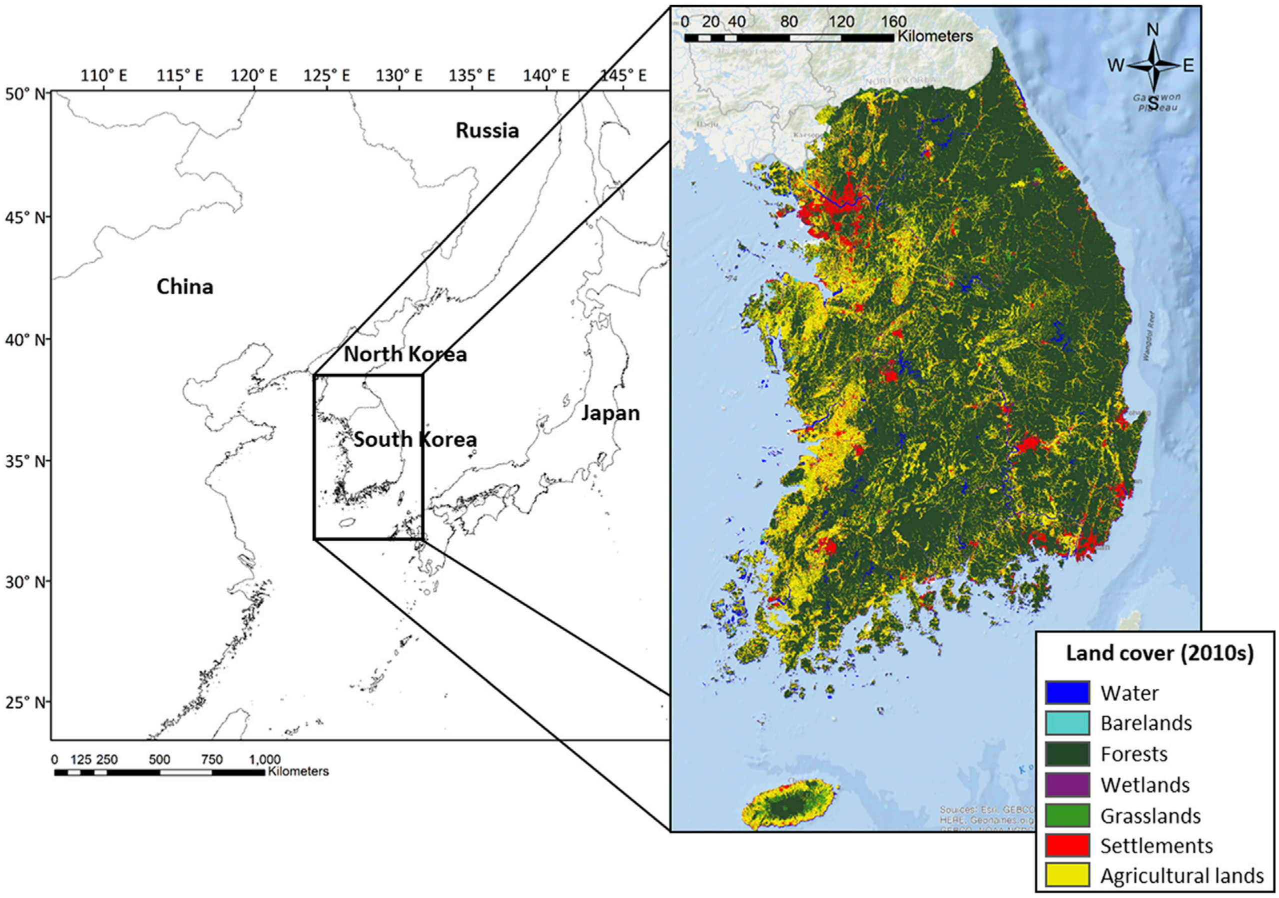

FIGURE 1
Geographical location of study area and land cover.

2 Materials and methods

2.1 Study area

South Korea covers approximately 9,998,430 ha, of which 63.7% are forests and 19% are agricultural land (Park et al., 2020; Kim S. J. et al., 2021) (Figure 1).

The main forest types are coniferous, broad-leaved, and mixed forests, with approximately 40.5%, 27.0%, and 29.4% of the total forest area in 2018, respectively (KFS, 2019; Kim et al., 2021b). In South Korea, land planning and management until 1960s have mainly focused on the resource supply resources for economic development rather than the sustainability of resources and ecosystems (Kim, 2005). Since the 1970s, along with national forestation programs including strict legislative regulations against forest conversion (Bae et al., 2012; Kim G. et al., 2021), there has been an increasing demand for forest conservation and management (Lee et al., 2020). Recently, the government has focused on forests as carbon sinks and the removal of national carbon emissions through forest management (The Government of the Republic of Korea, 2020). However, despite increasing efforts to conserve the environment, forests are still recognized as convertible land to settlements or croplands for various purposes, such as food or fuel production or urbanization (Kwak, 2020).

According to KOSTAT (2019), the cultivation area of agricultural land has been continuously decreased from 1,729,982 ha in 2012 to 1,564,797 ha in 2020. This increase in idle agricultural land is due to urbanization, an aging population, and a shortage of labor, which have intensified the reduction of the agricultural worker population (Rhee et al., 2009; Lee et al., 2021). As these lands can hardly be converted back for their original purpose (Cai, 2021) and have been devastated over time (Kim and Ahn, 2005), they have been the main issues to be solved in rural areas. At the same time, the government pays attention to greenhouse gas emissions from agricultural activities and seeks the ways to reduce carbon emission from agricultural land (The Government of the Republic of Korea, 2020). As one solution, MOTIE (2017) planned to install 10 GW of solar panels by 2030 utilizing idle agricultural land in rural areas.

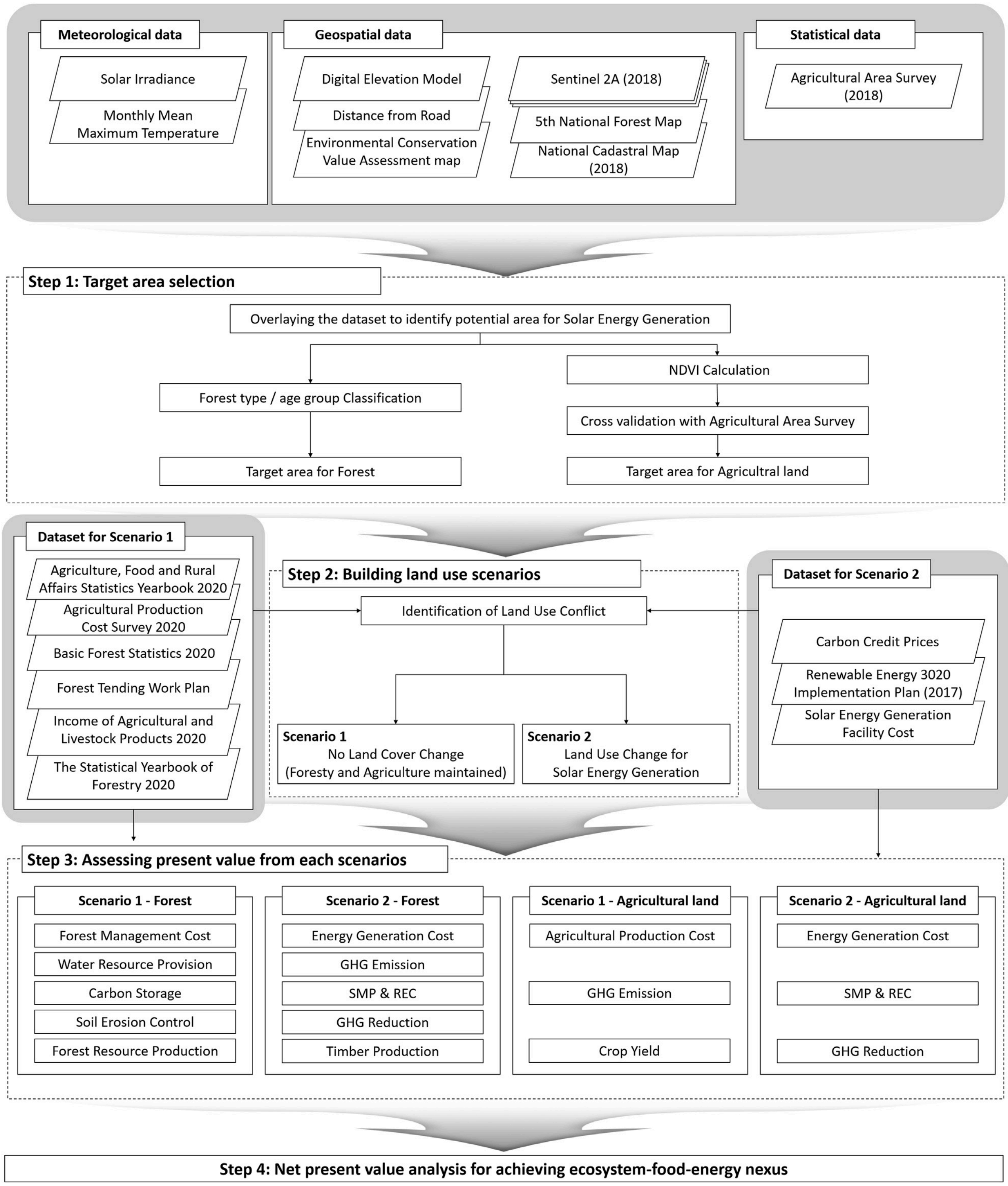

FIGURE 2
The overall research flow of this study.

2.2 Method

In this study, land use cases for forest and agricultural land were assessed separately, and the study was divided into four steps (Figure 2). In Step 1, the target area for assessment was detected. Based on the selected target area, two different land use scenarios were built in Step 2. In Step 3, the present value (PV) of cost and benefit from these scenarios were assessed, and the results were compared and analyzed in Step 4.

2.2.1 Step 1: Target area selection

Firstly, for target area detection, the conditions for solar panel installation area reviewed based on previous research. The factors to be considered for installation were classified into three categories: meteorological, topographical, and social.

For meteorological conditions, the solar irradiance was selected to be over 4,000 MJ/m^2 (Kwon et al., 2008; Kim et al., 2018). The panel efficiency standard related to temperature was set to 0.5% decrease for every 1°C increases from 25°C according to Lee and Lee (2015). In topographical conditions, solar panels are generally installed in areas with an inclination of less than 10° in Korea (Kwon et al., 2008). In addition, to secure sufficient insolation, the aspect was designated from southeast to southwest (Jang, 2010). The elevation standard was determined to be less than 100 m considering the installation cost (Jang, 2010; Son and Eum, 2017). For socio-economic conditions, because the closer in proximity to the road, the more difficult it is to incur sufficient sunlight in the mountains and the lower the solar efficiency due to fine road dust (Jang, 2010), a standard with a distance from road was set to be more than 50 m. Additionally, we excluded areas with higher value to conserve using the environmental conservation value assessment map from Ministry of Environment (MOE).

The maps for each condition were overlaid, and forests and agricultural land were extracted. For the forest, coniferous, deciduous, and mixed forests were extracted with stand age information based on the fifth forest map from Korea Forest Service (KFS). For the agricultural land, only the idle agricultural land was considered as the target area. As there were no geospatial data related to idle agricultural land, the normalized difference vegetation index (NDVI) values were calculated using Sentinel 2A images in 2018. The maximum NDVI composite for agricultural land was collected based on the 2018 National Cadastral map. The NDVI value from the area most similar to the statistical record of idle agricultural land area in 2018 was set as the threshold in this study (Maxwell and Sylvester, 2012). Finally, the area with NDVI less than the threshold was defined as idle agricultural area and extracted.

2.2.2 Step 2: Building land use scenarios

To build a land use scenario, the land use conflict related to solar energy generation was defined. Recently, the nexus perspective for dealing with land use demand has been required based on the realization of interdependent synergies and trade-offs among policy, environment and economic (Sharmina et al., 2016; Moon and Hwang, 2018; Nie et al., 2019). Accordingly, it is necessary to comprehensively consider direct and indirect factors when considering the costs and benefits of land use. However, in this study, only the costs and benefits directly resulting from the targeted land use were calculated. This was because of the necessity of quick and simple way to present the cost and benefit for other options such as forest conservation or restoration of idle farmland in Korea, where rapid land conversion is taking place among forest owners due to the economic efficiency and stability of solar energy business (Kim et al., 2019). Therefore, in this study, the analysis was conducted under two land use scenarios. As the evaluation was carried out based on the same area in Scenarios 1 and 2, land price was excluded from the evaluation. Based on these concepts, the items for assessing the costs and benefits for each scenario and land cover were decided.

2.2.2.1 Scenario 1: No land cover changed

For the Scenario one in the forest, the total target area for forest was assumed to be maintained every year. In this study, four individual ecosystem services, water resource provision (WP), carbon storage (CS), soil erosion control (SC) and forest resource production (FP), were determined as benefits considering the timeliness and urgency of Korea's policy (Kim et al., 2010; Choi et al., 2016; Song et al., 2016; Lee et al., 2020, 2018; Kim et al., 2021b). The forest management cost (FC) referred to the Forest Tending Work Plan (KFS, 2018). In the case of agricultural land, as idle lands need to be restored or diverted to prevent the devastation of the land itself, all the target areas for agricultural land were designated to be restored for the original land use. It was assumed that restoration would be carried out from 2018 to 2030, with one-thirteenth of the total area to be restored every year. The crop yield (CY) was evaluated (Seo et al., 2006) as benefit, and agricultural production cost (AC) and GHG emissions from agriculture (GHG E) were calculated as the costs.

2.2.2.2 Scenario 2: Land use changed for solar energy generation

Solar panels (total 28.8 GW) were planned for installation through large-scale projects from 2018 to 2030, with 10 GW in rural areas (The Government of the Republic of Korea, 2020). Therefore, Scenario 2 in the forest was set that 18.8 GW of solar panels would be installed evenly in forests for 13 years. It is determined that 1 MW of facility should be installed every 1 ha in the forest (Lee and Kim, 2020). The resulting benefits were designated as REC and the system marginal price (SMP) profits and GHG reduction (GHG R) effects of replacing fossil fuels and timber

TABLE 1 The factors and methods of NPV assessment in forest and agricultural land.

Target	Scenario	Category	Factor	Method	
				Quantification	Monetization
Forest	Scenario 1	Cost	Forest management cost	-	Data from KFS (2019)
		Benefit	Water resource provision	The amount of water storage	Data from Seo et al. (2006)
			Carbon storage	The amount of carbon storage	Data from MOE
			Soil erosion control	The difference amount of soil collapse between stocked and unstocked forest	Data from KFS (2019)
			Forest resource production	Forest resource profits from forestry	Data from KFS (2020)
	Scenario 2	Cost*	Energy generation cost	-	Data from Lee and Kim (2020)
			GHG emission from forest conversion	The amount of GHG emission from forest conversion	Data from KPX**
		Benefit*	SMP	-	Data from KPX**
			REC	-	Data from KPX**
			GHG reduction by replacing fossil fuels	The amount of solar energy generation and GHG emission	Data from KPX**
			Timber production from forest conversion	The amount of timber from forest conversion	Data from KFS***
Agricultural land	Scenario 1	Cost	Agriculture production costs	-	Data from MAFRA (2020) and KOSTAT (2020)
			GHG emission from agriculture	The amount of GHG emission from agriculture	Data from KPX**
		Benefit	Crop yield	The amount of crop yield	Data from MAFRA (2020) and KOSTAT (2020)
	Scenario 2	Cost	Energy generation cost	-	Data from Lee and Kim (2020)
		Benefit	SMP	-	Data from KPX**
			REC	-	Data from KPX**
			GHG reduction by replacing fossil fuels	The amount of solar energy generation and GHG emission	Data from KPX**

*In calculation, the cost and benefit factors from Forest-Sc1 for remaining forest were included. **KPX (Korea Power Exchange): https://onerec.kmos.kr/portal/index.do ***KFS (Korea Forest Service): https://www.forest.go.kr/kfsweb/kfi/kfs/cms/cmsView.do?mn=NKFS_02_01_04_03_02&cmsId=FC_003478.

production profits (TP). As costs, GHG E from cutting wood was included in addition to energy generation installation and maintenance costs (GC). In this scenario cost and benefit from remaining forest were also calculated until all panels got installed. In the case of agricultural land, it was assumed that solar panels were installed in one-thirteenth of the target area every year from 2018 to 2030, and that 10 units of 100 kW facility would be installed on every 1 ha in this study (Lee and Kim, 2020). The benefitting factors were the same as in the forest, but GC was selected as the only expense.

2.2.3 Step 3: Assessing NPV for each scenario

The assessment items were decided in Step 2, and the assessment factors and methods for each factor were determined in Step 3 (Table 1). NPV analysis is a simple but well-established valuation method that discounting and forecasting incremental cash inflows and outflows for each period to present time at the start of the project (Bilqist et al., 2018). It can be determined by the difference between benefit and the cost (Giaccone and Canova, 2009).

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{B_t}{(1+d)^t} - \sum_{t=1}^{n} \frac{C_t}{(1+d)^t}$$

where, B and C are the benefit and cost of year t during the period n, and d is discount rate. The discount rate, 4.5% was determined according to the General guidelines for conducting a preliminary feasibility study in Korea.

TABLE 2 Data used in the study.

Category	Data description	Source
Geospatial data	5th National Forest Map (2006–2010)	KFS
	Digital Elevation Model	NGII
	Environmental Conservation Value Assessment Map	MOE
	National Cadastral Map (2018)	MOLIT
	Node Link data	NTIC
	Sentinel 2A (2018)	ESA
Meteorological data	Monthly Maximum Temperature (2019)	KMA
	Solar Irradiance (2019)	KMA
Statistical data	Agricultural Area Survey (2018)	KOSTAT (2019)
	Agricultural Production Cost Survey (2020)	KOSTAT (2020)
	Agriculture, Food and Rural Affairs Statistics Yearbook (2020)	Lee & Kim (2020)
	Basic Forest Statistics (2020)	KFS*
	Carbon Credit Prices	KPX
	Forest Tending Work Plan	KFS (2018)
	Income of Agricultural and Livestock Products (2020)	MAFRA (2020)
	Renewable Energy 3,020 Implementation Plan (2017)	MOTIE (2017)
	Solar Energy Generation Facility Cost	MAFRA (2021)
	The Statistical Yearbook of Forestry (2020)	KFS (2020)

*https://kfss.forest.go.kr/stat/ptl/main/main.do

2.2.3.1 Net present value assessment in forest

The FC was calculated using to the Forest Tending Work Plan of the KFS (2018) and the research report of the KFS (2019). Forest management was assumed to be conducted every 64 ha considering the ratio of managed area to stocked forest in 2019 (KFS, 2020). WP was estimated as the potential amount of water provided annually by forest using the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST)-Annual water yield (AWY) model (Song et al., 2015; Kim et al., 2017). The InVEST-AWY model has been used widely for ecosystem services assessment, and the water yield estimation for Korea using InVEST-AWY model have been acknowledged as one of the most appropriate models. The economic value of WP was calculated using alternative cost data by multiplying the sum of dam construction, depreciation, and the maintenance costs of the dam (Seo et al., 2006). The ecosystem service of the CS was calculated using the unit amount of tree CS obtained using InVEST-Carbon storage and sequestration, which has been widely used to estimate carbon pool in Korea (MOE, 2015; Han et al., 2018; Chun et al., 2019). The economic value of CS was calculated by multiplying the total amount of CS by the carbon credit price. Carbon credit price data from 2018 to 2020 were obtained from the Korea Power Exchange (KPX), and the price from 2021 to 2030 was predicted through linear regression. To reduce uncertainty, it was assumed that the carbon credit price after 2030 will be the same as that in 2030. SC was quantified as the difference between the amount of soil collapse in stocked forests and the amount of soil collapse in unstocked forests using soil runoff data (Kim et al., 2010; MOE, 2015). It was converted into an economic value by applying a debris barrier construction cost, adapting a discount rate of 4.5% (MOE, 2015). The ecosystem service of FP was evaluated using the FP record of KFS (2020), which consists of wood production, tree fruit, wild greens, mushrooms, sap, medicinal plants, and fuel.

In Scenario 2, the GC in the forest was estimated (Lee and Kim, 2020) and fluctuations with time were considered similar to the carbon credit price. The amount of GHG E from forest conversion was estimated according to Paustian et al. (2006), by multiplying the abandoned amount of cut timber by forest type (Min et al., 2017). The economic value of GHG E was calculated by adapting the carbon credit price. The REC price data from 2012 to 2020 and SMP data from 2010 to 2020 were collected from KPX, and both were used to predict the future price using linear regression, similar to carbon price prediction. In addition, the benefit of GHG R from replacing fossil fuels was quantified through an alternative cost method by calculating the annual amount of electricity obtained through solar energy generation and the amount of GHG E when the same amount of electricity was obtained through fossil fuels. Finally, the potential amount of TP from forest conversion was estimated by applying the wood recycling rate and the unused (abandoned) rate (Min et al., 2017) to the amount of domestic timber harvested in 2019, and the economic value was calculated using the wood trade unit price of the KFS.

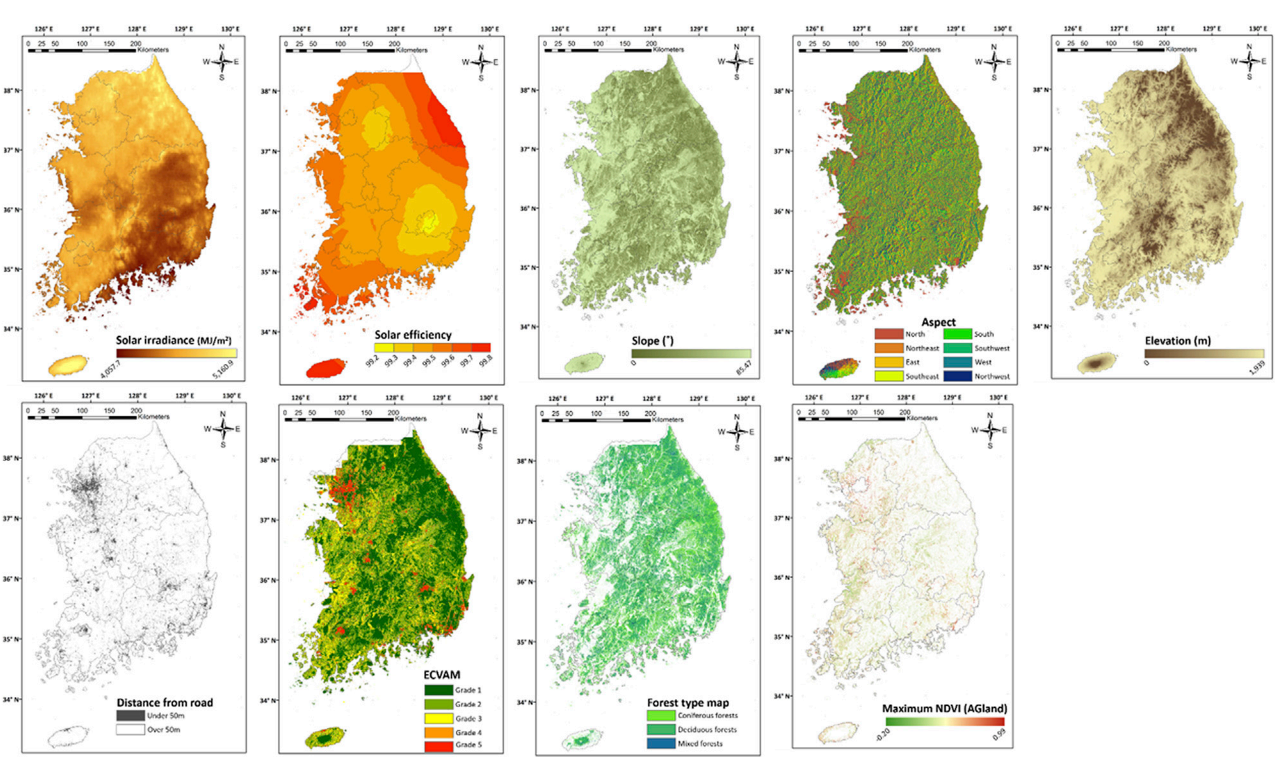

FIGURE 3
Factors considered for target area selection and result; **(A)** Solar irradiance, **(B)** Solar efficiency based on maximum mean temperature, **(C)** Slope, **(D)** Aspect, **(E)** Elevation, **(F)** Distance from road, **(G)** EVCAM (H) Forest type map, **(I)** Maximum NDVI in agricultural.

2.2.3.2 Net present value assessment in agricultural land

The costs and benefits of Scenario 1 on agricultural land were calculated as the sum of those of paddy fields and fields. The ratio of paddy fields to fields was designated as the average of their ratios from 2012 to 2018 (MAFRA, 2020). AC was calculated using the operating cost data of paddy rice (KOSTAT, 2020) and major crops (MAFRA, 2020). As agricultural activities accompany GHG E (Johnson et al., 2007), the amount of GHG E was calculated according to Paustian et al. (2006). The amount of CY per hectare was calculated based on MAFRA (2020) and KOSTAT (2020). The assessment for Scenario two on agricultural land was conducted in the same method for Scenario two on forest.

2.2.4 Step 4: Net present value analysis for achieving ecosystem-food-energy nexus

The estimated costs and benefits and land cover from each scenario were collected and compared in Step 4. In this step, the changes in net profits and cumulative net profits according to the scenarios were contrasted. In addition, to achieve the ecosystem-food-energy nexus, additional revisions of the carbon price or energy cost were conducted.

2.3 Materials

Spatial data for the target area selection and ecosystem services assessment were prepared and spatially adjusted. Statistical data including national statistics and reports were obtained from the government, national research institutes, and previous studies (Table 2).

3 Results

3.1 Potential solar energy generation area

By overlaying the studied factors (Figures 3A–G), the potential solar energy generation area was extracted. The total potential area before extracting forest and idle agricultural land was 5,51,393 ha. Jeollanam-do had the largest potential area (1,12,307 ha) followed by Chungcheongnam-do (1,01,890 ha).

The target area for the forest extracted by overlaying the forest type map (Figure 3H) was 21,929 ha. In terms of administrative districts, Chungcheongbuk-do was suggested to have the largest potential area (4,679 ha), followed by Jeollanam-do (4,010 ha).

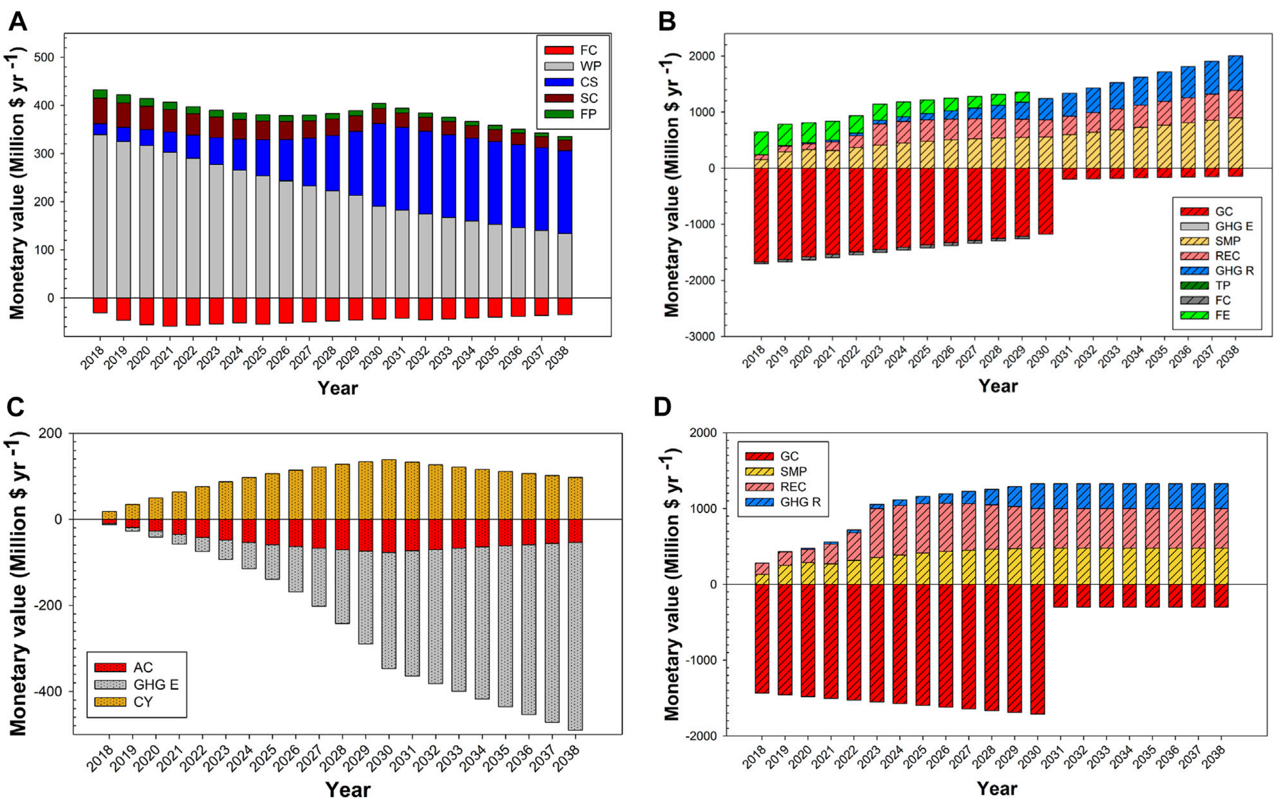

FIGURE 4
Present value of cost and benefit from forest under Scenario 1 **(A)**, and Scenario 2 **(B)**, and from agricultural land under Scenario 1 **(C)**, and Scenario 2 **(D)** (FC: Forest management cost, WP: Water provision, CS: Carbon sequestration, FP: Forest resource production, GC: Generation cost, GHG E: GHG Emission, GHG R: GHG Reduction, TP: Timber production, FE: Forest ecosystem service, AC: Agriculture cost, CY: Crop yield.

The maximum NDVI composite for agricultural land is shown in Figure 3I. The threshold value of NDVI was derived as 0.35 based on the regional idle agricultural land data of the agricultural area survey as verification data (R^2 = 0.52). Accordingly, idle agricultural land based on NDVI is shown in Figure 3I with 66,126 ha when the statistical record in 2018 was 61,040 ha (KOSTAT, 2019). After overlaying Figure 3I, the final target area for agricultural land was extracted as 16,169 ha. Regionally, Gyeonggi-do had the widest area (38,995 ha), followed by Jeollabuk-do (20,211 ha).

3.2 Cost and benefit from each land use scenario

The cost and benefit were estimated as monetary value of Scenario 1 in forest (Figure 4A). In 2018, the benefits were provided in the order of WP (339.46 million \$ yr^{-1}), SC (53.06 million \$ yr^{-1}), CS (22.77 million \$ yr^{-1}), and FP (17.42 million \$ yr^{-1}). However, the carbon price increased with time, and the benefits from CS continuously increased. In 2022, CS accounted for a larger portion of the benefits than SC, which was 44.58 million \$ yr^{-1} at 48.40 million \$ yr^{-1}, and in 2033, CS was 172.27 million \$ yr^{-1}, which was 5.49 million \$ yr^{-1} more than 166.78 million \$ yr^{-1} of WP, which was the highest benefit until the previous year. As for the cost, it was assumed that the management of the target areas would begin in 2018, and the FC increased from approximately 31.07 million \$ yr^{-1} in 2018, and to 56.63 million \$ yr^{-1} in 2022.

As a result of analyzing the cost of Scenario 2 in the forest, by 2030, when installation costs are incurred, annual GC accounted for about 1.6–2.6 times of the annual benefits, which are maximum at 1,671.66 million \$ yr^{-1} and minimum at 1,175.63 million \$ yr^{-1} (Figure 4B). The impact of these vast GC maintained until 2033, whose NPV was -1,224.67 million \$ yr^{-1}. The proportion ranking of the benefit factors of scenario 2 in the forest has changed four times. In 2018, the benefit from FE from remained was the largest at 402.52 million \$ yr^{-1}, followed by SMP at 152.69 million \$ yr^{-1}, REC at 85.87 million \$ yr^{-1}, GHG R at 4.54 million \$ yr^{-1}, and TP at 0.18 million \$ yr^{-1}. However, the ranking changed as the SMP in 2020 was estimated

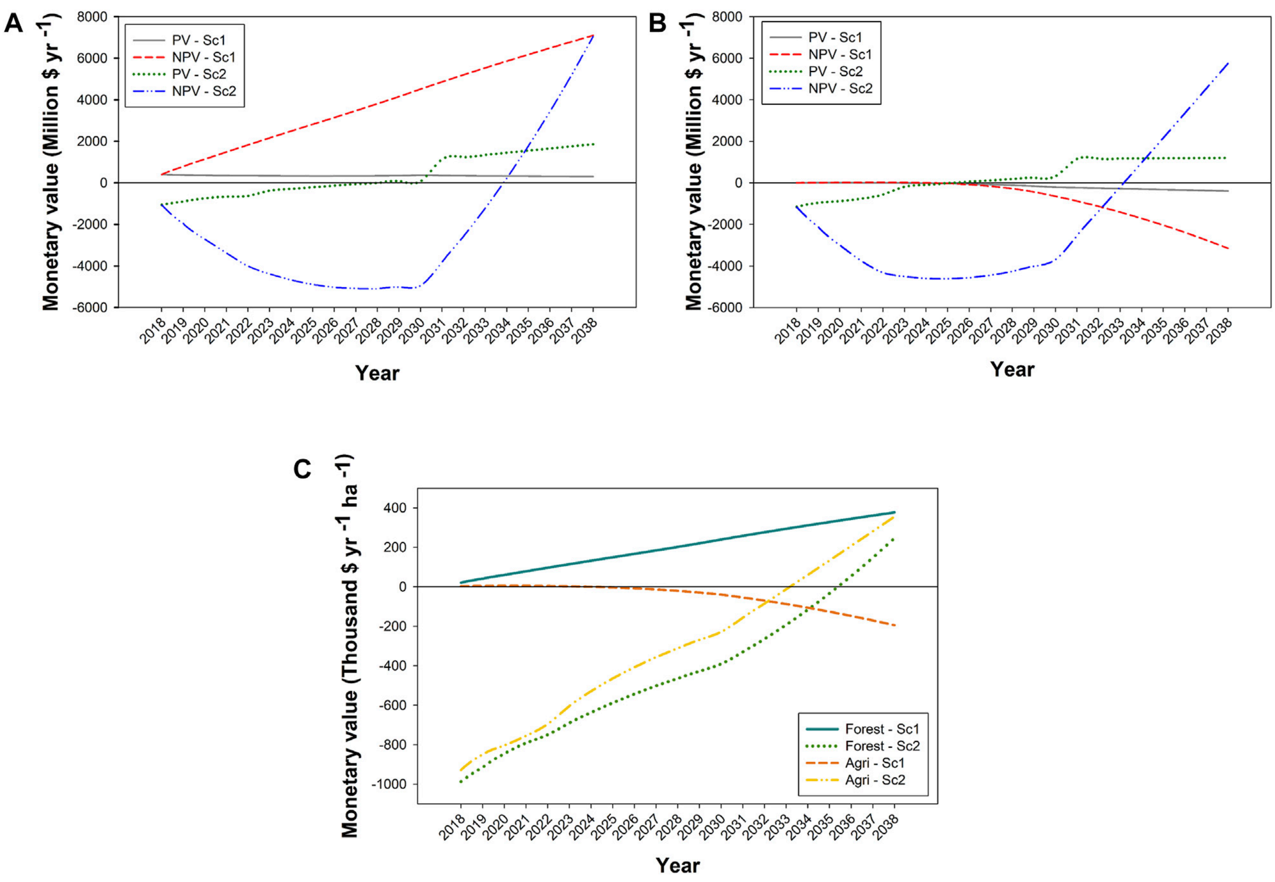

FIGURE 5
Comparison of NPV and cumulative NPV between scenarios in forest **(A)** and agricultural land **(B)**, and comparison of the cumulative net profit per hectare for each scenario in forest and agricultural land **(C)** (PV: Present value, NPV: Net present value, SC: Scenario, Agri: Agricultural land.

to be 436.78 million \$ yr^{-1}, which is higher than the FE of 330.07 million \$ yr^{-1}, and REC, which provided less benefits than FE by 2022, rose to 376.44 million \$ yr^{-1} in 2023, exceeding FE calculated at 242.20 million \$ yr^{-1} in the same year.

In Scenario 1 on agricultural land, CY was estimated as the only benefit, from 18.06 million \$ yr^{-1} in 2018 to 138.44 million \$ yr^{-1} in 2038 (Figure 4C). The AC was about 0.56 times of the benefit from CY each year. The GHG E from the restoration of idle farmland to farmland has increased over time, resulting in an increase from 3.21 million \$ yr^{-1} in 2018 to 436.34 million \$ yr^{-1} in 2038.

3.3 Net present value analysis for ecosystem-food-energy nexus

In Scenario 1 in forests, increased ecosystem function was observed as forests matured and old forests were reforested through forest management (Figure 5A). However, the value of monetized ecosystem services decreased according to the application of the discount rate when calculating PV. CS continued to increase as the price of carbon credits is expected to increase. Accordingly, the highest PV of scenario 1 in the forest was at 360.18 million \$ yr^{-1} in 2030, and the final NPV in 2038 was 7,097.20 million \$. Meanwhile, Scenario 2 PV in forests continues to increase from a low of -1,056.94 million \$ yr^{-1} in 2018, rising to 1,858.08 million \$ yr^{-1} in 2038. Accordingly, the final NPV in 2038 was estimated to be 7,043.95 million \$. However, unlike Scenario 2 in forests Scenario 2 in agricultural land was found to be more competitive than Scenario 1 (Figure 4D). Scenario 1 on agricultural land showed a net loss of PV from 2023 at 6.75 million \$ yr^{-1} to 2038 at 393.10 million \$ yr^{-1} (Figure 5B). Accordingly, the NPV was also recorded as -3,150.57 million \$ in 2038. Compared to Scenario 2 in forest, which had a surplus from 2029, Scenario 2 in agricultural land recorded a surplus PV of 56.22 million \$ yr^{-1} from 2026, resulting in NPV of 5,750.25 million \$ by 2038, starting from 977.41 million \$ in 2034.

In the scenarios developed for forests and idle farmland, the NPV per hectare was identified because there was a limitation that the target area for each year was different. In addition, since Scenario 2 in forests was developed under the assumption of converting existing forests, costs and benefits corresponding to Scenario 1 in forests were included in the cost and benefit calculation. To avoid duplicate calculations and misunderstandings, only the area converted for solar energy and costs and benefits from solar energy generation were considered in the NPV per hectare analysis. As a result, in Scenario 1 in forests, the NPV per hectare steadily increased over time, reaching an NPV of 377.29 thousand \$ ha^{-1} by 2038. In Scenario 2 in forests, although there is an NPV of deficit through 2035, the NPV from 2036 to 2038 increases significantly, producing an NPV of 246.54 thousand \$ ha^{-1} in 2038. Scenario 2 in farmland did not include costs and benefits of deforestation, so surplus per hectare was derived earlier than in Scenario 1 in forests, resulting in an NPV of 355.85 thousand \$ ha^{-1} in 2038. However, while restoring idle farmland to farmland, GHG E from agriculture had a major impact, resulting in a surplus until 2024 and a deficit of 194.97 thousand \$ ha^{-1} by 2038.

4 Discussion

4.1 Analysis on net present value assessment of each scenario

In this study, the area and distribution can be used to determine solar energy generation in forests and idle agricultural land. Based on the suitable area selection, the economic values of the two scenarios with two different land covers were compared. According to the Korea Energy Agency (https://recloud.energy.or.kr), the actual distribution of solar energy plants based on their capacity was similar to the results of this study. By 2020, the solar installation capacity was the highest in Jeollanam-do, followed by Jeollabuk-do, Chungcheongnam-do, and Gyeongsangbuk-do.

As a result of the forest ecosystem services, CS had the highest value as in NIFoS (2020). This was owing to the impact of the carbon credit price. Each ecosystem service was quantified using the fixed average amount of each service by decade. Therefore, the annual change in these ecosystem services could not be reflected, unlike in CS, which has annual carbon credit price data. In addition, when converting the quantitative value of forest ecosystem services into monetary values, a different costing method was applied to each ecosystem service. In case of CS and FP, as markets for carbon and wood have been actually formed, the market price considering the economic balance of supply and demand could be reflected directly. However, in the case of WP and SC, since there is no market price of the object, the supply-based replacement cost method and restoration cost method were used (Kwak et al., 2013). In other words, the demand for ecosystem services was not reflected in monetization. Therefore, if demand-based values can be harmonized with supply-based value, the evaluation result of Scenario 1 for forests will possibly be different.

As all scenarios included carbon related costs or benefits in this study, the predicted carbon credit price acted as important key during economic assessment. The carbon credit price is a fundamental driver for low carbon economy which leads a structural and rapid change (Hepburn et al., 2020). The International Monetary Fund has suggested to set a global average carbon price as \$75 per ton by the end of the decade (Parry et al., 2021). In addition, according to Stiglitz et al. (2017), a carbon price was required to be at least \$50–100 per ton CO_2 by 2030 for cost-effective GHG reduction considering the Paris Agreement. EU have planned to enlarge the coverage of carbon pricing (World Bank, 2020), and currently, the average carbon price in EU is estimated to be around \$65.07 to \$81.36 per ton in 2022 (Twidale, 2021). In line with EU, Korea achieved the world-largest increase of carbon price over past years (Santikarn et al., 2020), and it is expected to be higher considering strong policy for GHG reduction (KEITI, 2021). As the results of NPV analysis may vary depending on future carbon prices, it is necessary to flexibly establish future land use plans by developing scenarios of various price options.

4.2 Suggestion for supporting decision-making on land use management

The main purpose of this study was to support the establishment of land policies that encompass a variety of abstract values that have been rarely reflected in policies (Ruhl et al., 2021). Based on the results and findings, several suggestions were drawn for supporting land use management.

First of all, it is strongly suggested to keep the “sustainability” in view (Vardakoulias, 2011). In Scenario 2 in the forest, the cumulative profit was lower than that of forests for 20 years after starting development. Moreover, if the cost required for the demolition of expired panels and for forest restoration after 2038 is included, the final cumulative value will slightly decrease (Croxford and Scott, 2006; Eicker et al., 2015). In other word, the results may vary depending on the period or evaluation item setting. Therefore, the direction of land policy should not be set based only on the cumulative value up to the setting environment, but the sustainability and resilience of the value should also be considered. Ultimately, it is necessary to include land productivity, and biodiversity as well as sustainability in the policy making stage of land use (Pérez-Soba et al., 2008; Veldhuizen, 2021).

Secondly, considering land use for sustainable energy, it is suggested to develop solar energy in a direction that maximizes the use of the existing land use without damaging the vegetation cover by utilizing the agro-photovoltaic design or PV modules with smart farm technology (Kim, 2020; Kwon and Lee, 2021). Regarding the insufficient amount of solar energy for Renewable Energy 3,020 Implementation Plan, it is necessary to prioritize between possible sites, and to plan land use while taking into account sustainability and other available land use options.

Above all, what this study would like to emphasize is to promote applying natural asset to land use management. The value of the ecosystem service was as profitable as the solar energy generation in long-term perspective, even though the number and value were considered conservatively in this study. However, in the actual land planning, regardless of the importance in the feasibility evaluation, the value of public goods or services such as ecosystem services have difficulties to be reflected due to the limitation to estimate based on market prices (Kim and Cho, 2005). Ecosystem services should be further systematically linked to other natural environment investigations, environmental impact assessments, and feasibility assessments (Kim et al., 2014; Raum, 2018). This linkage can be developed based on the agreed way of ecosystem services assessment based on the scientific quantification and socio-economic consideration.

Furthermore, the land use management on idle agricultural land needs to be improved. It was confirmed that GHG E from agricultural land were as large as forest CS. In fact, MAFRA (2021) predicts that the amount of greenhouse gas generation in the agricultural sector will continue until 2050 due to the impact of agricultural production activities despite the decrease in cultivation area. Despite the importance of food security, it is recognized that efforts to reduce GHG E in the agricultural sector are necessary. Therefore, it is necessary to pay attention to science and politics to reduce emissions from the agricultural sector as much as possible, and to increase the efficiency of food production per area (Balafoutis et al., 2017; Frank et al., 2017). In particular, there is an urgent need for a land use policy on how to use the relevant land in a situation where idle agricultural land increases due to the decrease in farmland area (Tao et al., 2020). In particular, since it is not possible to properly identify the idle farmland, it is necessary to research the area and location of the available idle land before establishing a land use plan and prepare relevant statistics (Long et al., 1995). Based on these statistics, the benefits through land use conversion from idle agricultural land such as reforestation or renewable energy generation should be compared. In this context, agricultural land sites and energy generation sites should be selected considering land productivity and land neutrality. Consequently, it encompasses two of three prerequisites of land policy, "the efficiency and promotion of economic development" and "protection of the environment and sustainable land use for present and future generations" (FAO, 2002; Albaladejo et al., 2021).

4.3 Limitation and implications

This study focused on the necessity to reflect trade off among SDGs to decision making for land use management and to find the concrete way to reflect the economic values of nature assets. Although this study compared the cumulative values up to 2038, future environmental, social, and economic conditions such as changes in the value of ecosystem services or monetary values were not considered. Instead, NPV analysis enabled the estimation and transformation of current values to future values. If the concrete numerical changes can be reflected by considering economic field in future study, the reliability of the result will improve. Second, the scenario developed in this study to derive economic value according to land use tends to be rather extreme. To overcome the low land use efficiency, now in reality the solar energy policies are being developed and promoted in the direction of saving land resources, such as marine solar power or urban building-based solar power. Although this study did not reflect these alternatives to focus on the utilization of forest and idle agricultural land, more detailed and specific scenarios need to be developed in further research. In addition, indicators used to evaluate each scenario may be further added. For example, the number of ecosystem services suggested by Costanza (1997) was total of seventeen, which was three times more than the considered in this study. In addition, in the case of agriculture, there may be additional ecosystem service values such as flood reduction and habitat value. However, only the value of food production and cost of GHG emission were evaluated in this study.

Nevertheless, this study can deduce implications that it is worth applying the quantitative or monetary value of natural assets in decision making process. Even though we only considered a few ecosystem services with conservative method to assess the value for forest conservation and maintenance, they were sufficiently comparable and competitive with the benefits of solar energy project. In this process, the possibility that ecosystem services can contribute to land use policy was also found. Most importantly, this result should not lead to claims that the land should be used for greater economic interest. The purpose of this study was not to overlook factors that are not easily evaluated as economic values when prioritizing among sustainable values. Land planning should be established to increase synergies, identify, and reduce the trade-offs between sustainable developments from a nexus point of view.

5 Conclusion

An acceptable policy decision must be made through an analysis of pros and cons based on various trade-offs (Kim et al., 2021a). In this context, the significance of ecosystem services is often claimed to inform policy and decisions (Daily et al., 2009; Laurans and Mermet, 2014; Martinez-Harms et al., 2015; van Oudenhoven et al., 2018), and the demand for ecosystem services to be included in land policy or governance is much higher recently (TEEB, 2010; Elmqvist et al., 2013; Langemeyer et al., 2016). While the actual value of nature cannot be presented objectively and statistically to decision makers (Krieger, 2001), forests tend to lose priority in land competition with solar power generation, which shares the same goal of carbon neutrality but has intuitive economic values. The transition to a low-carbon society and guaranteeing the sustainability of the natural environment share the biggest and ultimate goals of responding to climate change. Consequently, a land use plan that manages and pursues both goals is of utmost importance and should be achieved using an accurate ecosystem service assessment and economic evaluation.

This study attempted to resolve the land use conflict in the transition to a low-carbon society by comparing the economic values of each land use. South Korea which struggles for a low-carbon transition, was selected for assessment. The economic valuation of the two scenarios was conducted for forest and agricultural land based on the potential area for solar energy generation. In the economic value assessment, an ecosystem service evaluation, including environmental value, was introduced beyond the traditional NPV analysis perspective despite various limitations, such as the lack of evaluation items for forest ecosystem services or the use of static unit values and predicted carbon credit price. In addition, the factors that are not currently included in decision-making, such as carbon emission from agricultural land, were included to maintain focus on carbon neutrality. This study can be extended to include additional ecosystem services assessments and a newly developed monetary method. This study can support the decision making related to land use planning and management, as well as forest conservation and agricultural policies regarding carbon neutrality.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JK; conceptualization, methodology, writing—original draft preparation, EP and CS; methodology, writing-reviewing, MH; methodology and validation, H-WJ: data preparation and processing, and W-KL: conceptualization and writing-reviewing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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