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Sustainable Built Environment and Urban Growth Management

Edited by

Wann-Ming Wey

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Special Issue Editor

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About the Special Issue Editor

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Editorial

A Commentary on Sustainably Built Environments and Urban Growth Management

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Abstract: The concept of urban growth management first emerged in the United States in the 1950s. Its goal was to solve problems stemming from urban sprawl by applying integrated planning, management, and regulation, and to adjust to different development trends in different spaces and times. From the viewpoint of the studies on the link between sustainably built environments, urban growth management, and their interactions, this special issue includes theoretical and empirical studies on sustainable built environment planning and design, sustainable growth management strategies, and other related emerging topics, such as intelligent use of information and communication technologies (ICT) to sustainably build environments, as well as smart cities research with big data, data mining, cloud computing, and internet of things (IOT) ideas.

Keywords: urban growth management; sustainable built environment; quality of life (QoL); smart city & big data

1. Background and Literature Review

During the 21st century, numerous urban developments have gradually deviated from their original urban plans, resulting in the spread of urban sprawl and uncontrolled land development. These effects have produced a number of urban problems, such as serious air pollution, poor environment quality, congestion, and inappropriate land development with low urban density, all of which have negatively affected the quality of life (QoL). The growth management concept was first adopted in the United States to solve problems associated with urban sprawl. Contemporary city planners can use multi-objective growth management methods to simultaneously achieve urban development and QoL. In 2010, the EU failed to meet its Lisbon Strategy goals and subsequently adopted a new strategy called Europe 2020, in which it introduced three essential growth constructs: smart, sustainable, and inclusive growth. The EU also asserts that urban development can improve QoL if the concept of development is replaced with the concept of growth [1–3].

Urban development has deviated from its original planned scope, and the resulting urban sprawl and land overuse have generated various problems. The Lisbon Strategy, initiated in 2000, was intended to make the EU the most competitive economy in the world by 2010. Its main targets were (1) labor participation above 70%, (2) research and development (R&D) expenditure above 3% of the GDP, and (3) an average economic growth rate above 3%. However, the EU did not achieve these three targets. After the failure of the Lisbon Strategy, the then-president of the EU, Manuel Barroso, proposed the Europe 2020 strategy based on essential concepts like smart, sustainable, and inclusive growth [2,3]. How to guide urban development toward growth and increase QoL is thus the central question of the present study. Past studies have argued that growth management is achieved by imposing rigorous guidance and control on regional development in order to ensure improved QoL. As described by Timothy Chapin, four emerging waves of growth management policy in the United States have been evolving since the 1950s [4]. Chapin asserted that growth management policy has focused on control in the past, but should focus on smart and sustainable growth in the future. However, cities are complex systems affected by society, as well as the economy, environment, and culture. Traditional urban development in the decades since World War II has faced numerous problems, such as long-distance transportation, inefficient services, air quality deterioration, land use fragmentation, and inadequate city images. These problems have had negative effects on QoL [5]. As to the livability and sustainability of cities, urban planning and its relevant transportation deploying have a particularly profound and positive effect [6], and are crucial to the quality of life to urban residents at the same time.

Although rapid socioeconomic development has accelerated urbanization and suburbanization, it has also placed a sizeable burden on the sustainability of resource use and city livability. To create a humanized and sustainable living environment, Jane Jacobs advocated the concept of human-scale, livable communities in the 1960s, and the World Commission on Environment and Development proposed the concept of sustainable development in *Our Common Future* in 1987. Urban planning and activities have a profound effect on the livability and sustainability of a city [7].

It is worth noting that various scientific innovations in the urban development field are flourishing, especially between cutting-edge technologies and their emerging requirements. Often these cutting-edge technologies claim that they could promote the sustainability and livability of the city, or even make the city, society, or environment smarter. For example, Ahmad and Mehmood [8] suggested that future cities will be further driven by developments in information and communication technology, and that logistics will play a critical role in future cities, due to the increasingly micro-dynamic nature of socioeconomic and globalised production and consumption patterns. Naim and Rashid [9] also reflected that the ICT-based and industry-driven approaches maybe are not the only solutions for urbanization and future city designs. Based on the above insightful rethinking and reflecting, we thus realize that the common ground and means of ICT-based or industry-driven approaches often tend to directly achieve sustainability or livability through innovative technologies, mechanisms, or intelligent systems [7].

2. Important Issues for Sustainably Built Environments and Urban Growth Management

During the past decade, there has been an increasing interest in the link between the sustainably built environment and urban growth management in the field of urban studies. This interest is motivated by the possibility that urban development planning and design principles associated with the built environment can be used to manage individual activities and improve the quality of urban life. Sustainably built environments are relatively important to urban growth management that deals with environmental problems, housing issues, and community well-being. Nowadays, the sustainable built environment planning in most cities has come to a turning point, as the traffic and population growing has become a serious concern and put tremendous pressure on both the environment and people in these cities. It is therefore important to find ways or new lifestyles, such as compact transit-oriented development (TOD) formulations for cities that are more flexible, inclusive, and sustainable. Furthermore, for sustainable built environment and urban growth management, not only the growth management principles (including smart growth, sustainable growth, and inclusive growth) should be taken into account, but the innovative/smart planning strategies like mixed use design, green transport, and new urbanism are utilized in planning a sustainably built environment to prevent urban sprawl. On the other hand, a number of built environment attributes, measured both objectively and subjectively, were related to levels of physical activity, including walking, cycling, driving, etc. The priorities for built environment planning were arranged according to their different weights. Thus, the priorities in resource allocation were clearly defined, thereby preventing poor resource management and waste, which will be importantly addressed in this special issue.

Basic standards for the living environment have long been established, excepting adjustments responding to the rapidly aging society. In 1961, the World Health Organization (WHO) recommended that the fundamentals of a healthy residential environment include effective fulfillment of human needs and harmony with local factors, such as climate, geography, and social practice, as well as customs and traditions, which may be summarized into four key characteristics: safety, health, convenience, and comfort [10].

It is regrettable that administrative subdivisions established by the relevant government units seem not to employ evidence-based governance or consult any objective analytical results based on urban big data; these units appear particularly concerned with whether governance conforms to the agenda and regulations promulgated by the central government. Therefore, it is necessary for us to assist the relevant government agencies in constructing a scientific, quantitative, and objective planning framework to replace the existing outdated planning philosophy, in order to correct the prominent shortcomings of past operations planned solely in accordance with the qualitative judgment and decision-making of official units or planners. The primary goal is to explore or extract big data to improve final decision-making, as well as future strategies, especially in the situation of new urban datasets generating rapidly in the near future [11]. Based on the previous discussion, the numerous datasets and design techniques generated by the decision matrix computing and the grey prediction model involved in this study may also be considered big data [12].

Nowadays people are aware that cities around the globe are being redesigned to become more smart and sustainable. Despite fruitful research progress in sustainability for cities individually, not too much research has been made by integrating the two themes of "smart" and "sustainable" together. Against this background, it is possible to state that there has been growing research that has been systematically investigating sustainable and smart cities, as well as the specific roles planning, development, and management play in those cities' sustained success in the near future. In this special issue, we hope to aim to gather diverse views and report progress towards both smart and sustainable cities under the consideration of urban growth management principles. The main objective of this special issue is to compile and present the cutting edge work of researchers who focus on joined-up thinking regarding studying a sustainably built environment within the urban growth management concept. By doing so, we believe this special issue on "Sustainable Built Environment and Urban Growth Management" contributes to the knowledge pool in this important area, as well as provides new evidences driven from state-of-the-art and state-of-the-practice research.

The issues about the sustainably built environment and urban growth management raise the common paradigm of the future urban development framework. For example, the urban green belt release has led to urban growth within the associated regions and cities, resulting in an increase in the temperature and the accumulation of pollutants in the atmosphere [13]. Also, the distortion and key factors for specific sites to assess urban sprawl and propose a preliminary course of action for peri-urban growth management is discussed [14]. Furthermore, monitoring and quantifying land use and cover changes (LUCC) have been identified as one of the main causes of biodiversity loss and deforestation in the world. LUCC are also essential to achieve proper land management [15]. Achieving sustainability requires the strengthening of resilience. One paper tries to quantify the susceptibility, vulnerability, and the response and recovery behavior of complex systems for multiple threat scenarios. That approach allows the evaluation of complete urban surroundings and enables a quantitative comparison with other development plans or cities [16]. In addition, one research forecasts the development scale of various buildings in future urban blocks, in order to provide an effective approach to estimate the carbon dioxide generated by the traffic volume [17].

3. Concluding Remarks and Research Directions

The special issue generates new insights by investigating the growth management principles that have emerged firstly to confront negative urban influence. Numerous developed countries failed to achieve their initial development strategy goals and soon afterwards implemented more specific and essential strategies of three innovative growth constructions: smart growth, sustainable growth, and inclusive growth. Following various innovative growth constructions or management principles, contemporary urban agents, including practical planners or official decision units, will be able to pursue urban sustainable development and growth, as well as QoL simultaneously.

In light of sustainable built environment and urban growth management-related matters discussed by the contributors of the special issue, we believe that research frameworks, technical requirements, and findings here not only provide new insights into the functioning of current growth constructions or management principles, but will be used as feasible and important directions for practical planners or official decision agents, in order to facilitate urban sustainability and QoL in the end.

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Article

Simulation of Urban Growth and Urban Living Environment with Release of the Green Belt

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Abstract: Green belts in developing or developed countries have been released because city-center development has reached a saturation point, and the strict protections and restrictions within green belts has led to an increase in opposition from local residents and property owners. However, green belt release has led to urban growth within the associated regions and cities, resulting in an increase in the temperature and the accumulation of pollutants in the atmosphere. We intend to prove quantitatively the effect of the release of green belts at the local level based on the interactions among land cover, climate, and air quality and to provide information for policy decisions accordingly. Our simulation results show that the urban areas of Jeju and Chuncheon, in South Korea, where green belts have been completely released, will increase by up to 21.83% by 2025 and 123.93% by 2020, respectively, compared to areas that have retained green belts. The simulations also show that the surface temperature within the released region of Jeju and Chuncheon will increase by up to 0.83% by 2025 and 0.03% by 2020, respectively. The average atmospheric concentrations within the released region of Jeju and Chuncheon were modelled to increase by up to 256.93% by 2025 and 337.29% by 2020, respectively.

Keywords: green belt; urban growth; land cover; urban living environment; climate change; surface temperature; air quality; atmospheric concentration; conservation; sustainable use

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1. Introduction

Rapid urban growth and land development following industrialization and urbanization have led to overpopulation, housing shortages, traffic jams, and damage to the environment [1]. To address these issues, the green belt system was introduced. However, green belts have been released, especially in developing or developed countries [2,3], because (1) development of the city centers has reached a saturation point and (2) the strict protection and development restrictions within green belts has led to an increase in opposition from local residents and property owners [4,5].

Developing or developed countries have been attempting to rationalize the change in the type of land use (land cover) by releasing green belts in locations with low conservation value, or where the purpose of the original designation has been achieved. Portions of green belts have been released, and such adjustments are expected to continue in the near future, based on applicable regional urban master planning. In combination with increasing demand and pressure for community development, land use changes rapidly with the release of green belts. Urban regions released from their green belts have spread in connection with existing downtowns. The expansion of urban regions that have been released from green belts is threatening ecosystems and their associated natural services, owing to the acceleration of production activities and an energy-consumptive lifestyle within them.

Therefore, we should evaluate and predict the impact of green belt releases quantitatively in various fields and deal with these threats to nature conservation and human well-being. Although there have been numerous studies globally on the impact of green belt releases, including in the food, resource, water, biodiversity, real estate, community service and health fields [6–9], there has been a lack of studies aiming to demonstrate its impact on the living environment, especially concerning the climate and air. As awareness increases regarding the fact that land cover change can amplify or mitigate climate change, recently, the number of studies on the evaluation of the interaction between land cover change and climate change has also increased [10–12]. However, there is a shortage of studies evaluating the entire system of green belt release, urban growth, climate change, and air pollution.

In this study, we intended to quantify green belt release effects at the local level, based on the interactions among land cover, climate, and air quality. As, however, the effects of the release of green belts becomes more apparent over a longer period of time, it is difficult to prove them conclusively through short-term, empirical observations. Therefore, we deduced long-term effects indirectly, by setting a future target year, defining scenarios, and simulating urban growth and urban environmental changes that would be expected by that year. This study will support policy decision makers in approving or disapproving the release of green belts, by providing more information regarding the changes to the urban environment caused by green belt release.

2. Materials and Methods

2.1. Study Area

The South Korean Ministry of Land, Infrastructure and Transport (MOLIT) released the entire green belt (82.6 km^2) within Jeju Island, which had been designated and maintained for 30 years, on 4 August 2001. On 13 December 2001, all green belts (291.8 km^2) within Chuncheon and some (2.6 km^2) in Hongcheon (the administrative district next to Chuncheon) were also released.

Using our case studies, we examined urban growth following the release of green belts and its impact on the urban living environment. Jeju and Chuncheon were used as sites for this research (Figure 1) as they have the following characteristics: (1) Due to their geographic and environmental isolation, it was possible to perform an accurate impact assessment of green belt releases, as the possibilities of external urban development pressure, or conurbation were low; (2) these regions comprise medium-sized cities, which allowed spatial analysis at a medium-scale resolution.

2.2. Assessment of Effects from the Release of Green Belts

The study flow is shown in Figure 2, and includes the following six steps: (1) we set up scenarios in which green belts were maintained or released; and (2) estimated the urban region area for the target year, based on increasing trends in the urban area for a certain period of time. (3) Using spatial and statistical techniques, we then analyzed the location characteristics of regions where the land cover was converted into urban land. (4) The probability of the change from non-urban lands to urban lands was estimated based on those characteristics. (5) The estimated probability allowed us to predict changes in the spatial structure within regions released from the green belts by expanding them to the extent of the estimated urban area of the target year. (6) Based on changes in land cover, the ground surface temperature and atmospheric concentrations within those regions were predicted by applying the urban meteorology and climate prediction model.

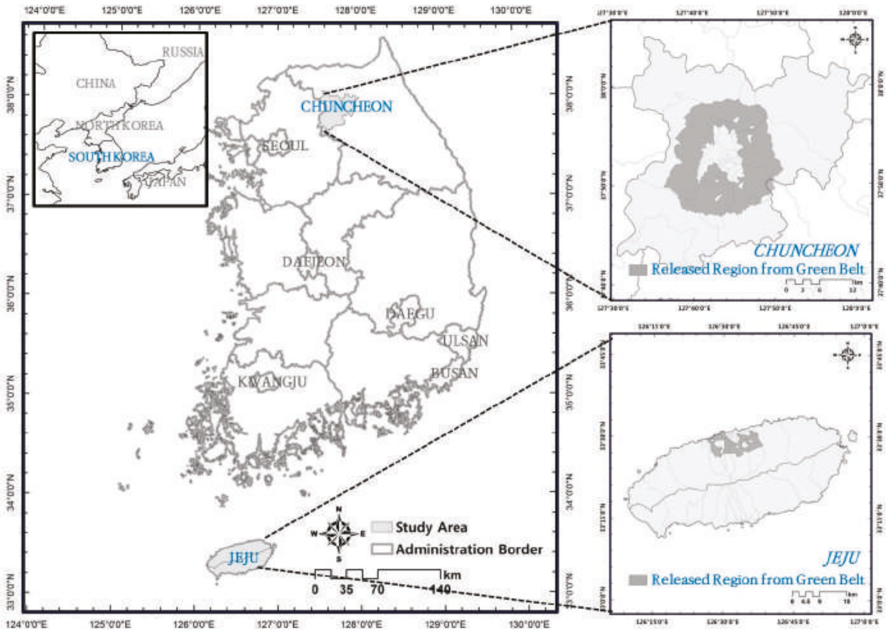

Figure 1. Study area: Jeju and Chuncheon are medium-sized isolated regions, and green belts within these regions which had been maintained for 30 years were released totally in the early 2000s. These regions were used as study sites to prove quantitatively the effect of the release of green belts.

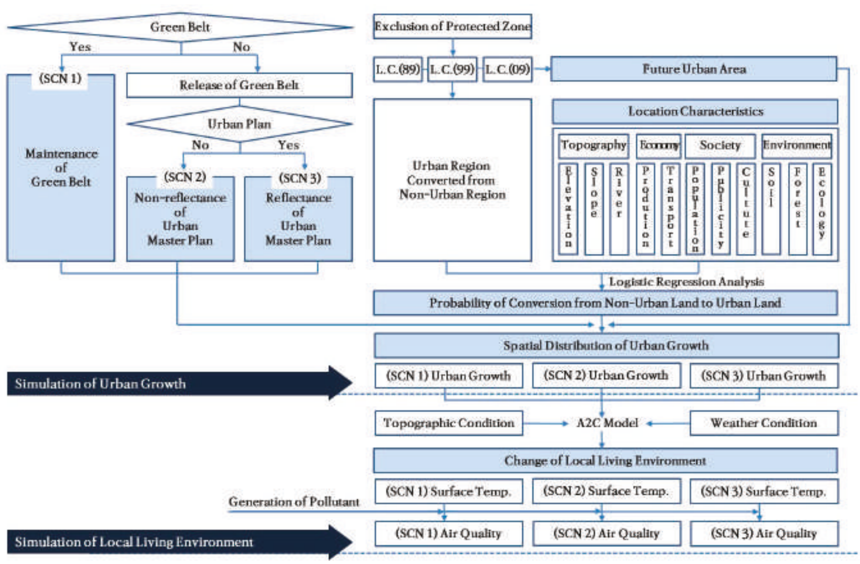

Figure 2. Flow chart: the main flow of this study is as follows: (1) the set of scenarios, (2) the estimation of urban area for the target year, (3) the identification of location characteristics to determine land cover change, (4) the estimation of the probability of conversion from non-urban land into urban land, (5) the simulation of urban growth by green belt release, and (6) the simulation of urban living environment by urban growth.

2.2.1. Scenario Development

We set up scenarios to determine to what extent urban sprawl would continue after release of the green belts, compared to the case in which the green belts were maintained (Table 1). Scenario 1 (SCN 1) was defined as BAU (Business As Usual), and in SCN 1, it was assumed that (1) the sites maintained their green belt boundary as originally designated, and (2) the fluctuation trend of urban areas over the maintenance of the green belt continued until the target year (the target year for simulating urban growth and living environment change following the maintenance or release of the green belts was set as the year to reach an objective in each urban master plan (Chuncheon Urban Master Plan, Jeju Metropolitan City Region Plan). The target year for the simulation of the Chuncheon site was set as 2020, and that of the Jeju site as 2025).

Table 1. Scenarios for analyzing the effect of green belt release: we set up scenarios to determine to what extent urban sprawl would continue after releasing of the green belts compared to that in the case in which the green belts were maintained (Table 1).

	SCN 1	SCN 2	SCN 3
Green Belt	Maintained	Released	Released
Development	Restricted	Non-restricted	Non-restricted
Urban Expansion	Restricted	General Expansion	Intentional Expansion
	Based on Linear Trend before Green Belt Release (1989–1999) *	Based on Linear Trend of Most Recent 20 years of available data (1989–1999–2009) *	Based on Reported Trend in Urban Master Plan

* When estimating the urban area of the target year, we used land cover maps prepared by the South Korean Ministry of Environment using LANDSAT satellite imagery from 1989, 1999, and 2009.

In South Korea, urban growth at the local level has generally progressed via the following process: (1) measuring the demand for development, (2) selecting green belt sites for release, (3) releasing green belts within the total releasable quantity, (4) centrally developing released regions, and (5) expanding built-up zones in connection with existing downtowns. In comparison with BAU, we set up Scenario 2 (SCN 2) to reflect this general progression of urban expansion within South Korea. SCN 2 assumed that an entire green belt was released and that the site maintained its urban growth trend, as shown over the most recently analyzed 20 years (1989–1999–2009) up to the target year.

For urban development to facilitate vitalization of the regional economy, the local government follows three steps in a forward planning process. (1) It estimates the future population of the target year, including the resident population, utilization population, and working population, by reviewing the overall demand for development, the currently available land, and development funds. Based on the estimated forward population, the local government (2) forecasts land demand for additional urban sites, including residential, commercial, and industrial sites, for the long term, and then (3) commences development. We set up Scenario 3 (SCN 3) to reflect the intentional aspect of urban expansion considering the land demand of the local government in comparison with that of BAU. In SCN 3, it was assumed that the entire green belt of the site was released and that the site would be urbanized to the extent of the values published in the urban master plan up to the target year.

2.2.2. Estimation of the Urban Area for the Target Year

A protected zone is the legally controlled geographic space for the purpose of preserving and improving ecological and cultural values [13,14]. It is difficult to alter a land category within the protected zone because property rights and specific actions within it should be reported and permitted in advance based on the relevant law. Therefore, we excluded protected zones when estimating urban areas for target years and the probability of conversion into urban lands.

We excluded the protected zones listed in Table 2 from land cover maps, and confirmed the fluctuation trends of urban areas by considering residential, industrial, commercial, cultural, sports, leisure, transportation, and public areas. Future urban areas based on SCNs 1 and 2 were estimated as follows: we determined linear equations using time-series analysis of urban areas to be derived from land cover maps and estimated future urban areas by inserting target years (2020, 2025) into the equations. In addition, the future urban area based on SCN 3 was substituted with the value of urban areas expected in the urban master plan.

Table 2. Protected zones excluded from the simulation of urban growth from green belt release: we excluded ecological, water and other protected zones when estimating future urban areas and the probability of conversion into urban lands, because it is difficult to alter a land category within protected zones due to the restriction on property rights and activities based on the relevant law.

Ecological Environment	Water Environment	Other Environment
• Ecological and Scenery Conservation Zone • DMZ (Demilitarized Zone) • Wetlands Protection Zone • Wildlife Protection Districts • Natural Park (Nature Conservation District) • Baekdu-daegan * Protection Zone (Core District)	• Riparian Zone • River Zone (Grades I, II, III) • Water Source Protection Zone	• Green Zone for Conservation • Ecosystem Preservation Zone • Cultural Preservation Zone • Green Belt • Absolute Preservation Zone • Natural Reserve • Natural Monument Designation Zone

* Vital Mountain Range of South Korea.

2.2.3. Identification of the Location Characteristics to Determine the Land Cover Change

Simulation of the change in land cover is based on understanding the statistical relationship between spatial patterns of land cover and the driving factors of land cover change [15]. Lim and Choi [16], Allen and Lu [17], Oh et al. [18], Lee et al. [19], and others identified elevation, slope, population density, soil, distance from a river/city/road, and presence of protected zones as factors for determining land cover change. Based on literature review and internal circumstances (in South Korea, the most significant factor leading to the government's policy decision-making on the release of green belts is the determination to retain the growing population within the urban region. Projects to construct public housing, infrastructure, and industrial complexes are implemented when green belts are released. To reflect this phenomenon, we selected production amount, distance from public transport, population density, distance from public facilities, and distance from cultural facilities as the economic and social factors affecting conversion of non-urban land into urban land), we selected factors affecting the conversion of non-urban land into urban land in terms of the overall (1) topography, (2) economy, (3) society, and (4) environment. From these factors, the elements that we selected as affecting the conversion of non-urban land into urban land were: (1a) elevation, (1b) slope, and (1c) distance from rivers; (2a) production amount and (2b) distance from transportation facilities; (3a) population density, (3b) distance from public facilities, and (3c) distance from cultural facilities; and (4a) soil, (4b) forest, and (4c) ecology. We constructed thematic maps with a spatial resolution of 30 m using these factors as raster data (Table 3).

Table 3. Construction of thematic maps via driving factors to determine the urbanization: based on the literature review, we selected factors affecting the conversion of non-urban land into urban land in terms of topography, economy, society, and environment, and constructed thematic maps as raster data.

Driving Factor		**Raw Data**	**Method**
Topography	Elevation	DEM	Construction of Elevation from DEM
	Slope	DEM	Construction of Slope from Elevation
	Distance from River	Stream Order Map	Calculation of Euclidean Distance from Rivers
Economy	Production Amount	Statistics Annual Report	Assignment of 1st, 2nd, and 3rd Industrial Production Amounts to Agricultural/Industrial/Commercial lands
		Land Cover Map (Middle Level)	
	Distance from Transportation Facility	Land Cover Map (Middle Level)	Calculation of Euclidean Distance from Transportation Lands
Society	Population Density	Statistics Annual Report	Assignment of Population Density to Residential Lands
		Land Cover Map (Middle Level)	
	Distance from Public Facility	Land Cover Map (Middle Level)	Calculation of Euclidean Distance from Public Lands
	Distance from Cultural Facility	Land Cover Map (Middle Level)	Calculation of Euclidean Distance from Cultural, Sport, and Recreational Lands
Environment	Soil	Soil Map	Reclassification by Soil Drainage Class *
	Forest	Forest Map	Reclassification by Forest Age Class **
	Ecology	Ecological and Natural Map	Reclassification by Ecological and Natural Class ***

* Soil Drainage Class: 1st class (very well), 2nd class ((very) well), 3rd class (well), 4th class (normal), 5th class (poor), 6th class (very poor), 7th class (exposed rock). ** Forest Age Class: 1st class (1–10 years old), 2nd class (11–20), 3rd class (21–30), 4th class (31–40), 5th class (41–50), 6th class (51–60), 7th class (61–70), 8th class (71–80), 9th class (81–90), 10th class (91–100). *** Ecological and Natural Class: 1st class (major habitat; major ecological axis; spectacular scenery; abundant biodiversity), 2nd class (worthy of conservation in the future; buffer for 1st class zone for the protection of a 1st class zone), 3rd class (all others; suitable for development or utilization).

2.2.4. Estimation of the Conversion Probability from Non-Urban Land into Urban Land

Logistic regression analysis is useful in situations in which the predictor variable is determined by the independent variable or judged by its presence and is suitable when the dependent variable is in the binary mode. It is the statistically applicable method for analysis and prediction of urban growth using several causative factors related to urban growth [11,17,20]. We calculated the conversion probability of transformation into urban regions by using the basic logistic regression model equation—Equation (1).

$$\ln\left(\frac{p}{1-p}\right) = \alpha + \sum \beta_i X_i \quad (1)$$

where p is the conversion probability for transformation into urban regions, X_i is the independent variable, α is constant, and β_i is the regression coefficient.

A sample of the independent variable was extracted via systematic random sampling. We extracted non-urban regions from the land cover map for 1989 and divided them into two categories using time-series analysis: (1) the regions that had been changed from non-urban lands to urban lands since 1989, and (2) all other regions. An equivalent number of pixels was extracted in regions that had been converted from non-urban land to urban land to that in all other regions that had remained non-urban. We conducted regression analysis on these pixels using the driving factors. At this time, logistic regression analysis was performed through phased selection of the variable (forward procedure). We established the logistic regression equation by obtaining the regression coefficient and constant and calculated the probability of the conversion of non-urban land into urban land by applying the regression equations based on the different scenarios, to each thematic map.

2.2.5. Simulation of the Urban Growth by Green Belt Release

The estimated probability allowed us to predict the changes in the spatial structure of the urban regions in which the green belt had been released by expanding them to the extent of the estimated urban area (refer to Section 2.2.2). Based on the conversion probability, we extended the urban region until it converged with the value of the area for the target year derived from the linear equations or urban master plan.

2.2.6. Simulation of the Urban Living Environment by Urban Growth

Land cover change affects the heat balance between the land surface and atmosphere above. The accumulation of heat balance changes would result in local changes of the climate and the air quality (the rise in surface temperature from land cover change induces an increase in the height of the atmospheric mixing layer. This leads to the degradation of air quality by the intensification of the greenhouse effect, because the mixing layer height determines the volume available for dispersion of emitted pollutants [21–24]). We performed simulations of the urban living environment, including the climatic and atmospheric changes, based on the results of the urban expansion prediction. As the Atmosphere to CFD (Computational Fluid Dynamics) (A2C) model is the forecasting model for urban climate and weather based on the 3D non-static primitive equation, it is appropriate for predicting the urban living environment within the complex topography of South Korea. We predicted change to the local climate and air quality within regions released from green belts by inserting land cover and topographic data (digital elevation model) into this model. At that time, the physical properties of the model—such as absorption, reflection, roughness length, maximum moisture, and surface thermal inertia—were reflected as fixed values based on measurements from the early summer when the atmospheric conditions were stable. Areas designated as manufacturing land within urban regions were assumed to be pollutant emission spots (the main cause of air pollution is vehicle operation (0.43 vehicles per capita in South Korea), but it is difficult to predict these for the study areas in the target year. Therefore, we decided to simulate air pollution concentration based on land cover change, because the larger the area of urban lands, the more vehicles there are, leading to more air pollution). In consideration of the overall conditions, such as the atmospheric model, handling devices, and time required, we degraded the spatial resolution of the land cover maps to 200 m and reduced the extent of the target regions to the land surrounding the released green belt area.

3. Results

3.1. Short-Term Effects of the Release of Green Belts Based on Observation

Prior to simulating urban change caused by the release of green belts, we analyzed actual observed short-term changes in land cover and air quality occurring before and after green belt releases.

The changes that appeared within the released regions of the Jeju green belt were as follows (Figures 3 and 4): the urban area within the released regions in 1999 (the 26th year after the designation of the green belt and 2 years before its release) was 3.90 km^2, a decrease of 26.44% compared with 1989 (the 16th year post designation). The agricultural area was 17.90 km^2, which was an increase of 21.00%, and the forest area was 55.10 km^2, increasing by 11.18% compared with 1989. The urban area within the released regions in 2009 (the 8th year after release) was 5.07 km^2, an increase of 30.14% compared with 1999. The agricultural area was 56.29 km^2, which was an increase of 214.50%, and the forest area was 15.34 km^2, a decline of 72.16% compared with 1999. The annual average concentrations of SO_2, NO_2, O_3, CO, and PM_{10} within the released regions (Ido-dong) in 1999 were 0.005 ppm, 0.018 ppm, 0.031 ppm, 0.700 ppm, and 33.00 μg/m^3, respectively. In 1999, the average concentrations of NO_2 and CO had increased by 16.67% and 75.50%, but the concentrations of SO_2, O_3, and PM_{10} had decreased by 40.63%, 0.54%, and 15.38%, respectively, compared with 1995, which was the 1st year of air quality observations for Ido-dong, and the 22nd year after green belt designation. In 2009, the annual average concentrations of SO_2, NO_2, O_3, CO, and PM_{10} were 0.002 ppm, 0.013 ppm, 0.041 ppm, 0.400 ppm, and 40.00 μg/m^3, respectively. In that year, the concentrations of SO_2, NO_2, and CO had decreased by 57.89%, 25.71%, and 42.86%, but the concentrations of O_3 and PM_{10} had increased by 32.97% and 42.86%, respectively, compared with 1999.

Changes appeared within the released regions of Chuncheon as follows (Figures 3 and 4): in 1999 (the 26th year after designation of the green belt, and 2 years before its release), the urban area within the released regions was 2.17 km^2, an increase of 87.32% compared with 1989, the 16th year after its designation. Compared with 1989, the agricultural area was 47.70 km^2, a decrease of 3.22%, and the forest area was 210.18 km^2, a decrease of 1.12%. The urban area within the released regions in 2009 (8 years after release) was 4.75 km^2, an increase of 119.48% compared with 1999. Agricultural area was 46.40 km^2, a decrease of 2.73%, and forest area was 213.53 km^2, an increase of 1.59% compared with 1999. However, grassland coverage was 5.13 km^2—a decrease of 44.33% compared with 1999. In 2009, the annual average concentrations of SO_2, NO_2, O_3, CO, and PM_{10} within the released regions (Seoksa-dong) were 0.004 ppm, 0.018 ppm, 0.025 ppm, 0.600 ppm, and 58.00 μg/m^3, respectively. By that year, the concentrations of NO_2, CO, and PM_{10} had increased by 100.00%, 50.00%, and 13.73%, respectively; SO_2 remained unchanged, and O_3 had decreased by 10.71% compared with 2004, which was the 3rd year after the release of the green belt, and the year that air quality monitoring commenced at Seoksa-dong.

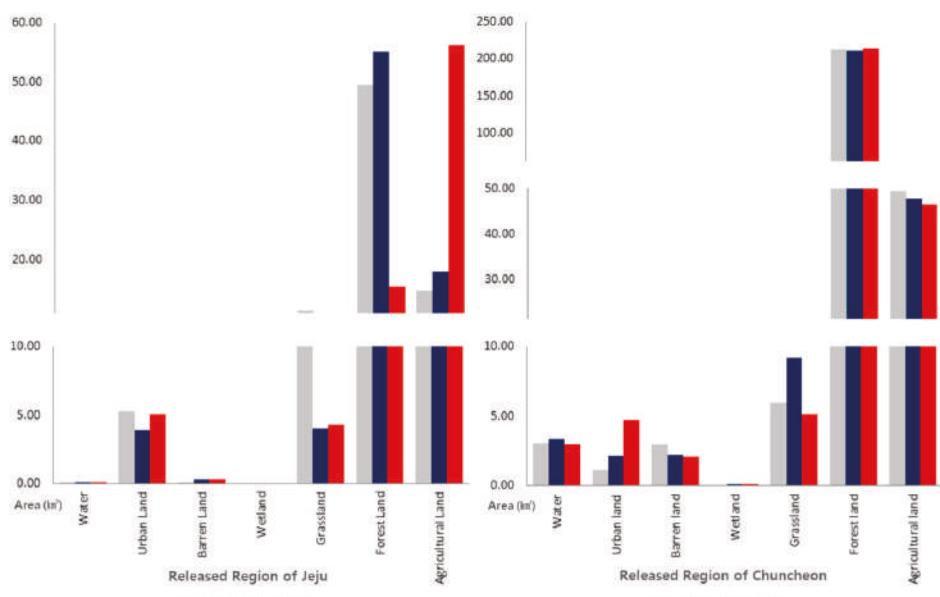

Figure 3. Land cover change before and after the release of green belts, based on observation; we conducted the time series (1989, 1999, 2009) analysis on the observed change of the area based on land cover type within the regions released from green belts.

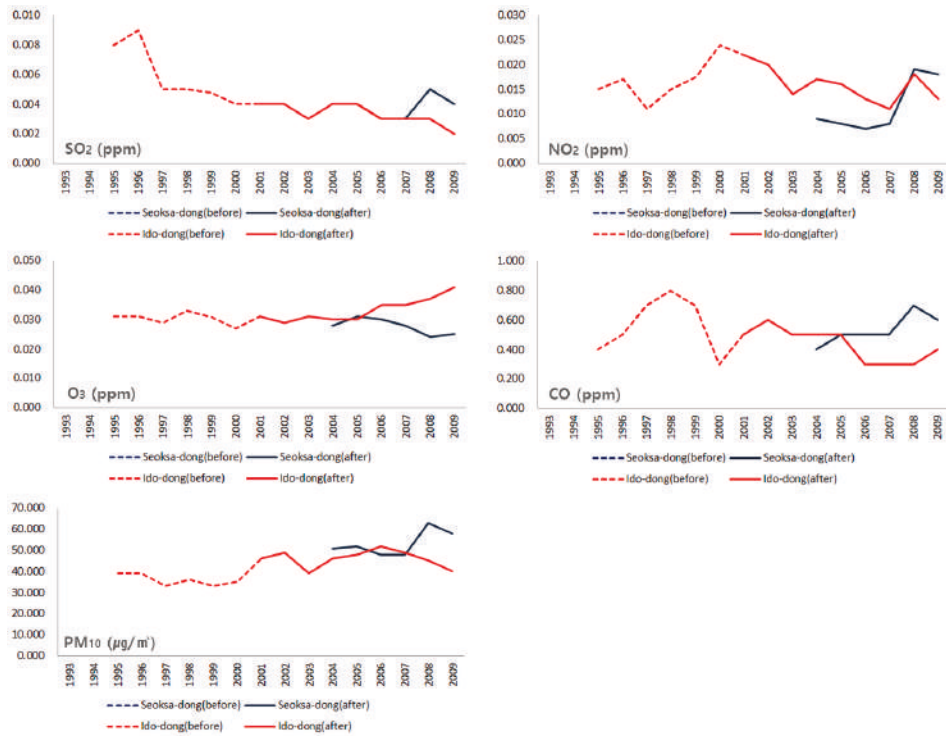

Figure 4. Air quality change before and after the release of green belts, based on observation: we conducted the time series (1999, 2009) analysis based on the observed change of air quality (SO_2, NO_2, O_3, CO, PM_{10}) within the regions released from green belts.

We intended to demonstrate the long-term effect of the release of green belts indirectly, by setting the future target year, defining scenarios, and simulating urban growth and environmental change based on the interactions between land cover, climate, and air quality. We decided to do this for the following reasons:

(1) As the effect of the release of green belts appeared to accumulate over a long period of time, it was difficult to demonstrate effects from just short-term empirical observations.

(2) Atmospheric gas concentrations are monitored continually, in order to track the status of air pollution and climate-changing substances in real time and at the national level. There are approximately 300 monitoring stations, acting as representative sites for air quality in South Korea, with just one of these in each of the released regions of Jeju and Chuncheon. Numerous external influences contribute to influence the monitored air quality values, not just effects from release of the green belts, and these other air quality influences cannot be separated from any actual air quality change caused by the release of the green belts. Therefore, there was a limit to our ability to validate the effect of the green belt release accurately, using observational data alone.

3.2. Long-Term Effects of the Release of Green Belts Based on the Simulation

3.2.1. Urban Area of the Target Year

The urban area of Jeju for the target year (2025) was 146.20 km^2 in SCN 1, 125.81 km^2 in SCN 2, and 178.11 km^2 in SCN 3 (Table 4). The urban area of Chuncheon for the target year (2020) was 19.64 km^2 in SCN 1, 28.99 km^2 in SCN 2, and 43.98 km^2 in SCN 3 (Table 4).

Table 4. Linear equation and estimated urban area for each scenario: we calculated the future urban areas by adding urban areas in protected zones to values to be estimated from the linear equations or to be cited from the urban master plan.

Scenario		Linear Trend Equation	Urban Area (Including Urban Area of Protected Zones)			
			1989	1999	2009	2020(25)
Jeju	SCN 1	y = 2.19x − 4290.39 (R^2 = 1.00 *)	69.39	88.86	98.89	146.20
	SCN 2	y = 1.44x − 2788.77 (R^2 = 0.95)				125.81
	SCN 3	-				178.11
Chuncheon	SCN 1	y = 0.68x − 1345.12 (R^2 = 1.00 *)	11.87	15.86	26.04	19.64
	SCN 2	y = 0.44x − 861.58 (R^2 = 0.93)				28.99
	SCN 3	-				43.98

* SCN 1 is the scenario considering the trend of urban expansion at the time of urban growth control via the designation and maintenance of the green belts, and the urban area of SCN 1 was derived by the following process: (1) calculating areas of urban lands to be extracted from land cover maps of 1989 and 1998, (2) deriving the linear equation between areas of two periods, (3) inputting the target year into the linear equation and deducting the urban area at the target year. Therefore, R^2 of the linear equation is 1.00.

Regarding Jeju, the value of the urban area in SCN 1 was higher than that of SCN 2, which assumes green belt release. The cause of this is considered to be that urbanization within South Korea progressed rapidly from the 1970s to the 1990s, but the speed of urban growth has slowed since then, causing the rate of urban growth from 1989 to 1999 to be higher than that from 1999 to 2009. As the equation based on the above-mentioned phenomenon was applied to calculating the future urban area, although the green belt was not released in SCN 1, the urban area in SCN 1 is 1.16 times greater than that in SCN 2. However, these values do not exceed the values reported in the urban master plan.

3.2.2. Location Characteristics and the Probability of Conversion into Urban Land

The analysis confirmed that population density, production amount, and barren land on the land cover map were positively correlated with the conversion of non-urban land into urban land (Table 5). The distance from public facilities, distance from transportation facilities, water on the land cover map, and ecological and natural class are negatively correlated with the conversion of non-urban land into urban land (Table 5).

In SCN 1, ecological and natural class, forest age class, and water on the land cover map primarily affected the conversion of non-urban land into urban land in Jeju, with wetland, barren land, forest age class, ecological and natural class, and soil drainage class the main conversion influencers in Chuncheon. In SCNs 2 and 3, wetland, barren land, grassland, and forest land on the land cover map, forest age class, and ecological and natural class affected the conversion of non-urban land into urban land in Jeju, with forest age class, soil drainage class, and barren land affecting the conversion in Chuncheon. The coefficients, constants, and thematic maps based on driving factors were applied to each logistic regression equation according to the scenarios, and the conversion probabilities were computed.

Table 5. Coefficients and constants based on the logistic regression analysis of the conversion into urban land; we obtained coefficients and constants for each driving factor contributing to the conversion of non-urban land into urban land by performing binary logistic regression analysis on systematic random sampling data ($p < 0.05$).

Item			Jeju		Chuncheon	
			SCN 1	SCN 2, 3	SCN 1	SCN 2, 3
Coefficient	Elevation		−0.0003	0.0004	−0.0079	−0.0027
	Slope		0.0031	−0.0005	-	−0.0089
	River		−0.0001	−0.0001	0.0009	−0.0004
	Population Density		0.0187	0.0313	0.0117	0.0109
	Public Facilities		−0.0006	−0.0004	−0.0004	−0.0002
	Cultural Facilities		−0.0001	−0.0001	-	−0.0001
	Production Amount		0.0003	0.0004	0.0004	0.0005
	Traffic Facilities		−0.0013	−0.0021	−0.0014	−0.0017
	Land Cover	Water	−1.2475	−0.4934	−0.6369	−0.7078
		Urban Land	-	-	-	-
		Barren Land	0.7086	1.2794	1.4004	1.7318
		Wetland	0.2250	3.0034	21.5742	-
		Grassland	−0.8611	−1.0632	0.9838	0.2797
		Forest Land	−0.8811	−1.0400	−0.1193	−0.1090
		Agricultural Land	-	-	-	-
	Soil Drainage Class	Very Well	-	-	0.9563	−0.9589
		(Very) Well	0.2890	0.4902	0.4139	−1.9050
		Well	0.6968	0.0033	0.9169	−0.7887
		Normal	-	-	1.4265	−0.7833
		Poor	0.3731	0.3299	0.9357	−0.6466
		Very Poor	0.3328	−0.0479	-	-
		Exposed Rock	-	-	-	-
	Forest Age Class	1st Class	−2.5156	2.2282	16.8759	−21.2623
		2nd Class	−0.5642	0.8666	15.1851	−0.6532
		3rd Class	−0.2923	0.1544	15.7588	−0.4955
		4th Class	0.0600	0.0748	16.5151	−0.9146
		5th Class	0.3716	0.1450	15.2279	−0.5156
		6th Class	0.3387	−0.2757	15.4118	−0.6132
		7th Class	-	-	-	-
	Ecological and Natural Class	1st Class	−2.6659	−1.4699	−2.3240	−0.7857
		2nd Class	−0.7273	−0.4247	−1.8046	−0.3780
		3rd Class	−1.0542	−0.3806	−1.8881	−0.4549
	Constant		1.2022	1.1127	−15.1472	3.6239

3.2.3. Change in Urban Growth, Climate, and Air Quality via Green Belt Release within Jeju

Results are shown in Table 6 and Figure 5. In SCN 1 (green belt maintained), the urban area of Jeju in 2025, including protected zones, was 146.20 km^2, an increase of 64.53% compared to the urban area in 1999 (the last year prior to the green belt release in which the actual urban area was known). The agricultural area was 357.19 km^2, which is a decrease of 9.37%, and the forest area was 1018.29 km^2, a decrease of 1.66%, compared to the area in 1999. Of the regions that were converted into urban land, 64.41% was utilized as agricultural land, 29.94% as forest land, and 4.24% as barren land in 1999. In SCN 2 (release of the green belt and development reflecting the past and current trends), the urban area of Jeju in 2025, including protected zones, was 125.81 km^2, an increase of 27.22% compared to that of 2009 (the last year after green belt release in which the actual urban area was known). The agricultural area was 799.28 km^2 (2.50% decrease since 2009), and the forest area was 646.96 km^2 (0.36% decrease since 2009). Of the regions that were converted into urban land, 76.08%

was used as agricultural land, 11.18% as barren land, and 8.66% as forest land in 2009. In SCN 3 (release of the green belt and development reflecting the local demand), the urban area of Jeju in 2025 was 178.11 km^2, reflecting an 80.10% increase since 2009. The agricultural area was 762.07 km^2 (7.04% decrease since 2009), and the forest area was 637.81 km^2 (1.77% decrease since 2009). Of the regions that were converted into urban land, 72.82% was classified as agricultural land, 14.49% as forest land, and 6.82% as grassland in 2009.

Based on SCN 1, the urban area within the released regions was 3.90 km^2 in 2025. The area based on SCN 2 was 7.11 km^2, an increase of 82.51%, and the area based on SCN 3 was 10.86 km^2, reflecting an increase by 178.70% since 1999, the year before the green belt release. The forest area within the released regions decreased rapidly owing to the expansion of urban areas. In 2025, the forest area of the released regions was 55.00 km^2 in SCN 1, 15.21 km^2 in SCN 2 (72.39% decrease), and 14.60 km^2 in SCN 3 (73.51% decrease). The more green belt released, and the higher the demand for local development, the more urban areas within the released regions and downtown expanded.

Table 6. Land cover change and living environment change in Jeju; we proved quantitatively the effect of the release of green belts within Jeju through the prediction of the urban expansion and the simulation of the urban living environment based on the interactions among land cover, climate, and air quality.

		Land Cover (km^2)							Surface Temperature (°C)		Atmospheric Concentration (g/m^2)	
		Urban Land	Agri. Land	Forest Land	Grass Land	Wet Land	Barren Land	Water	Released Region	Down Town	Released Region	Down Town
1989		69.39	379.32	924.93	466.55	0.59	7.83	37.12	-	-	-	-
1999		88.86	394.12	1035.46	322.08	0.39	15.10	29.17	-	-	-	-
2009		98.89	819.76	649.29	271.38	0.38	15.34	31.29	-	-	-	-
2025	SCN 1	146.20	357.19	1018.29	321.28	0.39	12.67	29.16	31.45	32.47	2.67×10^{-07}	4.42×10^{-06}
	SCN 2	125.81	799.28	646.96	270.40	0.38	12.33	31.17	31.71	32.63	8.70×10^{-07}	4.33×10^{-06}
	SCN 3	178.11	762.07	637.81	265.98	0.38	10.81	31.17	31.45	32.36	9.53×10^{-07}	4.51×10^{-06}

The average surface temperature in the released region in 2025 was 31.45 °C in SCN 1, 31.71 °C in SCN 2, and 31.45 °C in SCN 3. The surface temperature in the existing downtown (classified as downtown on the land cover map of 2009) was 32.47 °C in SCN 1, 32.63 °C in SCN 2, and 32.36 °C in SCN 3. The surface temperature in regions released from the green belt and the existing downtown in SCN 2 increased by 0.83% and 0.49%, respectively, compared to those of SCN 1. However, the temperatures in SCN 3 decreased by 0.01% and 0.34%, respectively, compared to those of SCN 1, because the spatial resolution of the land cover had been degraded from 30 m to 200 m, resulting in the decrease of urban expansion (we tried to improve the spatial resolution of the input and result data from 200 m to 90 m and simulated the local climate change. At 90 m spatial resolution, the surface temperature in the released regions was 29.21 °C in SCN 1, 29.38 °C in SCN 2, and 29.49 °C in SCN 3. The surface temperature in the downtown was 29.81 °C in SCN 1, 30.13 °C in SCN 2, and 29.89 °C in SCN 3. The surface temperature in regions released from the green belt and in the existing downtown in SCN 3 increased by 0.96% and 0.27%, respectively, compared to those of SCN 1. This shows that the release of the green belt led to the increase in the urban surface temperature compared with the maintenance of the green belt). However, the difference between the average surface temperature within downtown and the released region decreased by 1.02 °C in Scenario 1, 0.92 °C in SCN 2, and 0.91 °C in SCN 3, indicating that higher-temperature regions expanded after the green belt release.

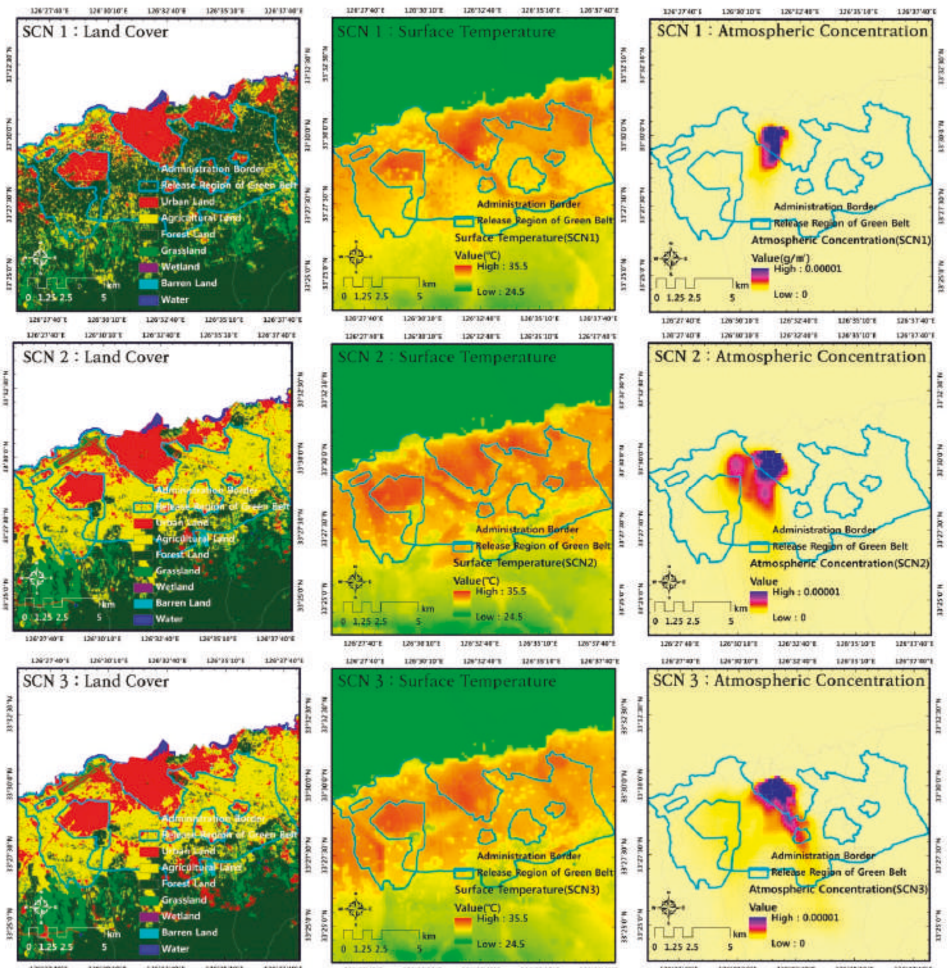

Figure 5. Spatial distribution of urban growth, climate, and air quality in the region released from the green belt within Jeju; we represented spatially the effect of the release of green belts within Jeju through the prediction of the urban expansion and the simulation of the urban living environment based on the interactions among land cover, climate, and air quality.

The average atmospheric concentrations within the released regions in 2025 were 2.67×10^{-07} g/m^2, 8.70×10^{-07} g/m^2, and 9.53×10^{-07} g/m^2 in SCNs 1, 2, and 3, respectively. The average atmospheric concentrations in SCNs 2 and 3 rapidly increased by 225.84% and 256.93%, respectively, compared to that of SCN 1. In 2025, the atmospheric concentrations in the existing downtown in each scenario were 4.42×10^{-06} g/m^2, 4.33×10^{-06} g/m^2, and 4.51×10^{-06} g/m^2, respectively. The average atmospheric concentration of the downtown in SCN 2 decreased by 2.04% compared to that of SCN 1. However, the average atmospheric concentration of the downtown in SCN 3 increased by 2.04% compared to that of SCN 1.

3.2.4. Changes in Urban Growth, Climate, and Air Quality via Green Belt Release within Chuncheon

Results are presented in Table 7 and shown in Figure 6. In SCN 1, the urban area of Chuncheon in 2020, including the protected zone, was 19.64 km^2, reflecting an increase of 28.83% since 1999. The agricultural area was 105.03 km^2 (1.22% decrease since 1999), and the forest area was 906.10 km^2 (0.15% decrease since 1999). Of the regions that were converted into urban land, 36.24% was utilized as forest land, 34.39% as agricultural land, and 17.20% as barren land in 1999. In SCN 2, the urban area of Chuncheon was 28.99 km^2 in 2020, an increase of 11.33% since 2009. The agricultural area was 101.01 km^2 (1.73% decrease since 2009), and the forest area was 915.29 km^2 (0.05% decrease since 2009). Of the regions that were converted into urban land, 60.34% was classified as agricultural land, 16.61% as forest land, and 12.54% as barren land in 2009. In SCN 3, the urban area of Chuncheon was 43.98 km^2 in 2020, an increase by 68.89% since 2009; the agricultural area was 90.05 km^2 (12.39% decrease since 2009); and the forest area was 912.64 km^2 (0.34% decrease since 2009). Of the regions that were converted into urban land, 71.01% was used as agricultural land, 17.50% as forest land, and 5.74% as barren land in 2009.

In 2020, the urban area within the released regions in SCN 1 was 2.09 km^2. It was 5.63 km^2 in SCN 2, reflecting an increase of 170.21% since 1999, before the release of the green belt. In SCN 3, it was 14.03 km^2, reflecting an increase of 573.84% since 1999. The agricultural area decreased as the urban area within the released region expanded. In 2020, the agricultural area within the released region was 47.47 km^2 in SCN 1, 45.76 km^2 in SCN 2 (3.62% decrease since 1999, before the release of the green belt), and 39.45 km^2 in SCN 3 (decrease of 16.90% since 1999).

Table 7. Land cover change and living environment change in Chuncheon; we proved quantitatively the effect of the release of green belts within Chuncheon through the prediction of the urban expansion and the simulation of the urban living environment based on the interactions among land cover, climate, and air quality.

		Land Cover (km^2)							Surface Temperature (°C)		Atmospheric Concentration (g/m^2)	
		Urban Land	Agri. Land	Forest Land	Grass Land	Wet Land	Barren Land	Water	Released Region	Down Town	Released Region	Down Town
1989		11.87	114.04	908.59	16.28	0.05	8.66	56.04	-	-	-	-
1999		15.86	106.33	907.47	23.97	0.12	10.19	51.58	-	-	-	-
2009		26.04	102.79	915.78	13.81	0.14	7.09	49.85	-	-	-	-
2020	SCN 1	19.64	105.03	906.10	23.51	0.12	9.54	51.58	31.02	33.37	2.95×10^{-08}	3.50×10^{-05}
	SCN 2	28.99	101.01	915.29	13.51	0.14	6.72	49.84	31.03	34.34	1.28×10^{-07}	3.71×10^{-06}
	SCN 3	43.98	90.05	912.64	12.79	0.14	6.06	49.84	31.03	34.41	1.29×10^{-07}	4.64×10^{-06}

The average surface temperatures within the released regions in 2020 were 31.02 °C, 31.03 °C, and 31.03 °C in SCNs 1, 2, and 3, respectively, and the average surface temperatures within the existing downtown were 33.37 °C, 34.34 °C, and 34.41 °C. These values indicated that the surface temperatures of the downtown in all scenarios increased after the green belt was released. As a result of releasing the green belt, the surface temperatures within the released region increased by 0.03%, on average, and those within the downtown increased by 2.91–3.12% compared to those in SCN 1.

In 2020, the average atmospheric concentrations within the released region were 2.95×10^{-08} g/m^2, 1.28×10^{-07} g/m^2, and 1.29×10^{-07} g/m^2 in SCNs 1, 2, and 3, respectively, and the average atmospheric concentrations within the downtown were 3.50×10^{-05} g/m^2, 3.71×10^{-06} g/m^2, and 4.64×10^{-06} g/m^2. The atmospheric concentration within the downtown was improved by releasing the green belt. However, the average atmospheric concentrations within the released regions in SCNs 2 and 3 increased by 333.90% and 337.29%, respectively, compared to that in SCN 1.

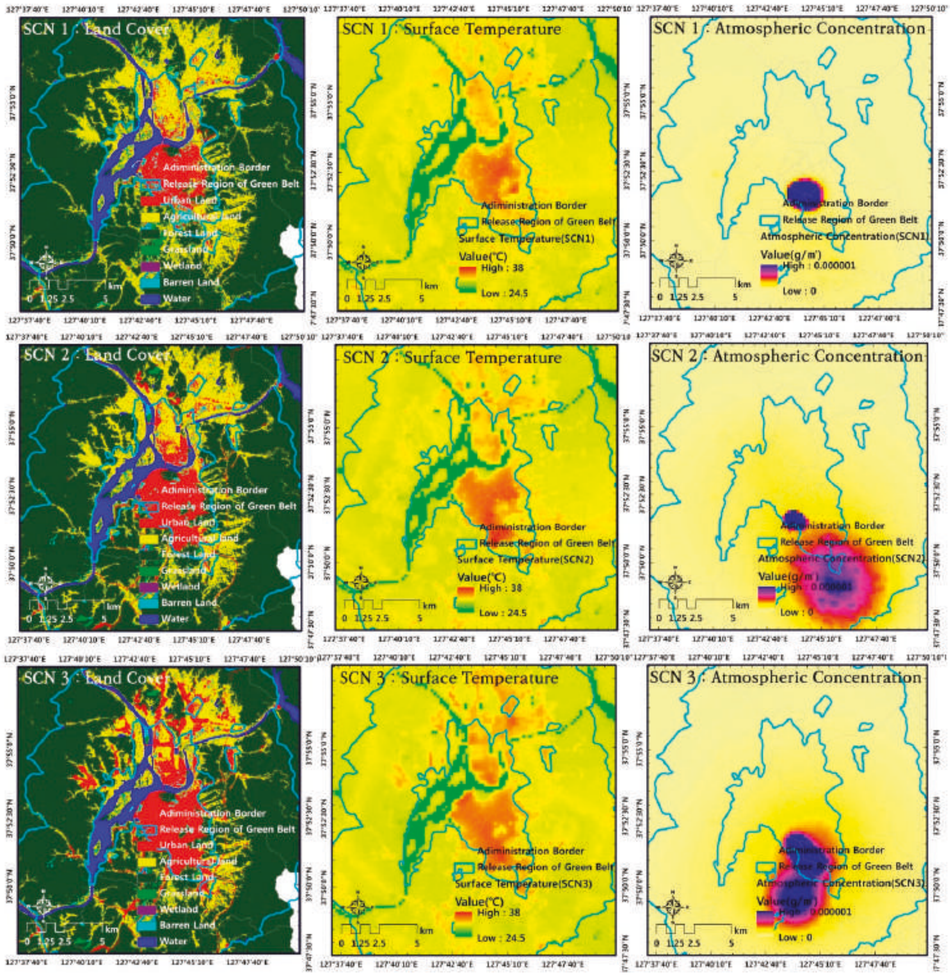

Figure 6. Spatial distribution of urban growth, climate, and air quality in the region released from the green belt within Chuncheon; we represented spatially the effect of the release of green belts within Chuncheon through the prediction of the urban expansion and the simulation of the urban living environment based on the interactions among land cover, climate, and air quality.

4. Discussion

4.1. Effect of Green Belt on the Restriction of the Urban Expansion

The green belt system was introduced to prevent urban sprawl through the designation of development restriction zones and the limitation of activities performed within these zones. We identified the effect of green belts on urban growth control by simulating the future urban area based on the maintenance or the release of the green belts. This simulation demonstrated that green belts promoted and integrated the development district into the center of the city, preventing large-scale development and the spread of development outside of the city. This was shown in our projections, whereby future urban areas of Jeju and Chuncheon decreased by up to 17.92% and 55.34% in the scenario in which the green belt was maintained compared with those in the scenario in which the green belt was released.

However, green belts within developing or developed countries that had been maintained for several decades have been released, and their release is expected to continue for economic vitalization reasons [2,3]. Based on this study, green belt release could lead to expansion of existing urban regions and even acceleration of leapfrogging development (the logistic regression analysis of conversion into urban land showed that population density, production, and barren land on the land cover map were positively correlated with conversion of non-urban land into urban land. On this basis, it can be confirmed that urban land expanded around existing urban lands, as shown in Figures 5 and 6). This goes against the purpose of the green belt, that is, to restrict urban expansion, conserve the natural environment, and secure the living environment of urban residents.

It is expected that urban development will continue to expand as a result of urban master planning focusing on urban growth and targeting agricultural land surrounding cities, which is vulnerable to conversion into urban land. It is possible that the urban spatial structure will be changed in the following sequence: urbanization of regions released from green belts, urban spread connected with existing downtowns, and urban sprawl. Broad urban sprawl negatively affects forest land, which produces resources and energy, improves air quality, mitigates climate change, conserves ecosystems, and improves health [25,26]. There is concern that urban expansion will lead to encroachment onto urban farmland and will damage forest land. Protected zones, as well as forest land, might be released, which would reduce the quality of the urban environment if development demand increases continuously and development capacity exceeds the availability of developable land within non-protected zones of the city.

4.2. Effect of the Green Belt on Conservation of the Urban Living Environment

The green belt ensures a healthy living environment for citizens through the prevention of urban sprawl and conservation of the natural environment that surrounds cities. However, urban growth that results from green belt release leads to a higher temperature in downtown centers, and a lower temperature outside the city. The high-temperature region of >32 °C will expand across the existing downtown and new urban regions as a result of green belt release. The average surface temperature within the released region in the scenario that was set for green belt release increased by up to 0.83% in Jeju and 0.03% in Chuncheon, compared to that of the scenario in which the green belt was maintained. Surface temperature rise due to land cover change induces an increase in the atmospheric mixing layer height which in turn determines the volume of the air shed into which emitted pollutants disperse. This enhances degradation of the air quality through intensification of the greenhouse effect [21–24], because the higher the mixing layer height, the less it is influenced by the external weather conditions that dilute pollutants.

In the short term, this phenomenon will cause pollutants to accumulate in the urban canopy directly above their emission source and the atmospheric concentrations will increase. The average atmospheric concentrations within the released region in the scenario of green belt release increased by up to 256.93% in Jeju and 337.29% in Chuncheon compared to that of the scenario set for green belt maintenance. If entire green belts are released and development is accomplished to accommodate all local development demand, more pollutants will be accumulated, and higher atmospheric concentrations will appear. In the medium/long term, this could result in the more frequent occurrence of severe weather phenomena, including tropical nights and localized heavy rain. This could deplete the output of primary and secondary industries and accelerate energy consumption. In addition, it is postulated that this, in turn, could create obstacles to the supply of energy within the urban region.

4.3. Sustainable Management of Green Belts for Coexistence between Nature and Humans

In the initial stage of urbanization, the primary purpose of the national policy within the developing or developed countries is economic development. Existing downtowns that have already been equipped with infrastructure are generally selected as the development sites for economic growth because the effectiveness and productivity of the national land use are considered important. Because of significant investments in existing downtowns, population growth is remarkable and social infrastructure is created accordingly. This results in the expansion of urban lands.

The green belt system was introduced as a means for controlling urban growth because development expanded from urban regions to suburban regions. However, green belts have been released to promote the rationalization of land use change, because the discomfort of residents and landowners worsened owing to standardized and excessive regulations. In South Korea, particularly, the population is concentrated in urban regions—the urban residential population proportion was 91.82% in 2017, and it is necessary to prepare housing and infrastructure for their support of the concentrated population. However, development sites are in short supply within urban regions. Accordingly, South Korea's government releases green belts surrounding urban regions and implements development plans and projects for these released regions from green belts. As a result, horizontal sprawl, and vertical growth within the released regions, have caused cities to expand and to be combined, resulting in changes in the urban spatial structure. A wide range of human activities that consume natural resources have led to changes in the living environment, including increases in the surface and atmospheric temperatures, expansion of high temperature regions, and changes in wind speed. These changes have caused accumulation of pollutants in the atmosphere.

In South Korea, England, Japan, Canada, United States of America, Australia, New Zealand, France, Netherland, and Russia, green belts are being maintained [27]. Even then, parts of green belts have been released, or the related system abolished, in some of these countries—South Korea, England, and Japan [27]. Especially in South Korea, where there has been great environment benefit from retaining green belts over decades, green belts are now being released based on urban master plans, and this phenomenon is expected to continue into the near future. As green belt release occasionally contributes to resolving urban crises, in combination with time and space situations, such as housing shortages and their high cost [9,28], there is debate with regard to the need to adjust green belt borders and to the regulations that apply to their conservation [28–31]. Importantly, it is almost impossible for released green belt areas to be re-designated as green belts, for economic and social reasons, and it is also difficult to reverse the environmental damage; therefore, designation and release of green belts should be carefully decided, in order to promote coexistence between nature and humanity.

First, for the management of sustainable urban growth, green belts should be designated as confined regions, in which it is necessary to restrict development. This is necessary (1) to prevent disorderly urban sprawl, (2) to prevent neighboring cities from being linked by continuous urban corridor areas, (3) to conserve the natural environment and ecosystems surrounding cities, and (4) to ensure a healthy living environment for city dwellers. More effort should be made to preserve green belts with high conservation values, and to restore broken and damaged ecosystems within existing green belts, by restoring ecological corridors (the green (forest), blue (river), yellow (soil), and white (wind) networks) around green belts, connecting with ecosystems inside and outside of the green belts, and building green spaces.

Second, green belts should be used and managed sustainably, as they directly affect the lives of local residents. We should encourage lifestyle activities that have minimal influence on the ecosystem, through transferring technology, providing supporting finance for sustainable agricultural production, diversifying community support programs, and aiding development of compatible facilities. We could render parts of the green belts eco-friendly, by transforming them into public parks and constructing green leisure facilities on land purchased for that purpose. Traffic and movement networks (white belts) around the green belts should be constructed for commuting, while still ensuring low-density or low-impact use and maintaining a pleasant urban environment.

Third, green belts could have their shapes adjusted, or could be released if necessary, if issues arise concerning the adequate supply of urban land, or land-use rationalization, in their vicinity, provided environmental assessment of the green belt shows that the released land embodies low conservation value. Such a review should include the following questions:

- Is the urban development necessary, taking into consideration the decline of the city (that is, that the rate of urbanization has slowed down)?
- Should urban development definitely be accommodated within the green belt?

If the release and development of green belts is inevitable, it should at least be discouraged within more environmentally sensitive regions, in order to conserve the urban ecosystem that provides diverse ecosystem services, generates pleasant urban environments, and responds to climate change. It should be developed in connection with areas in need of urban regeneration, or urban revitalization, not in the context of building a new town or industrial complex.

We should encourage eco-friendly use and development of released areas, for tours or as recreational spaces for citizens, where the environmental burden of use is low, and the environmental impact assimilating capacity can be maintained. We should also ensure that a minimum green zone width is retained within the released region to prevent urban conurbation. We should:

- Select the released and developed locations from the green belt in light of the current situation and potential development impacts,
- Develop and apply techniques to minimize environmental change,
- Prepare measures to mitigate development impacts,
- Arrange solutions to reasonably manage pollutants,
- Establish and apply customized methods to reflect the local characteristics, and
- Periodically monitor whether the above measures are implemented or not.

Basic investigation should be carried out, and environmental monitoring using purpose-built facilities should be enforced. We expect the above measures to create a comfortable urban environment which promotes and maintains a harmonious balance between nature and human beings through the sustainable management of green belts.

5. Conclusions

Green belts are development-restricted zones created with the aim of preventing urban sprawl and ensuring a healthy living environment for citizens through conservation of the natural environment surrounding cities. However, green belts have been released to promote the rationalization of land use change, and the urban land within the released regions has enlarged through existing downtowns in response to increasing demand for community development. The environment of these regions has been degraded and threatened by the acceleration of development activities and a lack of management. Therefore, we conducted a quantitative assessment to prove the impact of green belt releases on urban growth and urban living environment degradation, focusing on the changes in land cover, climate, and air quality.

This study has concluded that the urban areas of Jeju (by 2025), and Chuncheon (by 2020), where green belt land was released, would increase by up to 21.83% and 123.93%, respectively, compared to the BAU scenario, where green belts were maintained intact. The surface temperatures within the released regions of Jeju (by 2025) and Chuncheon (by 2020) are predicted to increase by up to 0.83% and 0.03%, respectively. The average atmospheric concentrations within the released regions of Jeju (by 20205) and Chuncheon (by 2020) would increase by up to 256.93% and 337.29%, respectively.

However, these results have the following limitations. (1) Scenarios were set up based on the simple assumption that the current urban growth trends would continue into the future for the study areas. (2) A linear equation was applied to estimate the future urban area, owing to a lack of input data. (3) This prediction was accomplished at the medial spatial resolution level because of limited simulation models and infrastructure. Environmental change trends following the release of the green belts could be analyzed; however, detailed estimates were impossible. Therefore, a database including historic information on green belts should be generated. In addition, further studies should set and verify scenarios in consideration of future change and potential demands on the environment, economy, and society. Finally, various models based at the local, metropolitan, and national levels should be developed and applied; these models would help researchers and policy makers to predict future change, and the likely influence and demands of the urban environment, and to establish policies for the sustainable management of associated green belts.

Although limitations exist within this study, our results show that the significant benefits of green belts are compromised when they are released, their designated purposes are not followed, and their spatial characteristics are not considered. This causes exaggerated growth and expansion of existing cities, conurbation between existing towns and new towns, degradation of the environmental quality of downtown and released regions, and renders remaining green belt areas non-sustainable. It is impossible for green belts to solve all urban problems, and they in fact contribute occasionally to urban crises, in combination with issues of time and space [9,28]. There is debate with regard to the need to adjust green belt borders, and on the regulations to apply for their conservation [28–31]. This study has shown, however, that green belts are able to contribute positively to controlling urban growth, and to conserving the urban living environment, and that they require a minimal but necessary amount of maintenance. It is almost impossible for released green belt areas to be re-designated as green belts, or for them to be returned to their pre-release environmental state. Therefore, the designation and the release of green belts should be carefully decided in order to promote the coexistence between nature and human beings.

For the management of sustainable urban growth, green belts should be designated as confined regions in which it is necessary to restrict development. This is necessary for the following reasons: (1) to prevent disorderly urban sprawl, (2) to prevent neighboring cities from being linked by continuous urban corridors, (3) to conserve the natural environment and ecosystems surrounding cities, and (4) to ensure a healthy living environment for city dwellers. More effort should be made to conserve green belts with high conservation value, and to restore damaged ecosystems within them. Within green belts, human activities that do not degrade ecosystem functions, and minimally affect natural resources within the green belt zone should be encouraged. Parts of green belts should be dedicated to eco-friendly uses, by transforming them into public parks and constructing environmentally friendly facilities in land purchased for the purpose. Traffic and movement networks (white belts) around the green belts should be constructed for commuters, while ensuring that low-density use and low-impact use are encouraged, maintaining a pleasant urban environment. Green belts could have their shapes adjusted, or could be released if necessary, if issues arise concerning the adequate supply of urban land, or land-use rationalization, in their vicinity, as long as environmental assessment of the green belt shows that the released land embodies low conservation values. However, the release of green belts should be discouraged within environmentally sensitive regions in order to conserve the urban ecosystem, and released green belt land should be developed in connection with areas that are in need of urban regeneration or revitalization, and should not be used for building new towns or industrial complexes. We should select sites for release from green belts only after conducting analysis considering geographic, economic, social, and environmental factors, and should encourage eco-friendly use and development of released areas for tourism, or as recreational spaces for citizens, where the environmental burden is low, and the environmental impact assimilating capacity can be maintained. We should contribute to the sustainable management of green belts by introducing eco-friendly or low-impact development techniques, implementing environmental monitoring, and constructing environmental infrastructure within released areas. Finally, we should also ensure that a minimum green zone width is retained within the released region, to prevent urban conurbation.

This study is significant, as we intended to support policy decision-making with respect to green belts by predicting urban growth and the changes that green belt release could cause in the urban living environment using various development scenarios. We anticipate that a balance between conservation and use will be kept by managing green belts reasonably through more studies based on our research, and that healthy urban environments will be promoted and improved.

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Factors Causing Farmland Price-Value Distortion and Their Implications for Peri-Urban Growth Management

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Abstract: Taiwan's Agricultural Development Act (ADA) of 2000 relaxed farmland ownership criteria and allowed non-farmers to own farms. Although this opened up the market and induced a growth in farmland trading, relaxing these criteria without proper monitoring resulted in rapid development of farmhouses that fragmented farmlands, adversely affecting agricultural production and the quality of peri-urban environments, and increased management difficulties. Relaxing farmland ownership criteria also provided opportunities for speculation, which pushed up farmland prices, causing farmland price to deviate from its production value. We used a price:value ratio as an index of price-value distortion to explore farmland price-value distortion spatially using a geographical information system (GIS). Yilan County was used as a case study since its agricultural lands suffer high development pressure due to ready accessibility from the Taipei metropolitan area. Ordinary least square and quantile regression were used to identify factors driving distortion in Yilan County. Finally, we discuss the distortion and key factors for specific sites in Yilan to assess the urban sprawl and propose a preliminary course of action for peri-urban growth management. Our findings suggest that residential activities stimulate farmland price-value distortion but do not enhance farmland value. Designation of a land parcel as agricultural within an urban area allows for speculation and increases distortion. The land parcel's association with infrastructure such as road and irrigation systems, and the price of agricultural products, are significantly correlated with distortion. Most of these identified factors increased farmland price because of the potential for non-agricultural land-use. We propose that to resolve farmland price-value distortion in Yilan, multi-functional values, in addition to agriculture, must be envisioned.

Keywords: driving factors; farmland price-value distortion; GIS; price:value ratio; quantile regression; spatial spectrum

1. Introduction

A number of environmental impacts within farmlands and their surrounding areas are the result of current land-use planning and policies, which emphasize economic development over environmental protection, ecological conservation, and control of urban sprawl into farmlands [1,2]. Urban sprawl encompasses a complex pattern of land-use, transportation, and socioeconomic development [3], depending on the type of urban and rural planning and farmland policies [4]. Factories in rural areas, regarded as industrial land-use, are inextricably linked with urbanization and the urban sprawl pattern in Taiwan [5–7]. Moreover, urban sprawl into farmlands in Yilan shows a unique pattern due to the presence of farmhouses occurring both along roadsides and in the middle of farmlands, a result of amendments to the Agricultural Development Act (ADA) in 2000 that allowed for residential activities on farmland. The resultant pattern differs from the "Frog Jump" pattern observed in western countries. The urban sprawl developing along the roadside and in the middle of farmlands caused adverse impacts on the peri-urban environment and complicated sprawl management.

While agricultural production is the most conventional way of gaining revenue from farmlands currently, it is anticipated that there will be greater returns from farmlands through farmland readjustment in the future [8]. Urban sprawl onto farmlands in Yilan is a result of the comparative advantage of farmland owners and developers. The findings of Hardie et al. [9] suggested that in general, farmland and housing prices are determined by income, population, and accessibility variables. This implies that option values associated with irreversible and uncertain land development are capitalized into current farmland values. Plantinga et al. [8] decomposed farmland value into two components: (1) the quasi-rents from agricultural production and (2) the gains from potential land development at the nation's county level. Kostov [10] applied spatial quantile regression and hedonic land price to model agricultural land sales in Northern Ireland. Later, McMillen [11] applied quantile regression to spatial grid modelling in the Chicago area and in this way predicted the change in land values as one moves closer to the central business district of the city. Yoo and Frederick [12] used quantile regression to statistically explore the effects of land subsidence and earth fissures to residential property values in a study from Arizona. Few studies, however, have concentrated on the spatial pattern of both farmland price and value and their distribution difference at site scale with geographical information system (GIS) spatial analyses.

Current farmland prices are mostly driven by the option values of potential development, which often surpass the land's production value. Farmland prices are thus frequently higher than would be expected from their production value. With a lack of proper monitoring, speculators entered the farmland market, and a scattering of farmhouses emerged on the Yilan Plain. The agricultural production zone and surrounding areas continue to suffer from an array of environmental impacts caused by the increase of residential housing and over-development that occurred once the ADA was amended. Therefore, current farmland prices, representing the option values of potential farmland development, are a paradoxical excuse for farmland speculation in Taiwan. Because the agricultural development policy no longer stipulated that farmland had to be utilized for agricultural production and allowed development of residential buildings on farmlands, building companies and land owners triggered speculation of real estate on farmland. This caused a substantial farmland price increase and thereby distorted its price-value ratio. In Yilan, the price-value distortion of farmlands resulted in decreased agricultural production and affected farmland ecosystem services.

We used Yilan County as a case study to investigate spatial patterns of this price-value distortion. We used a GIS platform to integrate a farmland transaction database (price) with the value of crop production (using a "relative value from production" approach). A quantile regression (QR) was used to identify factors potentially impacting the price-value distortion for each farmland transaction. These factors were explored with spatial analyses to review the spatial pattern of the distortion relative to planning and management policies. This was used to propose potential measures to manage the price-value distortion and enhance ecosystem services of farmlands in Yilan.

2. Research Background

2.1. Farmland and Farmhouse Development in Yilan

Yilan County, located in the northeast of Taiwan, is adjacent to the Taipei metropolitan area (Figure 1). It has an area of 2144 km^2. 14.93% of the land is a plain, known as Lanyang Plain (24°37′–24°50′ N, 121°37′–121°50′ E). Its soil quality, sufficient precipitation, and efficient irrigation system make it an important agricultural production region in Taiwan. After Taiwan's Agricultural Development Act revised farmland ownership criteria to allow non-farmers to own farmlands in 2000, many urban civilians became farm owners and are now hobby farmers or simply build farmhouses in the production area. The completion of National Freeway No. 5 in 2006 shortened travel time, and commuting between Yilan County and Taipei city became feasible. This provided further incentives for urban residents to pursue agri-tourism in Yilan, or even to purchase farmland there. These factors all increased the transformation of Yilan from a conventional farming area into an agri-tourism industry. As a result, a large number of farmhouses were built on farmlands which caused a rapid urban sprawl pattern on the Lanyang Plain, hindering production as well as the development of agricultural industries in Yilan County [13].

To mitigate the problem, the "Regulations for Constructing Farmhouses on Agricultural Land in Yilan" (hereafter "Farmhouse Regulations") were implemented by the Yilan County Government in 1994. They provided guidance for building farmhouses that suited the landscape and environment. Subsidies were offered for compliance, which attracted speculators and led to more farmhouses appearing on the Lanyang Plain. The demand for farmland was strong, and elevated farmland prices and a unique pattern of urban sprawl emerged on the Lanyang Plain. As Huang [14] pointed out, when it is anticipated that farmland prices will be inflated in the future, speculation prevails. This is exactly what occurred in Yilan County. It is important to realize that once farmland has been converted into buildings, both cultivation area and agricultural production value are decreased, and farmland ecosystem services, which are socioeconomically and environmentally important, will suffer from the loss of farmland [15].

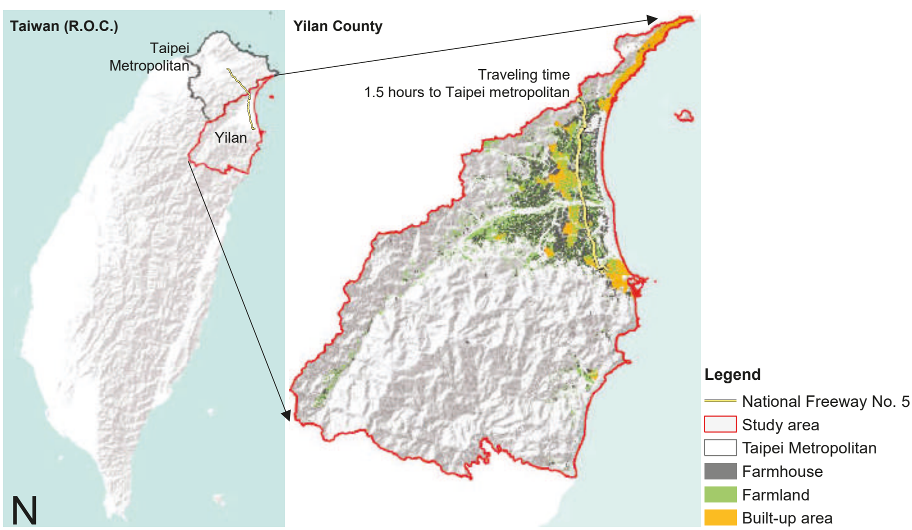


Figure 1. Study area.

2.2. Farmland Price and Value

When only farmers owned farmland, agricultural production was the most common source of revenue. As a result, farmland value was determined based on the output level or profitability of agricultural production, and transaction prices of farmland usually reflected its production value [16], implying little deviation between farmland price and value. Since the criteria for farmland ownership were relaxed and farmland policy shifted from "farmland should be owned by farmers" to "farmland should be used for agricultural production", non-farmers have been allowed to own farmland. This caused a loophole allowing for speculation. It is anticipated that farmland readjustment (consolidation) will generate high returns and that farmland price will begin to deviate from its original purpose (i.e., production [8]). Rather than agricultural production value, the development potential of farmlands will play a vital role in determining farmland value and price. Hardie et al. [9] suggested that income, population, and other variables determine average farmland and housing prices. Their research suggests that optional values associated with irreversible and uncertain land development are capitalized into present farmland values.

The value and benefits of farmlands are worth assessing from a conservation and ecosystem services perspective. The multi-functionality of farmlands in providing such benefits as production value [16], water retention [17], wildlife habitats [18], air quality improvement [19], recreational and landscape aesthetics [20], and ecosystem services [21] has been the subject of many studies. However, this multi-functionality is based on the premise that farmlands are utilized for agricultural production rather than speculation. The capital gain from the potential development of farmlands cannot be combined with production value and other ecosystem services. Although taking ecosystem services into policy consideration is important, due to the difficulties of evaluating the value of ecosystem services of farmlands, its impacts on farmland price are not included in this study. Farmland prices in the following study therefore reflect the expected value of potential development (i.e., the possibility of building farmhouses) and agricultural production value. Discrepancies between farmland production value and farmland prices can be treated as proxies of "distortion". Few studies have investigated the difference between prices and production values of farmlands, without which it is impossible to assess the significance of the role played by speculation.

3. Research Design and Data

3.1. Definition

Most previous studies have focused on factors influencing the price of farmlands, such as soil condition, production environment, and farmland productivity [22–24]. Since the advent of urbanization, additional factors have begun to influence land value. Arbitrage that hopes for appreciation may play a vital role in price decision. Therefore, analyzing the deviation between land price and its production value is helpful in understanding the current situation of farmland price distortion. The ratio of farmland price to farmland production value adjusted for the farmland price index, as defined in the present and earlier studies, reflects the level of distortion as follows:

$$\text{price} - \text{value distortion} = \frac{\text{price of farmland}}{\text{value of farmland}} \times \text{farmland price index}$$

The higher the ratio, the greater the distortion; a high distortion indicates a considerable discrepancy between farmland price and production value. Farmland price data were downloaded and summarized from the real estate transaction database provided by the Ministry of Internal Affairs. Farmland value was generated from the raw data of Taiwan's agricultural census in 2010. Farmland price indices were collected from the Platform of Real Estate Information from the Ministry of Internal Affairs.

Before 2000, most Yilan farmlands were utilized for agricultural production because of the limitations of the ADA and zoning control for agricultural areas (Figure 2). During this period, farmland value was usually influenced by agricultural production and transportation cost from the perspective of land economics and location theory. Enhancing production conditions by irrigation system and soil improvement are examples of key methods for increasing farmland value and price. In this period, there was no obvious difference between farmland price and value. The farmland price increased substantially after the amendments of the ADA. Since farmland production value did not change, the farmland price:value ratio increased, resulting in a clear upward trend of price-value distortion. Subsequent studies revealed that farmland buildings along roads usually dominate the unique urban sprawl pattern in the surrounding environment of urban areas.

We adopt the price:value ratio firstly to generate a single index to analyze the phenomenon of farmland price-value distortion, and secondly to organize various scenarios for analyzing development impacts on good quality farmland. We then use this to discuss potential issues arising from farmland protection and demand for urban development (Figure 3). For example, farmland with both a high transaction price and a high productive value is identified as a good quality farmland in Yilan. Its price:value ratio (price-value distortion) is usually a result of serious urban development impact. Therefore, besides distortion, relative and standardized measures based on crop production value and farmland price as determined from land transactions were also used to explore farmland value. The farmland price:value ratio shows an interesting distortion spectrum which highlights the conflict between land speculation, farmland preservation, and urban growth management.

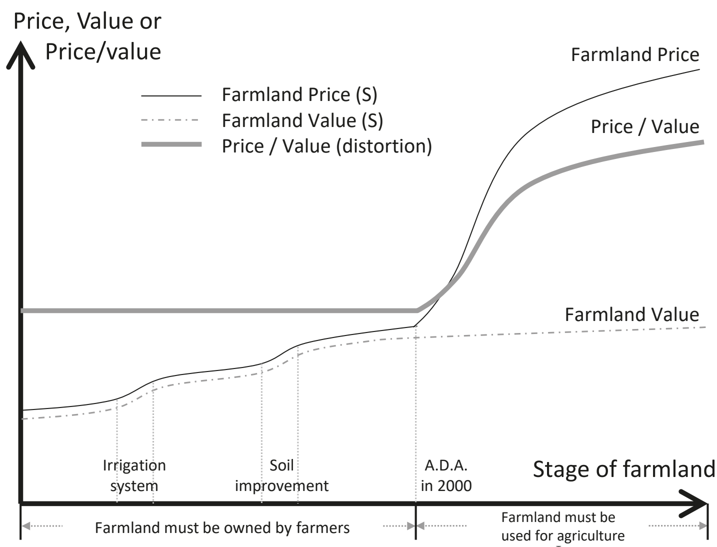


Figure 2. Change in farmland price-value distortion.

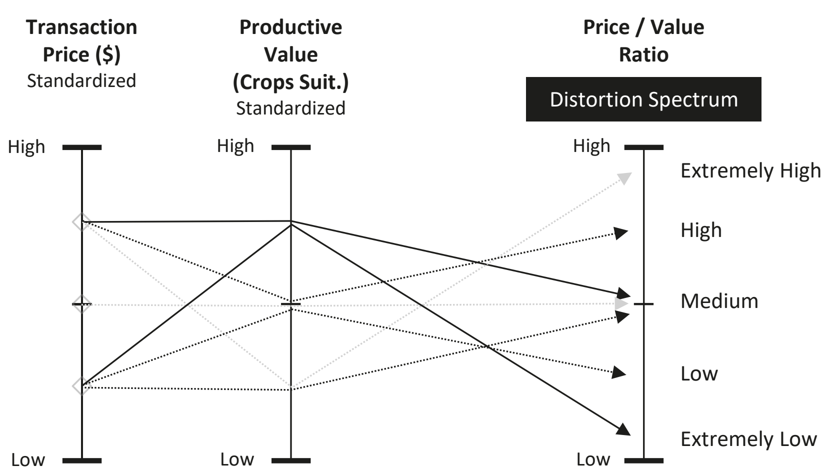


Figure 3. The farmland price-value distortion spectrum.

3.2. Research Design

A geographical information system (GIS) was used to integrate farmland transaction, to spatially illustrate the distortion spectrum (Figure 4), and to identify and estimate potential factors influencing the distortion. Quantile regression (QR) was also adopted to estimate the impact of factors on the distortion. The spatial pattern of the distortion relative to planning and management policies and their implications were discussed as well. Suggestions were provided to manage distortion, preservation, and urban growth management in Yilan.

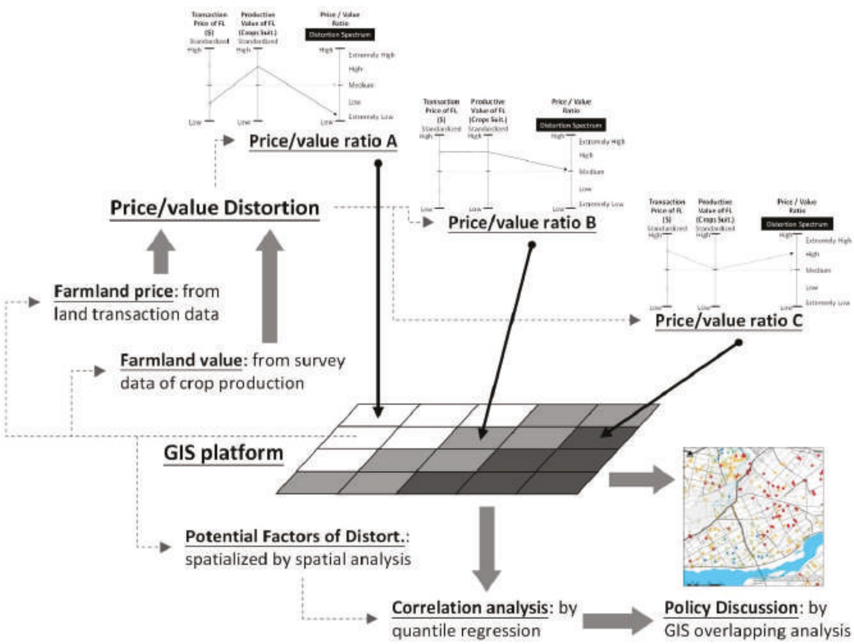


Figure 4. Research design.

3.3. Data

We selected eight potential factors influencing farmland price and production value: soil condition (a proxy for crop suitability); irrigation system; crop price variation; farmland use regulation; distance of farmland from urban area; width of the nearest road; complexity of land count and transaction; and real estate loan index [13,22–28]. Calculating farmland price and value in this study focuses on farmland itself without considering the price of farmhouses. In addition to calculating distortion and these factors (Tables 1 and 2), QR and ESRI ArcGIS were used to analyze the farmland price determination in Yilan County. Our findings indicate that the factors (or explained variables) do affect distortion.

Table 1. The definitions and sources of variables.

Variable	Definition and Data Description	Data Source
Price	Real transaction price of farmland (NT$/$m^2$) (transaction price of farmland from 2012 to 2015 is adjusted by consumer price index to have a common comparative base in 2016)	Actual real estate transaction cases, Ministry of the Interior (August 2012–September 2016)

Table 1. *Cont.*

Variable	Definition and Data Description	Data Source
Value	Production value of farmland (NT$/$m^2$/year) (average production value of crops per year is calculated from the original database based on the location for each farmland transaction)	Agricultural, Forestry, Fishery and Husbandry Census, Directorate General of Budget, Accounting and Statistics (2016)
Price_value	Price-value distortion (ratio of the real transaction price to production value, %)	(Same as above)
Avgattr	Soil conditions (0 is the poorest, 4 is the best)	NGIS Ecological Resources Database
near_water	Distance to the nearest canal (m)	Platform for the National Land Use Inventory
Agriprice	Annual crop prices variation (%)	Statistical database of Yilan County; Agricultural Statistics Yearbook, Council of Agriculture
use_urban	Agricultural zone in urban area (1 yes, 0 no)	Actual information of real estate transaction case, Ministry of the Interior
use_regular	General agricultural zone in non-urban area? (1 yes, 0 no)	(Same as above)
use_special	Special agricultural zone in non-urban area? (1 yes, 0 no)	(Same as above)
use_mt	Sloping and conservation zone in non-urban area? (1 yes, 0 no)	(Same as above)
near_urban	Distance to the nearest urban area (m)	Layers of use in urban planning, Construction and Planning Agency, Ministry of the Interior
Width	The width of the nearest road (m)	Taiwan Electronic Map, Ministry of the Interior
Landcount	Complexity of land counts (1, 2, 3, etc.) (many approaches could be used to define complexity of land. To simplify the problem, as well as to cope with the real situation of Yilan, the complexity of farmland ownership was applied in this research instead of common landscape metrics, Shannon index, or landscape complexity [29].)	Agricultural cadastral maps, Yilan County
Interestrate	Mortgage rate (%)	Deposit and loan rate of five leading domestic banks, Central Bank

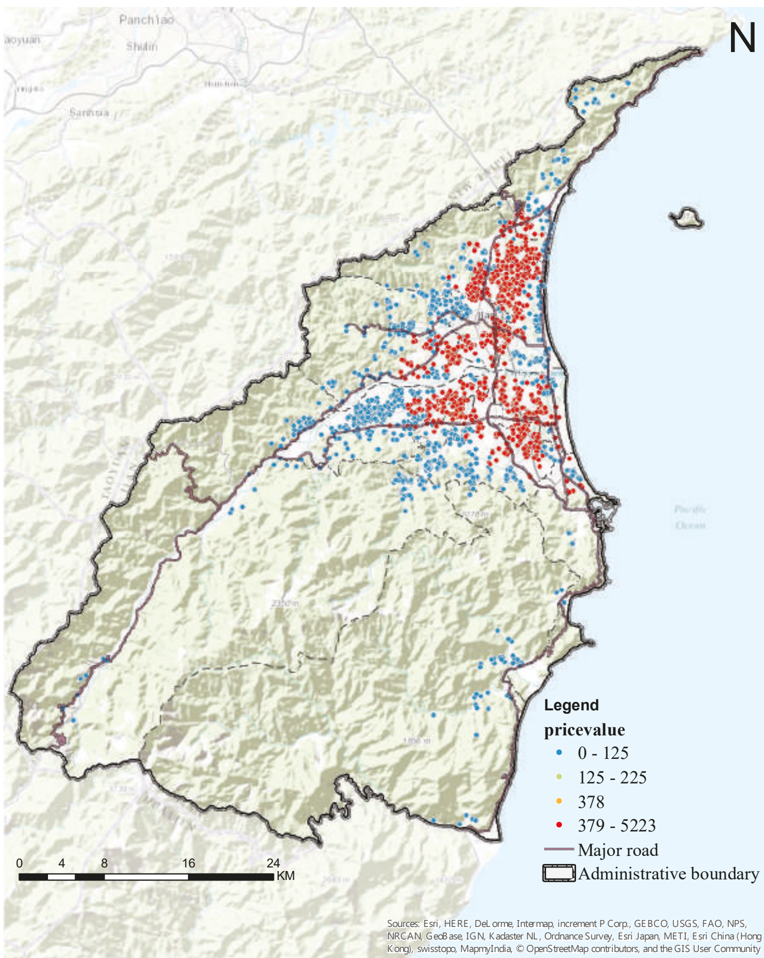
Table 2. Descriptive statistics of variables.

Variable	Mean	SD	Maximum	Minimum
Price_value	306.14	360.11	5223.48	0.19
Avgattr	3.16	1.27	4	0
near_water	258.94	507.44	4921.98	0
Agriprice	2.73	7.22	29.84	−50.34
use_urban	0.08	0.28	1	0
use_regular	0.16	0.37	1	0
use_special	0.68	0.47	1	0
use_mt	0.08	0.27	1	0
near_urban	2047.44	2200.73	38,770.77	0
Width	5.77	3.24	40	1
Landcount	8.74	6.66	75	1
Interestrate	1.37	0.04	1.38	1.12

3.4. Results

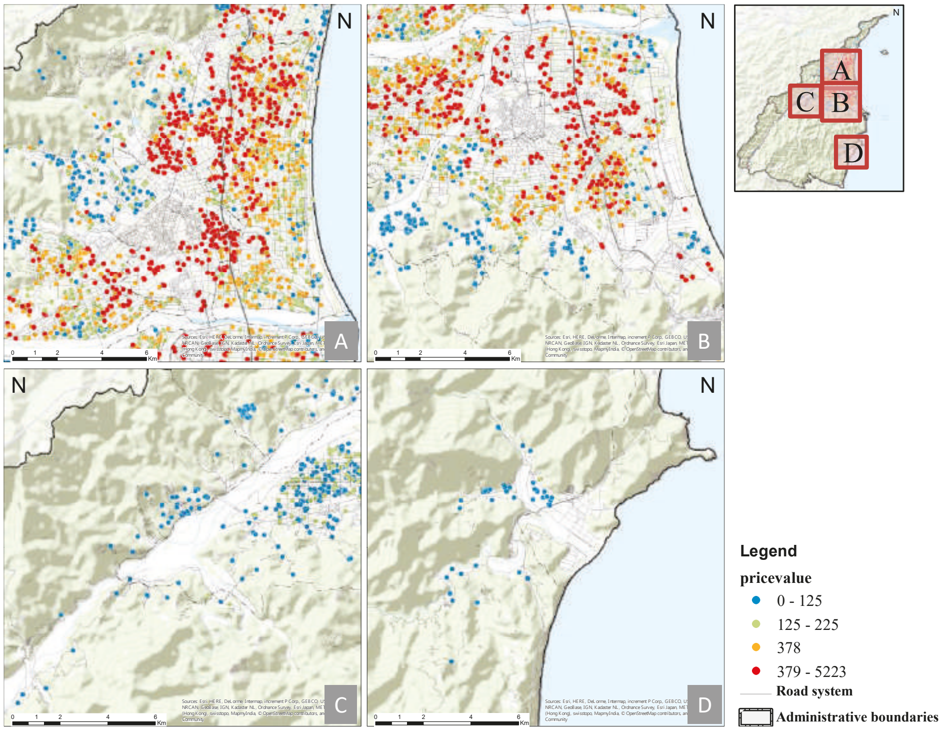
3.4.1. Illustration of Price-Value Distortion in Yilan County

The categories of distortion, from low to high, are shown as blue, green, orange, and red (Figure 5). To facilitate comprehension, quartiles were used to define the bounds of each distortion category. The calculated distortion categories of Yilan County indicate that areas in the plain were the most heavily traded. Among these, areas with a high density of high distortion instances were Yilan City (Figure 5(b),A), Luodong Township (Figure 5(b),B), Zhuangwei Township, Wujie Township, Dongshan Township, and Jiaosi Township. Transactions decreased with distance from the city or towns (as illustrated by the color distribution of the symbols changing from orange to green and then to blue in Figure 5). Figure 5 shows that these areas are east of Yuanshan Township, Sansing Township, Datong Township (Figure 5(b),C), and Nan'ao Township (Figure 5(b),D).



(**a**)

Figure 5. *Cont.*



(b)

Figure 5. Price-value distortion of farmlands in Yilan County. (**a**) Distribution of high and low distortion categories in Yilan County; **(b**) Distribution of distortion categories in specific areas. A and B present the areas with high distortion, in which A instances Yilan City and B is Luodong Township; C and D present the areas with low distortion, in which C instances the eastern of Yuanshan Township, Sansing Township, Datong Township and D is Nanao Township.

3.4.2. Ordinary Least Square (OLS) Regression and Quantile Regression (QR) Analyses for Price-Value Distortion of Farmlands in Yilan County

In addition to visualizing distortion by area with ArcGIS, quantitative analysis was used to examine the factors influencing distortion. In an ordinary least square regression model, the calculated distortion was treated as the dependent variable, and suitability for crop plantation, the distance to the nearest canal, crop price variation, land usage regulation, distance to the nearest urban planning areas, width of the nearest road, the complexity of land counts, and mortgage rates were treated as explanatory (independent) variables. The full regression model can be expressed as:

$$\begin{aligned} \text{price\_value}_i = \\ &\beta_0 + \beta_1\text{avgattr} + \beta_2\text{near\_water} + \beta_3\text{agriprice} + \beta_4\text{use\_urban} + \beta_5\text{use\_special} + \beta_6\text{use\_mt} \\ &+ \beta_7\text{near\_urban} + \beta_8\text{width} + \beta_9\text{landcount} + \beta_{10}\text{interestrate} + \varepsilon_i, \quad i = 1,2,3,\ldots,4641 \end{aligned}$$

The results of the OLS model are shown in Table 3. All factors except for land count complexity significantly affected price distortion.

We also applied quantile regression, an approach initially introduced by Koenker and Bassett [30]. The model is used to examine the dynamic movement in each quantile and its main concept focuses on minimizing an asymmetrically weighted sum of absolute errors [31]. The relationships between dependent and independent variables under various circumstances at each quantile were discussed. In comparison to OLS models, a QR model can process samples with a non-normal distribution. Furthermore, the QR model was used to overcome a sample selection bias and outlier problems that were encountered when running the OLS model [31]. To conduct the QR, five quantiles (θ = 0.1, 0.25, 0.5, 0.75, 0.9) were used in our analysis to evaluate the impact of each factor on different distortion categories. The results (Table 3) show that the nearest distance to the canal, crop price variation, land use regulation, width of the nearest road, and the complexity of land count have positive impacts on distortion. The higher θ, the greater the distortion and when θ is higher, the impact of factors influencing distortion are higher. The confidence intervals calculated from the results of the OLS and QR are shown in Figure 6.

Table 3. OLS (ordinary least square) and QR (quantile regression) results for the price-value distortion of farmland in Yilan County.

Variable	OLS	QR (θ)				
		0.1	**0.25**	**0.5**	**0.75**	**0.9**
constant	430.334 *** (3.02)	10.264 ** (3.11)	119.658 * (1.88)	266.637 *** (3.13)	249.612 (1.29)	1291.145 *** (3.31)
avgattr	2.196 (0.43)	1.807 (1.38)	0.736 (0.46)	4.619 * (1.73)	15.066 *** (3.98)	17.748 (1.47)
near_water	−0.0284 ** (−2.33)	−0.004 (−1.44)	−0.012 *** (−3.50)	−0.018 *** (−4.17)	−0.017 *** (−3.79)	−0.017 * (−1.73)
agriprice	1.779 *** (2.79)	0.125 (0.87)	0.577 *** (2.1)	1.080 *** (3.81)	1.170 *** (2.54)	1.719 (1.45)
use_urban	600.541 *** (29.82)	176.976 *** (4.20)	298.907 *** (18.49)	382.246 *** (12.20)	690.964 *** (9.47)	1335.272 *** (16.13)
use_special	82.934 ** (6.34)	63.083 *** (18.25)	79.733 *** (16.82)	92.831 *** (14.00)	120.048 *** (13.54)	117.442 *** (3.57)
use_mt	−64.989 ** (−2.37)	−23.172 *** (−4.52)	−48.019 *** (−7.48)	−77.340 *** (−7.55)	−84.817 *** (−4.91)	−157.409 *** (−3.33)
near_urban	−0.011 *** (−4.33)	−0.001 (−1.30)	−0.000107 (−0.02)	−0.002 * (−1.56)	−0.005 ** (−2.03)	−0.007 (−1.34)
Width	17.831 *** (12.62)	2.900 *** (3.31)	4.733 *** (6.38)	7.828 *** (6.76)	15.472 *** (7.12)	22.099 *** (5.00)
landcount	1.243 * (1.84)	−0.329 (−1.46)	0.299 (1.15)	1.173 ** (2.39)	3.271 *** (3.51)	2.968 *** (2.84)
interestrate	−235.224 ** (−2.28)	−71.725 ** (−2.44)	−54.222 (−1.18)	−130.992 * (−2.17)	−111.256 (−0.81)	−784.926 *** (−2.81)
Adj./Pseudo R−Squared F statistic VIF	0.283 183.99 *** 1.57	0.1674	0.1664	0.1652	0.1902	0.2658

Note: 1. n = 4641; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. 2. The variance inflation factor (VIF) is used as an indicator of multicollinearity.

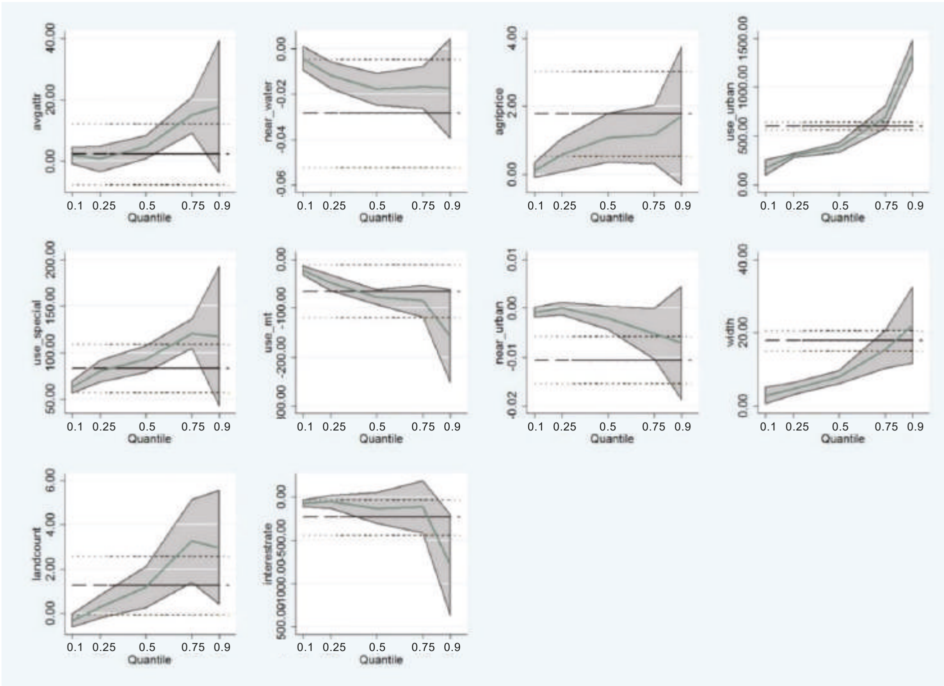


Figure 6. The distribution of OLS (ordinary least square) and QR (quantile regression) 95% confidence interval for each variable. Quantiles range from 0.1 to 0.9 and each quantile gap is 0.1. The shaded area represents the QR 95% confidence interval. The OLS regression line is the solid black line between the upper and lower dotted lines, which show the OLS confidence interval at 0.95.

1. Distance to the main canal

The results suggest that distance to the nearest canal has a significant negative impact on distortion, with $p < 0.01$ in the 0.25, 0.5, and 0.75 quantiles, and $p < 0.1$ in the 0.9 quantile. Our findings suggest that when the farmland is separated by 1 m from the nearest canal, the distortion is reduced by 0.012%, 0.018%, and 0.017%, for the 0.25, 0.5, and 0.75 quantiles, respectively.

2. Crop price variation

Crop price variation has significant impact on distortion with $p < 0.01$ in the 0.25, 0.5, and 0.75 quantiles. Higher crop price variation is associated with greater distortion. The model indicates that when crop price variation increases by 1%, the distortion will increase by 0.577%, 1.080%, and 1.170% for the 0.25, 0.5, and 0.75 quantiles, respectively.

3. Land-use regulation

Land-use regulation has a significant impact on the price distortion with $p < 0.01$ under various quantiles. The price-value distortion is higher when the farmland is located in urban areas. In addition, the higher the quantile, the greater the distortion when farmlands are located in urban regions. The distortion is lower when the farmlands are located on slopes or conservation fields in non-urban zones. Compared to urban areas, distortion decreased at higher quantiles in non-urban zones.

4. Width of the nearest road

Width of the nearest road significantly affects price-value distortion under various quantiles. When the width of the nearest road widens by 1 m, the distortion is increased by 2.900%, 4.733%, 7.828%, 15.472%, and 22.099% for the 0.1, 0.25, 0.5, 0.75, and 0.9 quantiles, respectively. This suggests that the higher the quantile, the greater the impact of road width on distortion.

5. Complexity of land count

The complexity of land count significantly affects farmland distortion with $p < 0.01$ in the 0.5 and 0.9 quantiles. This implies that an increase in the number of farmland transactions in buffer areas causes distortion to increase by 1.173%, 3.271%, and 2.968% in the 0.5, 0.75 and 0.9 quantiles, respectively. If the quantile is less than or equal to 0.75, higher complexity of land count results in a greater distortion. The distortion reached its peak in the 0.75 quantile.

4. Discussion

4.1. Designating an Urban Area Tends to Increase the Price-Value Distortion of Agriculture Zones

Few of Taiwan's urban plans have been designed from the perspective of agricultural development or the multi-functionality of agriculture. These plans often imply that farmlands located in urban areas will eventually be developed for non-agricultural use. Farmlands located in urban areas are targets for speculation (Figure 7). Due to the anticipated capital gain, the prices of these farmlands are increasing, which will hinder development in these areas. It will also increase the price-value distortion ratio. Therefore, designating urban zoning in agricultural zones tends to increase the price-value distortion of farmlands.

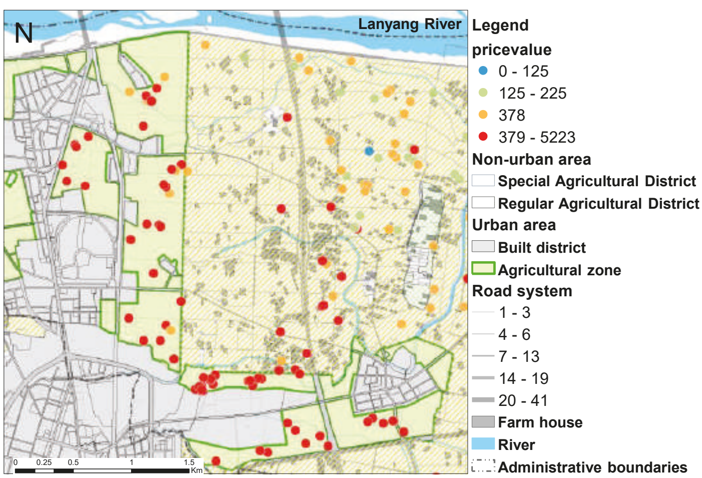


Figure 7. The farmland price-value distortion relative to the urban plan of Wujie Town.

4.2. A Better Road or Transportation System in Agricultural Zones Tends to Increase the Price-Value Distortion

Road or transportation system accessibility is important for agricultural marketing. The width of roads is often regarded as an indicator of transportation conditions. Under the Building Act of Yilan County, the width of the nearest road was set as a minimum requirement for constructing farmhouses. A better road system therefore tends to elevate the price of farmlands. Our model suggests that road condition is highly correlated with price-value distortion, and this is consistent with reality. Figure 8 illustrates clusters of high distortion that correspond to the pattern of road width in Yuanshan Town.

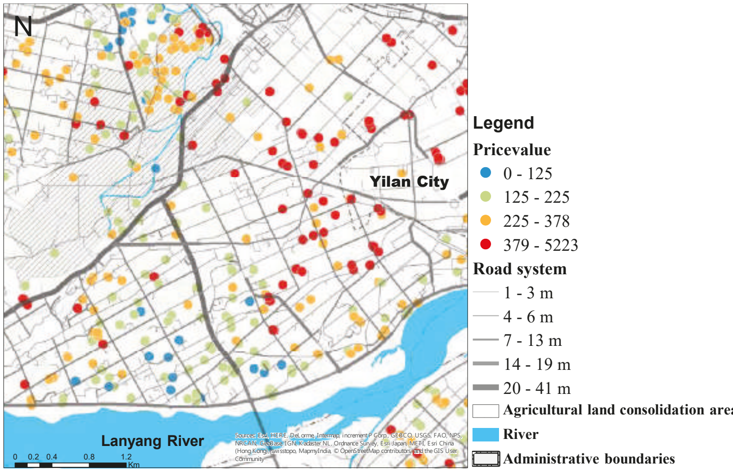


Figure 8. Distribution of price-value distortion in relation to road widths in Yuanshan Town.

4.3. Farmland Reform Policy Significantly Affects Price-Value Distortion

Farmland readjustment is one of the major policy mechanisms for improving the productivity of agriculture. The process aims to produce ordered farmland parcels suitable for mechanization and better irrigation systems. A better agricultural production environment increases land price but enhances the possibility of higher distortion. The regression analysis outcomes suggest that there is an important relationship between distortion and distance between farmlands and irrigation systems in Yilan. Figure 9 shows that in Yuanshan Town, higher distortion occurs in areas with better irrigation systems developed through the farmland readjustment plan. The Agricultural Development Act amendments in force since 2000 shifted the policy goal from "farmland owned by farmers" to "farmland used for agriculture". This policy relaxed the criteria for ownership of farmland, which positively affected farmland price, and this, in turn, elevated the price-value distortion of farmlands. Higher distortion and the appearance of farmhouses on good quality farmland as a result of this agricultural policy have become major challenges for the development of Yilan's agriculture.

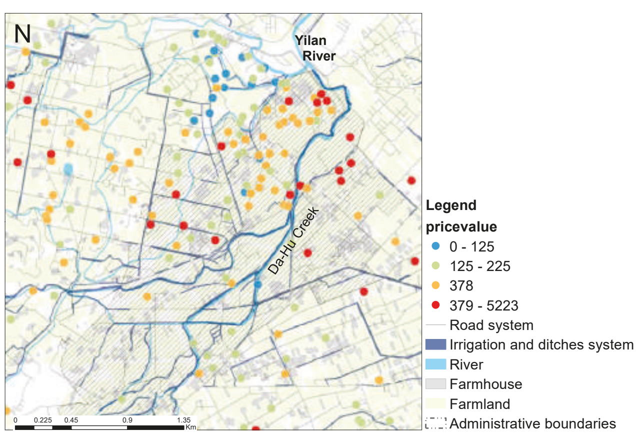


Figure 9. Distribution of price-value distortion relative to irrigation systems in Yuanshan Town.

4.4. Cases of Various Price-Value Distortions and Their Potential Impacts on Agriculture

Cases of high distortion are shown in Figure 10 (A1,A2). Farmlands located in the agricultural zone of an urban area often have higher distortions due to their higher transaction prices and lower production values. This situation suggests a possibility of engendering an expectation for developing farmlands in urban areas. Development would destroy any opportunity of benefiting from the farmlands' ecosystem services in urban areas because development is irreversible. Further, farmlands located in the special agricultural districts in the suburbs but in close proximity to urban areas often have higher transaction prices and production values; here, price-value distortions are moderate (Figure 10 (B1)) and there is serious conflict between farmland development and agricultural production.

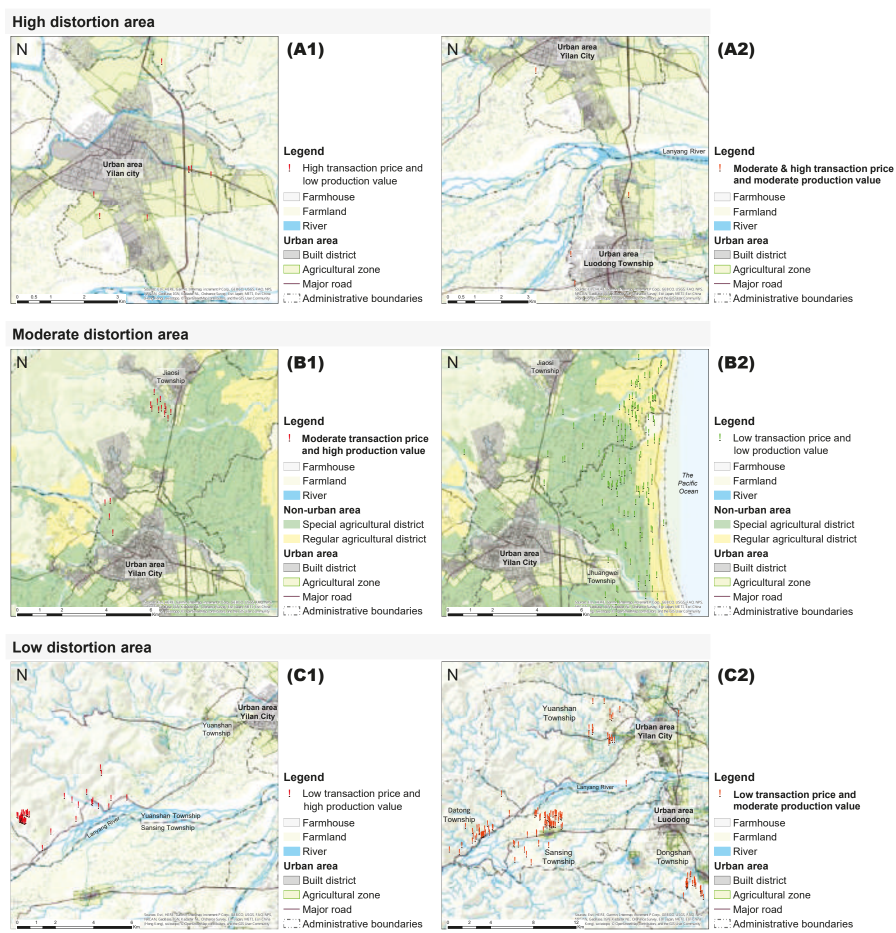


Figure 10. Cases of various price-value distortions. A1 represents the area of high transaction price with low production value; A2 represents the area of moderate and high transaction price with moderate production value; B1 represents the area of moderate transaction price with high production value; B2 represents the area of low transaction price with low production value; C1 represents the area of low transaction price with high production value; C2 represents the area of low transaction price with moderate production value.

Moderate distortions also occur when both the prices and production values of farmlands are low. This occurs in the regular agricultural district of suburbs (Figure 10 (B2)) and leads to a unique and widespread urban sprawl pattern in the rural areas of Yilan. Lower farmland price and higher production value generate low distortions, which occurs in the hilly area of Yilan County (Figure 10 (C1,C2)). Agricultural production in this area does not suffer from serious urbanization impacts. However, agricultural production itself has the potential to affect and pollute the environment through the use of fertilizers and pesticides. Clearly there are different cases of price-value distortion associated with the different farmland situations and characteristics, and these need to be taken into account by agricultural and urban planning departments of local and central governments. Therefore, a systematic approach of land administration is needed to consider the heterogeneity of these cases and inter-disciplinary cooperation from different departments in government is required [32].

5. Conclusions

Our findings indicate that policy reforms have significant impact on the farmland environment of Lanyang Plain and its surrounding regions. Investment in agricultural infrastructure was expected to improve production efficiency and increase production value. However, irrigation and road system improvements increased the price and thus the price-value distortion of farmland, which led to urbanization and impeded agricultural production in the region. The prices of farmland in agricultural zones within urban areas increased substantially due to speculation. This amplified the discrepancy between farmland price and its production value, which in turn increased the price-value ratio or distortion. Price-value distortion can be used as a proxy for the deviation between price and production value of farmlands, and can be mapped onto locations to explore reasons for the distortion and to understand its impact on agricultural development. Allowing non-farming use of farmlands can result in irreversible impacts on agriculture. Therefore, future urban planning has to consider the multi-functionality of farmland, and that the agricultural zone is not just for "reserving land for urban development." Greater consideration of factors such as the multi-functionality of agriculture may provide a healthier balance between economic benefits and environment sustainability, as well as a finer balance between farmland price and value (Figure 11). Moreover, location assessment of farmland readjustment and agricultural investment policy should work with payment policy for the ecosystem services of farmland to decrease the distortion.

Land Administration Systems (LAS) can facilitate the sustainable development of farmland. LAS focuses land on systematic relations among various factors, ecosystem services and interaction between local and central governments [32]. The complex adaptive system can provide insights when deconstructing the complex agricultural landscape system in peri-urban area based on physical flaws and influence [33]. Additionally, Land Value Tax for non-agricultural use, real estate boom and recession may influence farmland price and distortion. It will be inspiring to employ these approaches to explore the spatial pattern of distortion ratio based on adequate and available transaction data in the future. Multifunctional use of farmland is absent from this study, but could be taken into account in future research.

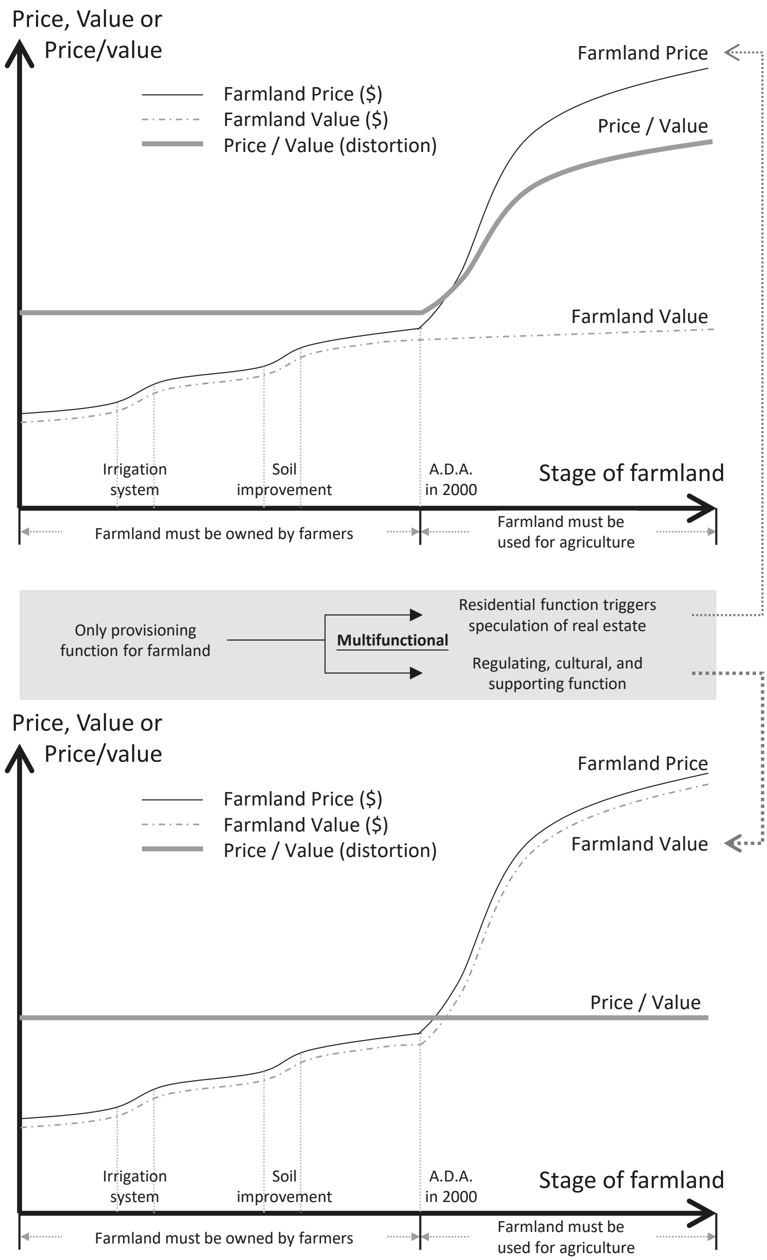


Figure 11. Enhancing farmland value from an ecosystem service perspective to manage farmland price-value distortion.

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Evaluating Social Performance of Construction Projects: An Empirical Study

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Abstract: The concept of sustainable development is gaining increasing popularity in construction industry. Previous studies have prioritized on the sustainable performance of construction projects from perspectives of economy and environment, social performance of construction projects has not drawn much attention. Social performance of construction projects refers to the extent which the projects meet the needs of current and future generations. Therefore, social performance of construction projects is critical for project success as well as social sustainability. However, a systematic framework for evaluating social performance of construction projects is absent. At the same time, existing methods are time-consuming and subject to certain degree of subjectivity. To overcome these limitations, the fuzzy analytical hierarchy process (FAHP) method is introduced in this paper to evaluate social performance of construction projects. A real-world hospital redevelopment project was employed as an empirical study to develop the systematic framework for social performance evaluation using FAHP method. By analyzing previous studies and the hospital redevelopment project, a systematic framework with 18 indicators of five dimensions (i.e., socio-economy development, socio-environment development, social flexibility, public service development, and environment and resource conservation) was developed. Social performance of two proposed schemes for hospital redevelopment project were evaluated using the FAHP approach. Results show Scheme 2 has a relative higher social performance sore than that of Scheme 1 and the hospital redevelopment project would improve socio-economy development, socio-environment development, social flexibility, and public service development, while it brings challenges to environment and resource conservation. More seriously, results indicate the hospital project may threaten healthcare and disease prevention of the local communities. Therefore, more measures should be taken to improve social performance of the hospital redevelopment project. The empirical study shows the proposed framework using FAHP method is viable for conducting social performance evaluation of construction projects, which could be helpful to improve social performance, reduce negative social impacts, and contribute to the social sustainability of construction projects.

Keywords: social performance; social performance evaluation; fuzzy analytical hierarchy process; empirical study

1. Introduction

It has been recognized that construction industry plays significant roles for the sustainable development [1,2]. Activities within lifecycle of construction projects have inherent impacts (i.e., economic impacts, environmental impacts, and social impacts) to the society [3]. Compared to economic and environmental impacts, social impacts associated with construction projects, are the least explicit in the "triple bottom line" principle of sustainable development [4,5]. Social impacts of construction projects refer to certain social consequences to human populations of construction projects that change the ways in which people live, work, play, relate to one another, organize to meet their needs, and generally cope as members of society [5,6]. The development of construction projects may lead to both positive and negative social impacts, e.g., land acquisition and disposal, resettlement of nearby residents, and resource depletion [7,8]. Under certain conditions, social impacts could evolve into social risks and even lead to social conflicts between different stakeholders if they are not dealt with carefully and properly [9]. To mitigate negative social impacts, social impact assessment (SIA) has widely been used within lifecycle of construction projects [10,11]. International Association for Impact Assessment (IAIA) defines social impact assessment (SIA) as processes of analyzing, monitoring and managing the intended and unintended social consequences, both positive and negative, of planned interventions (policies, programs, plans, and projects) and any social change processes invoked by these interventions [12]. Instead of addressing social performance of the project, the primary goal of SIA is to ensure the sustainability and equity of biophysical and human environment [13,14].

Social performance refers to an organization's response to anticipated or existing social demands [15,16]. As a project-oriented industry, the major goal of construction firms/organizations is to provide the society with varieties of construction projects, social performance of construction projects could be aggregated to the construction firms/organizations level and the industry level [17]. Therefore, social performance of construction projects is crucial for the social sustainability, which is to meet the demands of current and future populations and communities [14,18], and improving social performance has been a major concern by all stakeholders [5,19]. Previous studies have measured economic and environmental performance of construction projects, while social performance, as a critical and indispensable dimension for project success and sustainable development [20,21], has not been well studied [21–23]. It is vital to study the social performance of construction projects and evaluate social performance of construction projects, which would not only help the decision makers to make decisions when proposing a construction project but also enable the project managers to audit a project and determine what kind of future improvements could be made [24].

Social performance evaluation of construction projects could be defined as improving social performance by providing information about achievement of social aspects, it allows decision makers to determine its ongoing performance in meeting social criteria, which helps reduce social impacts, prevent social risks, improve the overall performance of the project, and finally contribute to social sustainability [15,25]. While various studies have discussed the SIA of construction projects [7,8,26], social performance evaluation of construction projects are rarely studied. Yuan [20] studied the social performance of construction waste management, which emphasized the management process of construction waste and the introduced research approach could not be transferred to evaluate social performance of construction projects. A previous study conducted by Shen, et al. [2] presented a checklist for evaluating sustainability performance, indicators reflecting social sustainability performance of construction projects were listed as reference for conducting further evaluation. Prior studies indicate that the research gap exists in social performance evaluation of construction projects.

This research developed a systematic framework for social performance evaluation of construction projects. A hospital redevelopment project was introduced as the empirical study. In addition, this study could also help to understand social performance of construction projects. The remainder of this article is as follows: Section 2 illustrates research background and the literature review. Detailed processes of FAHP-based method to evaluate social performance of construction projects are described in Section 3. A systematic framework for social evaluation is developed in Section 4 by analyzing prior studies and the introduced hospital redevelopment project. An empirical study of social performance of two proposed schemes for the hospital redevelopment project are evaluated using the developed approach, which is presented in Section 5. Results of the empirical study are discussed in Section 6. Finally, research findings and limitations are stated.

2. Research Background and Literature Review

2.1. Social Performance of Construction Projects

Social performance of construction projects reflects the extent to which the lifecycle of construction projects meets the demands of anticipated or existing social demands. Therefore, social performance of construction projects could be obtained by analyzing social impacts of construction projects and the requirements for social sustainability by diverse stakeholders. Shen, et al. [2] explored the indicators for social sustainability performance evaluation of different stages. Valdes-Vasquez, et al. [14] identified 50 processes for social sustainability consideration during planning and design phase of construction projects, and these processes were categorized into six categories, namely stakeholder engagement, user considerations, team formation, management considerations, impact assessment, and place context. Zuo, et al. [27] interviewed domain experts and 26 criteria of social sustainability were identified, which were further discussed from three dimensions, i.e., macro level, external stakeholders, and internal stakeholders. Tilt, et al. [7] applied SIA to explore social impacts in a large dam project. These impacts are identified as migration and resettlement of people near the dam sites, changes in the rural economy and employment structure, effects on infrastructure and housing, impacts on non-material or cultural aspects of life, and impacts on community health and gender relations. Almahmoud, et al. [28] studied social core functions (SCFs) of a construction project from perspectives of diverse stakeholders. Capital performance, health and physical comfort, accessibility, integration, usability psychological comfort, and operation health and safety were identified as SCFs of a construction project. Li, et al. [8] studied social impacts of an affordable housing project and indicators reflecting social impacts were discussed from three aspects as socio-economic effects, adaptabilities, and social risks. Wang, et al. [5], Shi, et al. [9], Liu, et al. [19], and Liu, et al. [29] also addressed the social risks of the construction projects. They suggested that the projects should not only be compliant with the regulations but also meet the requirements of diverse stakeholders, especially the end-users, which will improve project social flexibility and thereby contribute to project social sustainability.

2.2. Performance Management and Evaluation

Performance management, which is defined as a closed loop control system that deploys policy and strategy, and obtains feedback from various levels to manage the performance of the system [30], has been widely adopted by a wide range of industries [31,32]. Performance management could help the project managers to continuously improve its project management practices [33]. Construction industry is no exception to the gaining popularity of performance management. Several construction firms have adopted performance management to enhance the performance of construction industry at different levels, e.g., organization level, stakeholders level, and project level [31,32]. As a project-oriented industry, the performance of construction projects is crucial to project success as well as the satisfaction of the organization and diverse stakeholders [34]. However, there are diverse goals of construction projects; accordingly, construction projects performance management should also cover a wide range of themes, e.g., quality, cost, time, safety and health, environment, and client satisfaction [34–37]. Traditionally, the management of construction performance relied on three indicators (i.e., cost, time, and quality), which are lagging and fails to provide a holistic view [24]. Construction projects, e.g., infrastructure projects, are complex engineering systems, which require tremendous investment and would have profound and long-time impacts on the economy, environment, and society [38]. As opined by Atkinson [39], apart from "The Iron Triangle", more success criteria should be accepted in project management. There are increasing studies investigating on the social aspects of construction projects from diverse perspectives including safety and health [34,40], social impacts, social risks, social conflicts [7,9,19,34], etc. Social performance has been perceived as critical aspects for sustainable development and project success.

Performance evaluation is the process of determining the efficiency and/or effectiveness of past action, which has been widely adopted to measure the performance of construction projects [34].

Several frameworks were proposed to help the evaluation of construction projects performance. Among the proposed performance evaluation frameworks, three are the most prevalent in construction industry: European Foundation for Quality Management (EFQM) Excellence Model, Balanced Scorecard (BSC), and Key performance indicators (KPIs) model [32]. EFQM Excellence Model is a quality-based framework [31], which is frequently and more appropriately applied at the organizational level [32,41]. BSC framework consists of a range of "leading and lagging" indicators and the scorecard is divided into four perspectives, namely financial, custom, internal business, and innovation learning [31,34]. Different perspectives interact under certain principles [31]. Even though the BSC is more prevalent in performance management at project-level, four perspectives are far from enough to cover the performance of construction projects, and more perspectives should be supplemented to measure the performance of construction projects. KPI framework, which adopts the method of benchmarking, selects time, cost, quality, client satisfaction, change orders, business performance, and health and safety as the seven key performance indicators to measure the performance of construction projects. In practice, KPI framework is more flexible, indicators of different aspects could be clustered to measure certain aspects of project performance, which makes it widely adopted in construction projects performance measurement, and various studies have been conducted to measure the overall or partial performance of construction projects [34,42]. Based on KPI framework, several tools have been developed to help the evaluation of construction projects social performance such as SIA tool [12], checklist method [2], success factors identification, social network analysis [28], etc. However, current calculation methods for social performance management based on KPI framework are subjected to certain degree of objective [32]. Alternative approaches should be devised to reduce this limitation.

To sum up, performance management has been employed to help project managers continuously improve project outcomes, social performance as one of the key aspects for projects success and sustainability is gaining increasing interests by research scholars and practitioners. Unfortunately, social performance of construction projects has not been systematically studied. In addition, among three most prevalent performance measurement frameworks for performance management in construction industry, KPI framework based on benchmarking method is the most appreciated for developing tools to evaluate construction project social performance. However, since indicators for social performance are intangible, KPI–based approach is time-consuming in identifying indicators and relatively subjective. Therefore, considerations should be given to mitigate the subjectivity of these tools.

3. The FAHP-Based Method for Social Performance Evaluation

To improve the efficiency and reduce the degree of subjectivity, the fuzzy analytical hierarchy process (FAHP) was adopted in this study to develop the approach for the evaluation of construction projects social performance. The method of FAHP is developed from AHP method, which was first established by Saaty [43] in 1981. The AHP method has been widely used by scholars in many fields, including performance measurement [32]. However, the application of AHP method is yield to the degree of uncertainty and subjectivity. Zeng, et al. [44] pointed that experts may find it hard to select a single number in the comparison process. Instead of a definite value, it would be proper to give a range values for comparison, e.g., 2 to 5. To avoid the deficiency, FAHP approach proposed by Zeng, et al. [44] was employed in this research to conduct social performance evaluation. The FAHP approach consists of the following six successive steps.

Step 1: Identification of attributes

In the first step, the FAHP is adopted to identify the common attributes of the given problem. A comprehensive and accurate identification of these attributes is fundamental for the evaluation approach, as the study relies heavily on these attributes while the misconception of these attributes results in a failure of the research model. Similarly, as depicted by Bititci, et al. [30], performance measurement is usually determined by the metric of a number of indicators, and thereby the fundamental step would be the identification of indicators that could be employed to evaluate social performance of construction projects.

Step 2: Pairwise comparisons under fuzzy environment

Once the attributes related to the problem were clearly identified, a pairwise comparison among the common attributes has to be made: one over and another under the fuzzy environment. To set up this fuzzy pairwise comparison, experts are invited to complete a comparative questionnaire. Answers from experts are used to compare each attribute and convert the linguistic comparison into the fuzzy pairwise relation matrix.

$$\widetilde{A} = \begin{bmatrix} 1 & \widetilde{r_{12}} & \widetilde{r_{13}} & \cdots & \widetilde{r_{1n}} \\ \widetilde{r_{21}} & 1 & \widetilde{r_{23}} & \cdots & \widetilde{r_{2n}} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \widetilde{r_{n1}} & \widetilde{r_{n2}} & \cdots & \cdots & 1 \end{bmatrix} \tag{1}$$

Step 3: Defuzzification

The pairwise comparison was composed of fuzzy numbers in Step 2, and then these triangular fuzzy numbers are transformed into crisp numbers. The conversation process is called defuzzification process. For various types of defuzzification methods are buried in the literatures, this study utilizes the centroid method of defuzzification for its wide acceptance [45]. The linguistic variables described by fuzzy numbers are denoted by membership functions [45], which are presented in Table 1 and Figure 1, separately.

Table 1. Scale for relative importance used in the pairwise comparison matrix.

Intensity of Importance	Fuzzy Number	Linguistic Variables	Triangular Fuzzy Numbers (TFNs)	Reciprocal of TFNs
1	$\widetilde{1}$	Equally important	(1,1,3)	(1/3,1,1)
3	$\widetilde{3}$	Weakly important	(1,3,5)	(1/5,1/3,1)
5	$\widetilde{5}$	Important	(3,5,7)	(1/7,1/5,1/3)
7	$\widetilde{7}$	Strongly important	(5,7,9)	(1/9,1/7,1/5)
9	$\widetilde{9}$	Extremely important	(7,9,11)	(1/11,1/9,1/7)

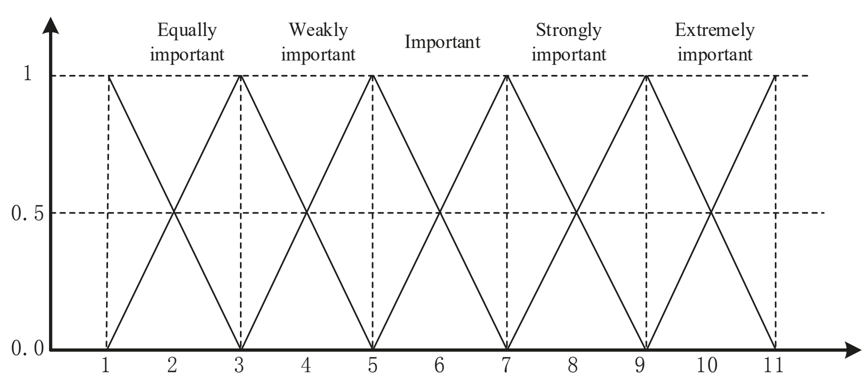

Figure 1. Fuzzy membership function for linguistic expressions for criteria.

Step 4: Estimation of global weights

The defuzzified pairwise comparison gained from the previous steps is processed through various standard arithmetic operations of formal AHP to seek the global weights of each attribute (W). The calculations processes standardize the defuzzified pairwise comparison matrix (all values in the matrix should be kept between 0 and 1) and calculate the eigenvalue (x) with the help of the sum of standardized rows, where the eigenvalue is the global weight of each attribute (W) [46].

Step 5: Consistency check

The collected data based on the experts' judgements are subject to a certain degree of subjectivity, which naturally has errors. Therefore, the consistency of these attributes of the criteria and the relevant steps should be checked. The consistency index (CI) introduced for a pairwise comparison matrix is listed below:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

where λ_{max} is the largest eigenvalue of the comparison matrix; and n is the dimension of the matrix or the number of decision criteria under consideration.

The consistency ratio (CR) is given as:

$$CR = \frac{CI}{RI(n)} \quad (3)$$

where $RI(n)$ is a random index relying on the size of matrix. The random index values of random matrices introduced are listed in Table 2. If the consistency ratio (CR) is equal to or less than 0.1, the result is acceptable. However, if the value is greater than 0.1, the decision makers have to remake pairwise comparisons to achieve consistency in their responses.

Table 2. Random index values.

N	1	2	3	4	5	6	7	8	9	10
RI(n)	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

Step 6: Establishment of assessment sets and fuzzy comprehensive assessment of multiple indices

Fuzzy comprehensive assessment method can be used to quantify the fuzzy indices or define the membership degree via building hierarchical fuzzy subsets, which is based on the fuzzy transformation to synthesize each index.

To quantify different attributes of each assessment index, the semantic scales of subjective assessments are used to establish assessment classes, namely, $V = (v_1, v_2, \cdots, v_n)$. Then, according to experts' responses, the score assessment matrix of the entire index system (R) can be acquired, which is denoted as follows:

$$R = (r_{ij})_{m \times n} = \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1n} \\ r_{21} & r_{22} & \ldots & r_{2n} \\ . & . & . & . \\ r_{m1} & r_{m2} & \ldots & r_{mn} \end{bmatrix} \quad (4)$$

where n is the number of the decision schemes; m is the number of indicators of index system; $R_i = (r_{i1}, r_{i2}, r_{i3}, \cdots, r_{im})$, $(i = 1, 2, 3, \cdots, m)$ is the single index fuzzy assessment class of index i; and r_{ij} is the membership degree.

The assessment score matrix (R) and the global weight of each attribute (W) obtained from Steps 4 and 5 are multiplied to get fuzzy evaluation results of the index system. The result of fuzzy comprehensive assessment of multiple indices is as follows:

$$Z = W \cdot R = \{Z_1, Z_2, \ldots, Z_n\} = \{w_1, w_2, \ldots, w_m\} \cdot \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1n} \\ r_{21} & r_{22} & \ldots & r_{2n} \\ . & . & . & . \\ r_{m1} & r_{m2} & \ldots & r_{mn} \end{bmatrix} \tag{5}$$

where Z_i is the final score of the ith plan after fuzzy comprehensive assessment. The decision scheme with the largest Z_i is the optimal plan.

4. Framework for Social Performance Evaluation of Hospital Redevelopment Project

To develop a systematic framework to evaluate social performance of construction projects, prior studies on social impacts associated with construction projects and requirements for social sustainability indicators for social performance evaluation are beneficial. Besides, to help the understandings of the proposed indicators, a hospital redevelopment project named "South New-Town hospital (Nan Bu Xin Cheng (NBXC) hospital in Chinese)", which locates in the southern part of Nanjing, the capital city of Jiangsu province, China, was introduced in this research as a complement to understand the social performance. The real-world project also helped to conduct the empirical study of the proposed FAHP-based evaluation approach. Social performance of two schemes proposed for the hospital redevelopment project were presented and evaluated using the proposed approach. Figure 2 presents the location and sketch of NBXC hospital projects.

Figure 2. Location and sketch of NBXC hospital project.

4.1. Social Impacts of the Hospital Redevelopment Project

Before NBXC hospital project was developed, a community hospital, which only had basic equipment and provided only outpatient service to the nearby residents, had run for years. However, the rapid urbanization accompanied with fast increase in aging population have led to great challenges to the capacity and service of hospitals [47]. As the community hospital could only provide basic medical service, it could no longer satisfy the demands of the nearby communities due to its outdated equipment and capacity. As shown in the left part of Figure 2, a military airport and several residential communities are around the former hospital. Therefore, this area was quite noisy due to the takeoff and landing of aircraft. In addition, the development of transportation system as well as the local economy were highly restricted by the military zone.

In 2010, the local government decided to redevelop the hospital and two schemes were proposed. The first scheme (Scheme 1) was to redevelop the hospital without demolishing it and just replace the outdated equipment with the latest one. This scheme would not change the land use of nearby area and thereby make little disturbance to the nearby communities. Accordingly, it would require little investment and improve the capacity of the hospital, which is seriously concerned by the local government when the populations are gradually increasing with the rapid urbanization of Nanjing. The second scheme (Scheme 2) suggested building the NBXC hospital project. The former building for the community hospital would be demolished in Scheme 2 to build the NBXC hospital project. Medical experts and advanced medical equipment would be introduced in the new hospital. Finally, Scheme 2 was selected and NBXC hospital project started from January 2012 and would begin operation in June 2018. Table 3 briefly compares the parameters of Schemes 1 and 2.

Table 3. A brief comparison of Schemes 1 and 2.

Parameter	Scheme 1	Scheme 2
Investment	Less than 1 million CNY	3.5 billion CNY
Capacity	No bed available	1500-bed
Service	Outpatient service only	Outpatient and inpatient service
Floor area	Less than 1000 square meter	Over 300,000 square meter
Other function	No other function	Research and development
Nearby facilities	Military airport	Subway station, business centers
Service area	Local community	National

To build NBXC hospital, the government negotiated with the military sector and changed the land use; the airport was relocated to another area of the city. The affected residents were resettled and compensations were also paid. As presented in Figure 2 and Table 3, the government invested 3.5 billion CNY on this project with an ambitious plan to improve the nearby circumstance. Finally, NBXC hospital covers an area of over six acres, which consists of several buildings providing inpatient, outpatient, and emergency healthcare services; buildings for research purpose; etc. The main building is a nineteen-story building with two stories underground, and a total floorage of >300,000 m^2, which could provide 1500-bed capacity for the public. One subway line and several municipal roads were built to make it easier for the public to get to the hospital. In addition, the newly built NBXC hospital was equipped with the latest technologies, and special considerations were also given to the medical waste management to avoid polluting the local environment. As declared by the government, NBXC hospital ranks among the first tier nationwide according to the Chinese medical ranking system. The operation of NBXC hospital would greatly help to enhance healthcare service of this area and satisfy the demands of the local residents for high quality healthcare service. In addition, with the advanced technologies and most famous experts, NBXC is also attractive for patients of all the country, which would drive the development of local economy.

4.2. Framework for Social Performance Evaluation of Hospital Redevelopment Project

Based on the extensive literature review and the case of the major hospital projects, 18 indicators were proposed for the social performance evaluation of the hospital redevelopment project and these indicators could be categorized into five dimensions (i.e., socio-economy development, socio-environment development, social flexibility, public service development, and environment and resource conservation). Eighteen indicators within five dimensions are presented in Table 4.

The first dimension shows that the development of the hospital redevelopment project may enhance the socio-economy. As stated by Shen, et al. [2], the development of construction projects would provide local employment opportunities and regional economic development. The development of a certain type of construction project, e.g., the hospital project, could change the industrial structure of the local economy. In addition, the development of construction projects may change the land use [48]. In this case, to develop the hospital project, the local government changed the land use by relocating the military airport and resettling some nearby residents.

The second dimension indicates that the hospital redevelopment project would change the socio-environment. The development of construction projects would help to deliver more infrastructure and enhance the service to the public [49]. Therefore, it would improve their living standard and the level of social security. As described in the case, the development of the NBXC hospital project changed the situation that people living near the military airport had to endure the noisy warplanes. Instead, people could receive high level of healthcare service. Major projects such as hospitals would be landmarks of the city and improve the regional reputation.

The third dimension indicates that the social performance of construction projects would be influenced by social flexibility of the construction projects, which is the adaptabilities of projects to the society (e.g., government, investor, end-users, etc.). The development of construction projects is to satisfy the appeals of diverse stakeholders within the lifecycle of projects [26] and meet the compliance with the policies (e.g., safety and health regulations). Specifically, the hospital project should give special considerations for the patients.

The fourth dimension is the public service offered by the hospital redevelopment project. Different types of construction projects may enhance specific public services by the development of specific infrastructure. For example, the development of transportation infrastructure would provide a faster, more convenient and economical means of transportation method for the citizens [50]. In the hospital project, NBXC hospital would improve the regional capacity of healthcare and disease prevention, promote the advancement of medical technologies and education, and enhance the ability of response to emergency healthcare service.

The last dimension is the influences of the hospital redevelopment project on environment and resource conservation. Most construction projects have great impacts on the landscape of the city. In most cases, the newly built projects are national, regional, or local landmarks. Therefore, it would help to prompt the image of cities. Construction activities and operation of the infrastructure would consume nature resource and generate waste, which may contaminate the environment [20]. In hospital projects, medical waste and disposals generated in the operation stage may spread viruses and threat the health of the public, which should be carefully dealt with [51].

Table 4. Framework for social performance evaluation of hospital redevelopment projects.

Target Layer	Dimensions	Indicators	Source
Indicators for social performance evaluation of the hospital redevelopment projects A	Socio-economy development B_1	C_{11} Employment rate	[2,50]
		C_{12} Regional economic development	[14,27,50]
		C_{13} Industrial structure	[2,50]
		C_{14} Land use	[7,48]
	Socio-environment development B_2	C_{21} Resident's living standard	[8,27]
		C_{22} Infrastructure and public service	[50]
		C_{23} Social security	[2]
		C_{24} Regional reputation	[9,19]
	Social flexibility B_3	C_{31} Stakeholders satisfaction	[5,50]
		C_{32} Compliance with policies	[40]
		C_{33} Patients satisfaction	Cases
	Public service development B_4	C_{41} Healthcare and disease prevention	Cases
		C_{42} Development of medical technologies and education	Cases
		C_{43} Emergency healthcare service ability	Cases
	Environment and resource conservation B_5	C_{51} Landscape of the city	[48]
		C_{52} Wastage management	[2,20]
		C_{53} Resource depletion	[2,21,27]
		C_{54} Environmental protection	[14,27,52]

5. An Empirical Study

To help evaluate the social performance of hospital projects, ten domain experts were investigated separately to contribute their expertise in this research. The criteria for the selection of experts are working experience and background. These experts should have over ten years of working experience in their working fields, which ensures that the investigated experts have a good knowledge of social impacts associated with the project. The expert team consisted of three from different department of local government, who are responsible for the development of this area; three from research institutions, who are familiar with construction project management and social sustainability; two from the contractor of NBXC hospital projects; and two representatives (i.e., one doctor and one nurse) of the NBXC hospital staff. These experts were visited individually and face-to-face investigations were conducted at their office to ensure the independence of this research. Research background and research approach were introduced to these experts to help them get a quick and comprehensive understandings about the project and this research, which would further ensure the quality of this research. After the introduction, the experts were first required to give remarks on the weight of social performance indicators based on their expertise.

Fuzzy numbers given by the experts determined relative importance of one index over the other, which further helped to build a fuzzy judgment vector. The judgment vectors help to form portions of the fuzzy pairwise comparison matrix, which is then adopted to determine the weight of each criterion. The result of consistency check indicates the objectiveness of the weight of each criterion. Meanwhile, the total sequencing weight sets of social performance assessment index system (W) is built, as shown in Table 5.

To quantify the magnitude of hospital redevelopment project affecting each social performance indicator, the semantic scales of each subjective assessment index was quantified and the assessment class $V = (v_1, v_2, \cdots, v_n)$ was further classified into fivescales (i.e., high, relatively higher, average, relatively lower, and low), as shown in Table 6. As suggested by Table 6, the standard values of social performance evaluation should be over 0.6, which indicates that the construction projects are contributory to the social sustainability.

Table 5. The weight for each indicator in social performance evaluation system.

A	B_1	B_2	B_3	B_4	B_5	Weight
	0.442	**0.252**	**0.063**	**0.129**	**0.114**	
C_{11}	0.182					0.080
C_{12}	0.512					0.226
C_{13}	0.084					0.037
C_{14}	0.223					0.099
C_{21}		0.533				0.134
C_{22}		0.237				0.060
C_{23}		0.140				0.035
C_{24}		0.098				0.025
C_{31}			0.406			0.026
C_{32}			0.322			0.020
C_{33}			0.271			0.017
C_{41}				0.209		0.027
C_{42}				0.391		0.050
C_{43}				0.401		0.052
C_{51}					0.134	0.015
C_{52}					0.383	0.044
C_{53}					0.197	0.022
C_{54}					0.286	0.033

Table 6. Weighted and standard values of the magnitude of construction redevelopment project.

Influential Degree	High	Relatively High	Average	Relatively Low	Low
Weighted Values	1.0	0.8	0.5	0.2	0
Standard Values	0.900~1.0	0.6~0.899	0.4~0.599	0.2~0.399	0~0.2

Notes: (1) Influential degree of social performance can vary according to the need of actual classifications, which is generally divided into five scales; and (2) weighted values and standard values are all determined according to experiences.

To provide a comprehensive view about social performance of the hospital redevelopment project, a comparative analysis of Schemes 1 and 2 is presented in this paper. Ten invited experts were asked to score the social performance indices of Schemes 1 and 2 based on Table 4. The mean values of these indicators in both scheme were calculated and the membership degree of 18 two-level indices was obtained, as shown in Table 7.

Table 7. Membership degree of social performance evaluation of both scheme.

Indicator	Membership Degree		Indicator	Membership Degree	
	Scheme 2	Scheme 1		Scheme 2	Scheme 1
C_{11}	0.911	0.256	C_{32}	0.867	0.156
C_{12}	0.722	0.244	C_{33}	0.756	0.111
C_{13}	0.600	0.156	C_{41}	0.433	0.533
C_{14}	0.533	0.300	C_{42}	0.778	0.211
C_{21}	0.756	0.211	C_{43}	0.633	0.278
C_{22}	0.689	0.244	C_{51}	0.467	0.300
C_{23}	0.533	0.244	C_{52}	0.622	0.722
C_{24}	0.567	0.089	C_{53}	0.466	0.567
C_{31}	0.911	0.022	C_{54}	0.700	0.811

The synthetized evaluation matrix (R) of both scheme could be developed according to Table 7. By taking the advantage of Table 3, total sequencing weight sets of social performance (W) can be obtained. Therefore, social performance of each scheme could be obtained as below.

$$Z = W \cdot R = \begin{bmatrix} 0.080 \\ 0.226 \\ 0.037 \\ 0.099 \\ 0.134 \\ 0.060 \\ 0.035 \\ 0.025 \\ 0.026 \\ 0.020 \\ 0.017 \\ 0.027 \\ 0.050 \\ 0.052 \\ 0.015 \\ 0.044 \\ 0.022 \\ 0.033 \end{bmatrix}^T \cdot \begin{bmatrix} 0.911 & 0.256 \\ 0.722 & 0.244 \\ 0.600 & 0.156 \\ 0.533 & 0.300 \\ 0.756 & 0.211 \\ 0.689 & 0.244 \\ 0.533 & 0.244 \\ 0.567 & 0.089 \\ 0.911 & 0.022 \\ 0.867 & 0.156 \\ 0.756 & 0.111 \\ 0.433 & 0.533 \\ 0.778 & 0.211 \\ 0.633 & 0.278 \\ 0.467 & 0.300 \\ 0.622 & 0.722 \\ 0.466 & 0.567 \\ 0.700 & 0.811 \end{bmatrix} = [0.692,\ 0.285]$$

The social performance of Schemes 2 and 1 are 0.692 and 0.285, respectively, which shows social performance of the hospital redevelopment project of Scheme 2 is much higher than that of Scheme 1. In addition, the result of Scheme 2 (0.692) is relatively high according to membership degree given by Table 6. It also suggests that the construction of NBXC project (Scheme 2) is a successful project from the perspective of social aspect and would contribute to the social sustainability of the society.

6. Discussion

This research proposed 18 indicators for social performance evaluation of the hospital redevelopment project from five dimensions. Ten experts were asked to contribute their expertise to evaluate the social performance of two proposed schemes based on FAHP method. The result of comparative analysis shows the development of NBXC hospital project has a relative high social performance and it would contribute to project success and social sustainability. A modified K-chart was employed to help the discussion of research results. In Figure 3, the shaded rectangle shows the indicators are positively associated with development of NBXC hospital project, where social performance of Scheme 2 is higher than that of Scheme 1, while the white rectangle indicates the negative relationship between indicators and development of NBXC hospital project, where social performance of Scheme 1 is higher than Scheme 2.

As shown in Figure 3, social performance of NBXC hospital project is positively reflected by socio-economy development, socio-environment development and social flexibility, as well as the development of public service. The increase of employment rate (C_{11}) and satisfaction of stakeholders (C_{31}) rank at the top among all indicators. The development of NBXC hospital helps to deliver more infrastructure (i.e., hospital, transportation infrastructure, etc.) and enhance the public service (C_{22}) which would create more job opportunities and meet the demands of diverse stakeholders, for example, the patients (C_{33}) as end-users are also satisfied by the development of NBXC hospital projects. To develop this project, the military airport and nearby resident communities were relocated. Local government made a sound plan for the land use (C_{13}), e.g., business center and subway station were built nearby NBXC hospital, which helps to increase the value of the nearby land and redevelopment the landscape of the city (C_{51}), and further stimulate regional economic development (C_{12}), adjust the industrial structure (C_{14}), and improve the living standard of the local residents (C_{21}). The newly built hospital also encourages research and development (R&D) in medical technologies and education (C_{42}). Medical service provided by NBXC hospital project would enhance social security (C_{23}) and improve emergency healthcare service ability (C_{43}) of this region. However, NBXC hospital as the first tier hospital in China would attract patients of other regions of the country, which may lead to risks of exposure to diverse disease and challenge healthcare and disease prevention (C_{41}).

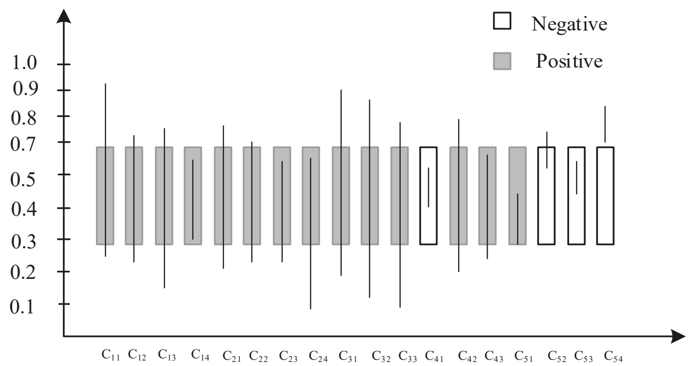

Figure 3. A modified K-chart of the research results.

The development of NBXC hospital project would negatively influence the society from the dimension of environment and resource conservation. The lifecycle of NBXC hospital project would consume enormous resource (C_{53}), and generate waste (C_{52}) (e.g., construction waste and medical waste), which would bring burden to the environment (C_{53}).

The scores of social performance evaluation of two proposed schemes show Scheme 2 would bring more social wellbeing to the society than Scheme 1 for the hospital redevelopment project. The score of social performance evaluation using Scheme 2 is 0.692, which also indicates relative high social performance of NBXC hospital project. Therefore, NBXC hospital project could be claimed to be a successful project from the social perspective and it will contribute to the sustainability of the society.

7. Conclusions

The concept of sustainable development suggests interactions of economic, environmental, and social dimensions [2]. However, social sustainability has received less appreciation than economic and environmental dimensions [28]. In the construction industry, social performance of construction projects not only contributes to social sustainability but also is critical for project success [19]. Evaluation of social performance of construction projects would help decision makers when proposing a project and project managers continuously improve social performance of construction projects.

This study developed a systematic framework for social performance evaluation of construction projects with 18 indicators developed from previous studies and a real-world hospital redevelopment project. These indicators help to evaluate social performance of the hospital redevelopment projects from five dimensions: socio-economy development, socio-environment development, social flexibility, public service development, and environment and resource conservation. In this research, public service delivered by hospital may vary from other types of infrastructure, e.g., schools and subways. However, the proposed framework could also be employed as reference to evaluate social performance of construction projects. While social impacts are intangible, and prior social performance evaluation using indicators are time-consuming and relatively subjective [13], FAHP method was introduced in this research to improve the efficiency and reduce the objectivity of the evaluation process to a certain degree.

The empirical study helps to showcase the processes to evaluate social performance of construction projects using the proposed framework and FAHP-based method. More importantly, the empirical study also helps to demonstrate how to improve social performance of construction projects based on the evaluation results. Specifically, the development of NBXC hospital project would improve the social sustainability of the society from perspectives of socio-economy development, socio-environment development, and social flexibility. Meanwhile, the development of NBXC hospital could also improve the landscape of the city due to a sound plan. However, the environment and resource conservation may be negatively impacted by NBXC hospital. As a hospital project, special considerations should be given to the associated risks of healthcare and disease prevention. By improving waste management, reducing resource depletion, and enhancing environmental protection, social performance of NBXC hospital project could be further improved.

However, this research was also subject to some limitations. For example, as stated by Vanclay [13], social impacts of construction projects are strongly correlated to the project context, while indicators for social performance evaluation are strongly dependent on the characteristics of construction projects. Therefore, future research should extend the flexibility and ensure the validity of the proposed framework.

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Measures and Steps for More Efficient Use of Buildings

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Abstract: As urbanization continues and more people move into cities and urban areas, pressure on available land for new constructions will continue to increase. This situation constitutes an incentive to review the need for interior space and uses of existing buildings. A great deal can be gained from using existing buildings more efficiently instead of constructing new ones: Reduced resource usage during construction (investments, natural resources, and energy), operation, and maintenance; more activity per square meter of buildings creates a greater basis for public transport and other services; more intensive use of buildings creates a more vibrant city without building on virgin land. The aim of this paper is to initiate a discussion regarding how digitalization can affect the demand and supply of interior space in existing buildings and elaborate on how policy can support more resource-efficient uses of space. New activity-based resource measurements intended for use in buildings are proposed, and several principles that have the potential to decrease environmental impact through more efficient usage of space are outlined. Based on these ideas for encouraging the flexible use of building spaces that are facilitated by digitalization and the new measurement approaches, a four-step principle for construction is proposed: The first step is to reduce the demand for space, the second is to intensify usage of existing space, the third is to reconstruct and adapt existing buildings to current needs, and the fourth is to construct new buildings. Urging political, municipal, construction, and real-estate decision makers to contemplate this principle, particularly in view of the new conditions that digitalization entails, will lead to more sustainable construction and, in the long term, a sustainable built environment.

Keywords: resource use; energy use; interior space utilization; buildings; sharing; digitalization

1. Introduction

In 2007, more than half of the population of the world lived in cities. In 2014, this figure was 54.4% and is predicted to reach 66% in 2050 [1]. One effect of urbanization and more people moving into cities and urban areas is an increased need for land for new buildings. One method of achieving this is to expand the urban areas (urban sprawl), another is to make the city denser (densification). A third is to use the existing building stock more efficiently. The EU Directive on the Energy Performance of Buildings (EPBD) [2] requires important measures to reduce the Union's energy dependency and greenhouse gas emissions and Energy Roadmap 2050 [3] explores the challenges posed by delivering the EU's decarbonization objective while at the same time ensuring security of energy supply and competitiveness. Buildings are responsible for 40% of energy consumption and 36% of CO_2 emissions in the EU, and it is predicted that 50% of the building stock that will exist in 2050 will have been built before 1975 [4]. Therefore, more renovation of existing buildings has the potential to lead to significant energy savings, potentially reducing the EU's total energy consumption by 5–6% and lowering CO_2 emissions by approximately 5% [4].

During 2016–2018, the Swedish Government has been focusing on five "Innovation Partnership Programs" [5], one of those being "Smart cities". Ever since the Program started, one of the authors to this paper who is a member of the advisory board to that program, has been leading a working group with participants from academia, industry and public administrations on how to use buildings more efficiently. This paper partly stems from that group's work.

While the European construction sector was hit particularly hard by the financial and economic crisis of 2008 and is still suffering from this, the Swedish construction sector faces challenges in relation to its capacity to construct new buildings. According to a forecast from the National Board of Housing, Building and Planning, Sweden needs 600,000 new homes to be constructed before 2025, along with other facilities that will provide services to inhabitants such as schools, daycare centers, shops and recreation facilities as the population grows [6]. Sweden has some of the highest construction costs in the EU after Norway, Denmark and Switzerland according to European Construction Costs (ECC) [7] and its new housing lies primarily in the upper end of the cost bracket, making it near-impossible for many groups to enter the housing market [8,9]. It is not only a matter of financing and affordability of new construction, but also of decreasing the environmental impact of construction. It is high time that options for new buildings were explored more deeply. Sweden is among the countries with the highest use of space expressed as floor area per capita, with 58 m^2/capita (16 for service and 42 for residential purposes); this follows Denmark and Cyprus, with 77 and 59 m^2/capita respectively, and is almost three times the floor area per capita in Serbia with 22 m^2/capita and Romania with 24 m^2/capita [4,10]. This is an incentive to review the need for new buildings and uses of existing buildings. A more efficient use of space means a reduced demand for building space. In practice, this could have vast implications on regional planning and ideas regarding how to develop regions in a more environmentally sustainable manner.

It is becoming increasingly important to take the environmental impact of production into consideration. In order to reduce the environmental impact of buildings, the resources used in terms of energy to extract, refine, process, transport, and fabricate a material or products must also be taken into account. In recent years, many studies have shown that so-called 'embodied energy' accounts for 45% of the total energy of a low-energy building over a lifespan of 50 years [11]. An analysis of the life-cycle energy of 60 cases from nine countries showed that operating energy represents by far the greatest energy demand for a conventional building during its life cycle, whereas low-energy buildings result in a net benefit in terms of their total life-cycle energy demand, even though there is a slight increase in the embodied energy [12]. In the future, it will likely be more a rule than an exception to consider embodied energy when designing new buildings.

Meanwhile, digitalization is changing more or less every aspect of society. Among other things, this means that the ways in which interior spaces are used are changing, and will change even more in terms of both housing, where different services make it possible to share temporary homes, and the matching of supply and demand. Digitalization is also laying the foundations for various new ways of sharing offices and office desks. Taken as a whole, much is to be gained from using spaces more efficiently and, through digitalization, new opportunities for this are appearing.

Thus, it seems there are potential environmental, social and economic benefits in using buildings more efficiently, and that digitalization can give some tools making this more feasible that previously. This paper focuses on Sweden because of the circumstances in that country described above. Even if this paper stems from Sweden, the general ideas should be relevant in all nations. It may however be more relevant for nations with a relatively high amount of building area, measured as square meter per capita. Some of the benefits of using buildings more efficiently rather than building new ones are:

(i) Resource efficiency in construction can increase.
(ii) Energy use for heating and operation can be reduced.
(iii) More people per square meter creates better support for public transport and other services.
(iv) More intensive usage of buildings creates more vibrant neighborhoods without building on virgin land.

1.1. Aim

The aim of this paper is to explore a new principle for reducing the resource use of buildings, and to combine this with a structured approach to discussing how interior space can be more efficiently used. How can these two perspectives highlight new avenues for policy development and new areas of innovation? In relation to this, several issues involving how requirements on measures for energy use in buildings can be formulated to assist in the drive for decreasing greenhouse gas emissions for the building stock, and the opportunities for change that come with digitalization, are explored.

1.2. Background

The following subsections of this paper introduce three important principles relating to reduced use of resources, the sharing of interior space, and alternative measures for energy use in buildings. These three subsections are the foundations of the 'Results' section that they precede.

1.2.1. Principles for Reducing Usage of Resources

Several sectors and areas have developed principles for increasing resource efficiency. Within transport infrastructure policy, the Swedish Transport Administration has explored the 'four-step principle' [13,14], which states that possible improvements to the transport system should be considered in a specific order. The first step is to consider measures that can affect the demand for transportation and choice of mode of transport. The second is to consider measures that could lead to more efficient uses of existing infrastructure. The third is to consider limited reconstructions. The fourth, which is only to be considered if the first three are not sufficient, is new and large-scale investment in the construction of road infrastructure [13]. Another example of guiding resource use through general policies is the 'waste management hierarchy', which is part of the EU waste directive (see Figure 1) [15]. The hierarchy states that, in order to reduce the negative impact of waste, five steps should be taken. Step 1 states that waste should be avoided through measures relating to product development and design. Steps 2–5 relate to when a product has become waste and focus on ways of reusing, recycling, and, as a last resort, disposing of products.

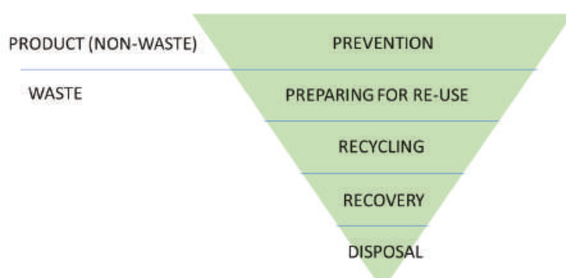

Figure 1. The 'waste management heirarchy'.

Within the area of energy use in buildings, there exist a number of strategies that resemble the 'waste management hierarchy' and the 'four-step principle' for transport. Berggren and Wall [16] identify four such strategies—'the Energy triangle', the 'Kyoto Pyramid passive energy design process ', the 'IBC Energy Design Pyramid,' and the 'passive house design principle'—to argue that reduced energy demand is the basis for such principles, positing better insulation and more efficient ventilation as possible solutions. Further measures to be taken after energy demand is reduced are use of renewable energy and clean fossil fuels insofar as possible, with smart technologies being used for both steering and heating.

1.2.2. Principles for the Sharing of Interior Spaces

An increased focus on sustainability and optimized resource usage has spurred interest in sharing things and spaces, leading to a focus on access to rather than ownership of e.g., transport modes and interior spaces.

Digitalization can assist in ensuring an increasingly efficient use of space. New sharing services have been introduced in recent years (see e.g., Reference [17]), and digital tools such as Airbnb (renting a home or property), Couchsurfing (sleeping on someone's sofa), Workaround (working in someone's office), and Coffice and Hoffice (working in a café or someone's home) allow pre-existing spaces owned by others to be utilized. These tools are part of a shift in approaches to how buildings can be used.

Different types of buildings are suitable for sharing to different extents on the part of different actors and activities. This has been studied by Brinkö et al. [18], who suggest a typology that classifies the options for sharing space and facilities within buildings for optimized use of existing buildings and minimizing the need for new ones. This was based on both literature (a large number of case studies) and interviews with stakeholders and resulted in the types of sharing being sorted into four groups. The first is sharing a specific facility—e.g., a desk or a workspace—within a semi-closed community, the second is sharing several facilities in an open or semi-closed community, the third is sharing a whole building or a physical space inside one within a closed community, and the fourth is sharing facilities between users in a network of buildings or organizations within an open, semi-closed, or closed community. These were then sorted according to a scale of sharing, from small to comprehensive. The characteristics of each type of sharing were defined by asking the following questions: What is being shared? When is it being shared? Why is it being shared? Who is sharing? How is it being shared? Digital services can be used to reveal underutilized buildings and offer space in the form of housing and premises to people and businesses who are moving into cities, thereby reducing environmental impact. CABE recommends that tenants and occupiers in office developments consider intensifying the use of space over time, taking into account increased internal and external mobility in order to achieve greater efficiency [19]. It seems like there are quite some ideas regarding how use of interior space can change, but it is not evident if the final outcome will be more or less demand for space.

1.2.3. Alternative Measures for More Efficient Energy Use in Buildings

For too long, there has been a too narrow focus on decreasing energy use in buildings by improving the energy efficiency of the existing building stock and creating new, low-energy buildings. The European building performance regulations are expressed in terms of kWh/m^2 heated area per year for buildings. This measure is advantageous for buildings that are used less frequently or by fewer users. Several recent studies, however, have explored energy use per person, rather than per square meter. Johansson [20] demonstrates that, as a performance indicator, energy use per resident is more relevant than energy performance per square meter, for all investigated building types. The average floor area per resident in multi-family buildings is lower than in 1–2 family buildings, while the energy use of many multi-family buildings is higher per square meter than that of 1–2 family buildings [15].

Sekki [21] proposes measuring energy efficiency in educational buildings by introducing indicators that take into account the number of users and the times at which a building is used. A number of new measures are suggested, taking schools as examples, including: Intensity of energy usage (energy consumption per actual number of schoolchildren using the building); specific energy consumption, adjusted for occupancy (total annual energy consumption per gross floor area times the ratio of actual daily use in relation to highest possible usage hours, i.e., 24); and specific energy consumption adjusted for usage and space efficiency (total annual energy consumption per gross area times a factor that includes the number of schoolchildren, average number of hours spent in the school per average space per schoolchild, and normal working hours—5.5 h for schools and 11.5 h for daycare centers).

2. Materials and Methods

This paper is the result of several different analyses, conducted using different research methods. First, a review of a number of approaches/tools/principles that are used as guides to reduce resource use within areas such as transport and waste was performed. Based on this, a new principle for reduced energy and resource use in buildings was developed and contextualized in relation to other relevant principles.

Secondly, several alternatives to the energy-per-square-meter metric were explored and reviewed. Based on this and a number of straight-forward examples of the forms that an intensification of space use can take, a basic categorization for the use of interior space was developed.

The combination of the principle and the categorization are proposed as something that can function as a basis for discussions regarding how space can be used more efficiently, with the potential benefits mentioned in the 'Introduction' section of this paper. Moreover, they are also proposed as potential catalysts for policy development and innovation in the 'Discussion' section, where a number of barriers to and drivers for more efficient use of interior space are summarized.

3. Results

3.1. The Four-Step Principle for Sustainable Use of Interior Space

The energy strategies in the 'Background' section are slightly less general in character than the transport and waste strategies presented. The transport and waste strategies begin with the causes of the resource use—the need for transportation and products, respectively—and then consider the aspect that is to be reduced (emissions and waste, respectively).

A corresponding approach in the energy strategies would have been to reduce the demand for climate-controlled space, and then to look at measures to reduce energy use per square meter, e.g., through insulation or more efficient heating and cooling technology.

Four steps for the sustainable use of interior space were tentatively suggested at a conference in 2017 [22], based on the four-step principle for transport infrastructure [13,14]. The four steps are further elaborated on here and contextualized in the setting of the principles for resources and energy usage in buildings, although these ignore the factor of demand for interior space. It is suggested that the four-step principle for interior spaces should be applied in any situation in which a demand for more interior space is identified. In such cases, the strategy for meeting demand should be based on a consideration of the following four steps, with the first step being the least energy- and resource-demanding:

1. Reduce the demand for space. A striking example of this is the reduction of postal and banking offices due to digitalization. Space in homes can be increased by replacing books and other physical media with digital equivalents. The storage needs of other objects could also be reduced through business-based models rather than ownership, and the highly efficient secondary market with various buy-and-sell services. Within industry, the need for remote trade is affected, and showrooms could be combined with efficient distribution via hubs to reduce the need for local space.
2. Intensify the use of existing space. If the same space requirement remains, increase space usage by using the space more intensively. This applies to office space as well as housing. With pop-up stores, it can also be applied to some extent to the retail sector. Recent decades have seen an intensification in the use of school buildings in Sweden through their being opened up to non-school activities outside of ordinary school hours. In addition, guest rooms can be shared by several households. Regardless of whether this happens on a global scale or in small groups such as within a city block, digitalization will contribute to the development of new opportunities. Households sharing space such as laundry rooms, kitchens, and social rooms allow the design and construction of small and cheap modern apartments.

3. Rebuilding can be a way of creating more useful space through the adapting of existing buildings, renovation of attics and basements into living spaces, and transformation of homes into offices or vice versa. It can also relate to creating flexible interior spaces that challenge the boundaries between housing, offices, and the retail sector. Furthermore, it is possible to create greater flexibility and, over time, adapt existing housing to changing lifestyles as the needs of households develop.
4. New construction is the last step but can be carried out in an advantageous fashion by building one or two floors onto existing buildings or parking garages, densifying the area without exploiting more virgin land at the expense of green areas. Even in new buildings, Steps 1 and 2 should be considered so that the space created can be used efficiently and is flexible in relation to future needs.

The four steps would precede the energy strategies mentioned in 1.2.1. Since they focus on the actual demand for space, whereas strategies such as the Energy triangle focus on reduced impact once the building has already been constructed.

3.2. Categorization of the Uses of Interior Space

The four-step principle above encourages greater co-use of space. This is a first step towards minimizing the environmental impact of buildings (used e.g., for housing, schools, office space). Rather than allowing large premises to be heated and ventilated to no avail, total energy use can be reduced by offering space in existing houses and premises.

In principle, the utilization of interior space can be increased by increasing the activities per space unit or per time unit. Various activities are suitable for different efficient uses of interior space. For some, it is easier to reduce the space per activity or service, while for others it may be more appropriate to use a large space for a more limited time. In the following, a categorization of different activities and services in terms of efficient use of space and their potential for sharing interior space is suggested. The uses of interior spaces for activities and services (with examples from housing, the retail sector, and offices) are divided into four categories:

1. Spacious interior spaces that are sparsely used: Retired couples ('empty nesters') with more than one house who spend considerable time abroad or at a summer house; retail buildings for the trading of bulky goods such as cars, furniture, etc.; offices with large rooms for each employee, irrespective of presence.
2. Dense interior spaces that are sparsely used: Homes for students, with minimal living space that is used mainly for sleeping; retail outlets for single goods with restricted opening hours; flexible office spaces with a low employee presence.
3. Spacious interior spaces that are frequently used: A widower remaining in a large old house or apartment, spending a lot of time at home; supermarkets with long opening hours; offices with large rooms for each employee and high presence.
4. Dense interior spaces that are frequently used: Homes for the elderly with minimal living space that are in use 24 h a day; co-operative housing with shared common rooms; service shops with long opening hours; flexible office spaces with high employee presence.

Considering these categories, using interior space more efficiently involves moving upwards and towards the right in Figure 2. Intensifying the use of interior space by densifying or extending the time of use can be achieved as follows:

Densifying use of interior space:

- Cooperative housing, sharing common areas such as a kitchen and living room, increases the number of people living in a specific space. At Tech Farm's property in Stockholm, 55 people live in 1100 m^2, which is 60% below the national average in terms of people per square meter.
- Rebuilding a house into a two-family house or generational housing (kangaroo living).

- Increasing the number of pupils in each classroom or children in each section of daycare centers.
- Open-plan offices without individual rooms.
- Several companies sharing meeting rooms, conference facilities, reception, lounge, canteen, dressing rooms, etc., within the organization or with other organizations.
- Retail outlets sharing showrooms for displaying limited collections within a small space, in an attractive location in which people can experience the products (touch, try, assess quality, colors etc.) and then order through e-shopping.

Extending the time of use:

- Gyms, shops, etc. being open 24/7.
- Shopping malls being open in the late evening or even at night during the week, which would be beneficial for those who work late or shifts and parents with small children.
- Activity-based flexible office spaces in which employees occupy a workspace only when at the office, and use different rooms depending on activities (meeting, desk work, phone calls, creative workshops).
- Activity-based schools without home classrooms.
- Sequential school use, i.e., schools used by one group of pupils for the first half of the day and by another for the second half.
- For sporting activities that require a certain space (athletics, tennis, ice hockey) and where there is no possibility to decrease the space or squeeze more people in at the same time, the time for which the space is used could be extended.
- Canteens, gymnasiums, and receptions could be shared between schools and homes for the elderly, as is practiced on the rural island of Casö, Finland.
- Churches that are used for a couple of hours a week by a small number of people could be used for other purposes during the rest of the week—as concert halls, conference centers, shelters for the homeless, and work hubs.
- Residential space is quite difficult to share, particularly over shorter time spans, although Airbnb has proven to be a successful way of sharing an apartment or house when it is not in use, as an alternative to hotels.
- Pop-up stores could be used to display goods in an attractive location for a limited time.
- Specially equipped rooms such as operating rooms, x-ray facilities, etc. could be operated 24/7, as is the case with delivery rooms (childbirth).

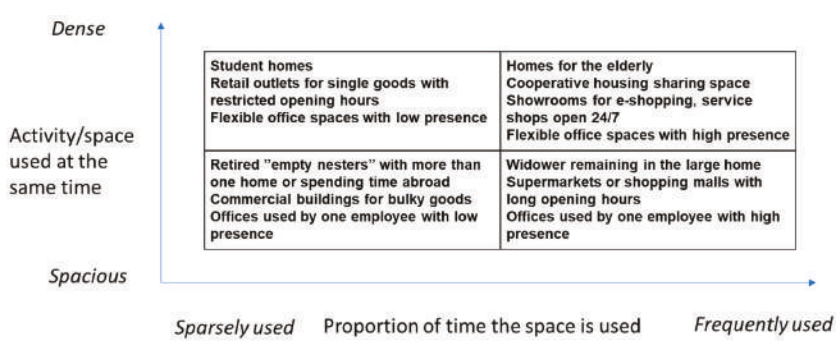

Figure 2. Categorization of use of interior space in terms of density and time of use.

It should be noted that the examples listed above function on the level of principles. The effect in practice will depend on several factors and must be thoroughly investigated. For example, the effect of

Airbnb has generally not been found to be an intensification of housing but an inflation in the housing market, resulting in loss of housing and more accommodation for visitors [23].

4. Discussion

This is a conceptual paper pointing at some new approaches to energy use in buildings. We have not provided empirical findings on effects of new measures or strategies. Rather, we are bringing thoughts from other areas into the field of energy use for buildings, with the ambition to encourage further research and empirical studies based on those thoughts.

The four-step principle developed is similar to other approaches to using resources more efficiently, such as the four-step principle for transport infrastructure. However, there are also differences, the primary one being that the four steps for buildings are more strongly interconnected and so should be regarded simultaneously. By designing with the lowest need for interior space possible in mind during the planning stage, a new building can be more efficiently used. In the case of the increasing demand for housing found in growing contemporary cities, all four steps may need to be applied at the same time. This article has presented the principle as a series of steps in order to emphasize the potential of using existing buildings more efficiently.

Giving too much consideration to the average use of space per person can be risky, as it may lead to the incorrect conclusion that everyone has surplus space in their home. Evidently this is not the case, particularly in urban areas, and factors other than the positive ones must be considered when looking at space-utilization opportunities. Table 1 summarizes several drivers of and barriers to the intensified use of interior space.

Table 1. Drivers and barriers to intensified use of space in household, company, school, and retail contexts.

	Densifying Activities (More Activities in the Same Space)	Extending the Time of Use (Use Space for a Greater Proportion of the Day, Week, Year)
Drivers (advantages)	Reduced environmental impact Cost reduction per activity/service Reduced cleaning costs for space that is not used	Reduced environmental impact Cost reduction per time of use Synergies between different users (shared equipment) Creating a vibrant atmosphere—'lively building' Increased safety and security as the building is in use more of the time
Barriers (disadvantages)	Crowded space Poorer air quality Need for more frequent cleaning Health problems Issues relating to territorial thinking, security, and privacy	Wear and tear Need for frequent refurbishment, leading to more material use and waste Complicated logistics Collisions between activities Competition for the most popular time slots Lack of demand during odd hours and off-season Need for staff 24 h a day and all year Less control over availability Issues relating to territorial thinking, security, and privacy Lack of incentives for profitability

During their lifetimes buildings are heated, ventilated, illuminated, cleaned, maintained, etc., entailing both costs and energy usage, which in turn have an impact on the environment. But do the regulations on energy use in buildings really encourage efficient use of energy in relation to the entire building stock? Although all new buildings are very energy efficient, any new buildings with heated spaces contribute to an increase in total energy usage. If buildings are used more frequently and by many users, the energy use will probably be slightly higher due to increased ventilation, lighting, consumption of hot water, etc. This has been observed in many multi-family housing areas built during the 1960s and 1970s, due to both poor energy performance and the fact that many people live in each apartment. There is undoubtedly a need to reduce energy use in these areas, but the living conditions in overcrowded apartments in socioeconomically fragile areas need to be considered. We also need to look closely at the buildings that use the most energy per person residing in each area. It may be wiser to develop policies towards resource-intensive households that have the ability to fund energy-efficiency measures to decrease their energy usage, and to encourage households that inefficiently use their living spaces to become more efficient. It is more important to reduce overall energy use than to reduce energy use per square meter.

Using indicators that represent more relevant measures of energy efficiency in buildings would be both fair and sustainable. There are, however, a number of issues that should be considered before any such measures are implemented.

Establishing the kWh-per-service or -per-activity metric, wherein a residence, workplace, school premises for a single pupil or student, daycare for a child, home for an elderly person, or place for giving birth is considered to be a service or activity, would encourage people to squeeze into smaller spaces, which means densification. The disadvantages to this are overcrowding, which can result in perceived congestion, poor air quality and health, and infections.

Establishing the kWh-per-time-used metric, wherein the built space is used for a larger proportion of the time of the day, week, or year, would encourage the use of buildings for more than one service or activity. This, however, would come with a demand on space in terms of time, which means a more intensive use of space due to the extended time of use.

The disadvantages of this are the increase in the wear and tear of the premises, as well as a lack of time for cleaning and maintenance, increased risk of collisions when changing activities, and higher incidence of double bookings and so on. The challenge would be to match different activities in terms of time, and to optimize the use of space over time. There could also be disagreements regarding interior design and furniture, limited storage possibilities, unclear division of responsibilities, and issues relating to the demands that contractual agreements place (or do not place) on co-users and co-occupants and systems of management, operation, booking, security, payment models, etc. Some premises are not attractive for use all of the time—hairdressers at night, theaters in the morning, etc.—but shopping malls, gyms, and laundry rooms could be used 24/7.

Premises for seasonal activities, such as skiing and beach resorts, could be used in other ways, such as for conferences, training courses, rehabilitation, etc. in order to extend the time of use.

As an incentive to decrease the use of interior space and hence the environmental impact of activities and utilities, this paper suggests that total GHG (greenhouse gas) emissions caused by energy use during the production of materials, transport, and operation of buildings per service provided (residence, education, work, shopping, recreation, etc.) is an accurate metric for measuring the sustainability of a building for cases in which the overall goal is to reduce GHG emissions.

Establishing a GHG-emissions-per-activity or -service metric may result in estimations of the lives of buildings that are greater than is realistic, ultimately entailing more maintenance and renovation than expected in order to continue the use of the building in the future. This would in turn increase the GHG value above the theoretical one, ultimately meaning that the initial assessment was misleading. There could also be difficulties in predicting GHG emission values for future energy production and operation of a building. Minimizing GHG emission per activity would favor the use of existing buildings as compared to new constructions.

The new dimensions and indicators that need to be developed can be based on new regulations and instruments, created for new business models for construction companies and property owners, and entail new concepts for designing housing and premises.

5. Conclusions

The aim of the research presented in this paper was to explore a new principle for reducing resource use in buildings, and to combine this with a structured approach to discussing how interior space can be used more efficiently. A four-step principle was developed further, involving (1) reducing demand for space; (2) intensifying usage of existing space; (3) rebuilding to create more useful spaces; and (4) constructing new, flexible houses. This will allow the environmental impact of the built environment and interior spaces to be decreased considerably.

A categorization of the use of interior space in terms of density and time of use has been presented. Measures for quantifying the environmental impact of buildings, expressed in terms of GHG emissions per activity rather than kWh/m^2, which would encourage decision makers to make more efficient use of interior space, have been presented.

By combining

- the four-step principle;
- the categorization of use of interior space;
- activity-based measures,

and suggesting approaches to matching the supply of spaces with demand that comes with the digitalization of society, we obtain an entirely new series of opportunities for policy makers (who wish to support reductions in energy and resource usage), innovators (who seek to find new areas to direct their attention towards), and business developers (who see the potential of new ways of providing space).

Researchers as well as decision makers in state functions, municipalities, and construction and real-estate companies are urged to contemplate the ingredients provided, particularly in view of the new conditions that digitalization entails. These can provide new recipes for lower resource usage, better premises, greater flexibility, and better meeting places. With this paper we have outlined a combination of ideas. Further steps include finding more data as well as exploring various ways of implementing the ideas both from a policy and from an innovation perspective.

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Exploring Antecedents of Green Tourism Behaviors: A Case Study in Suburban Areas of Taipei, Taiwan

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Abstract: Understanding user behaviors is the foundation to support the design and development of a sustainably built environment. This exploratory study used a mixed method to explore people's perception, motivation, intention, and behaviors of green tourism in Taiwan. The qualitative approach explored intrinsic and extrinsic factors that could influence people's intention to participate in green tourism. The quantitative approach provided evidence of influencing factors of green tourism. The findings suggested that variables, such as perception, attitudes, and self-efficacy, can indirectly influence green tourism behaviors through behavioral intention. This study suggests that government agencies should emphasize environmental education regarding the relationship between climate change and people's life; therefore, people will increase their environmental awareness regarding the urgent conditions of the environment, in addition to supporting green tourism and being more responsible for their tourism behaviors. For cities intending to accommodate tourism or Non-Governmental Organizations (NGOs) that are interested in promoting green tourism, it is critical to incorporate relevant factors, such as destination services and educational elements, into the design and development principles to built environment that supports green tourism activities.

Keywords: behavior; built environment; green tourism; intention; sustainability

1. Introduction

Over recent decades, global environmental change has been widely discussed, since many areas in the world are facing serious environmental problems. These problems are caused by industrial development, careless human behaviors, and unsustainable tourism behaviors. To help reduce these problems, every level, group, and society in the world should be involved in curbing these problems and the environmental design and planning for the tourism industry is no exception. Tourism activities directly and indirectly contribute to environmental issues because the use of airlines, tour buses, electricity, water, and many other resources requiring the consumption of natural resources and fossil fuels [1,2]. If the tourism industry continues to experience growth, it will exceed other industries and become the major source of global greenhouse gases (GHGs). To successfully achieve the reduction of GHGs, global policies, adopting environmentally friendly designs of the built environment, and a change in tourism travel behaviors are required. A number of international tourism organizations proposed their goals to reduce GHGs emissions. For example, the World Travel and Tourism Council [3] has used the CO_2 emissions of 2005 as a base line and, specifically, identified emission reduction goals of 25% to 30% by 2020 and 50% by 2035. The UK Department of Transport [4] identified sustainable low carbon travel in local areas. Some European countries and Australia have adopted methods to promote more sustainable travel programs for target populations [5]. Moreover, some studies have also suggested that people may decrease their intention to drive if the built environment can provide people with more alternatives to driving [6]. Based on the above discussion, tourism sectors and destination managers are aware of their responsibility to reduce carbon emission; therefore, the concept of green tourism has been promoted in many countries. To reduce the carbon emission resulting from the tourism industry, the Taiwan government has promoted green tourism in different regions. Various types of green tourism programs have been conducted in many counties in Taiwan [7]. The Green Tourism Association of Taiwan [8] defines green tourism as a travel mode that places an emphasis on people experiencing natural and cultural events, while leaving minimal carbon footprints and environmental impacts. Therefore, the main emphasis of green tourism is that energy consumption and CO_2 emissions, caused by the activities, products, and services of tourism, should be minimized [9,10]. However, some of these green tourism programs are not sustainable due to a lack of tourist participation. In other words, tourists might be hesitant about partaking in green tourism when they need to deal with public transportation, facing greater inconveniences, and paying more expensive travel costs [11,12].

To design better environments for green tourism promotion, it is important to understand the factors that influence tourists' intentions to participate in green tourism. Numerous studies explore tourists' willingness to participate in environmentally friendly behaviors [13,14]. However, Dolnicar, Crouch, and Long [13] suggested that most of the behavioral studies focus on ecotourism or nature-based tourism sectors instead of the general public; they argue that researchers should use samples from the general public to explore these tourists' characteristics and needs. The understanding of these needs will enable destination managers and planners to modify the built environment to encourage tourists to engage in environmental friendly behaviors and allow tourism suppliers to use those built environments to provide appropriate services and programs in the future. As such, it is imperative to explore the general public's perceptions, attitudes, and their current green tourism behaviors, as well as the factors that influence the practice of these behaviors. Moreover, most of the studies on behavioral theories focus on internal factors, such as personal attitudes and self-efficacy, that influence people's decisions to perform environmentally friendly behaviors [15,16] and rarely mention external factors, such as incentives or how the built environment can motivate people to execute certain environmental actions [17,18]. Therefore, it is imperative to investigate the external factors that could influence people's decisions concerning behaviors regarding green tourism. Based on the outlined reasons, the primary purpose of this study is to investigate the factors that influence people to participate in green tourism. The secondary purpose of this study is to explore how these factors influence people's intention to participate in green tourism. The third purpose of this research is to further explore factors that influence people's current green tourism behaviors.

First, we review the previous literature to form a basis for the investigation of possible factors that can predict tourists' intention and behaviors towards green tourism practices. We then use qualitative research methods to explore other factors that influence the general public's green tourism behaviors. Finally, we conduct quantitative measurement to explore the associations among green tourism behaviors and other factors.

2. Literature Review

In this section, we first reviewed the association between motivation and environmental behavior, followed by knowledge, perception, and environmental behaviors, and, lastly, attitudes, efficacy, intention, and environmental behaviors. The literature review explores the possible factors that could influence people's green tourism behaviors.

2.1. Motivation and Environmental Behaviors

Studies investigating motivation have long been a topic of interest in tourism and travel research. Motivation indicates people's psychological/biological needs and wants that can influence their decision-making [19,20]. Kasser and Ryan [21] described two types of motivation, which are intrinsic and extrinsic. Intrinsic motivation associates with internal feelings and instincts, such as the value or attitude toward actions, while extrinsic motivation relates to external reinforcement or social recognition, such as gaining benefits [21,22]. Previous studies showed that intrinsic motivation is a promising factor to guide environmental attitudes [23], as well as environmentally responsible behaviors [22,24,25]. This study aims to investigate the motivations that trigger people's intention to participate in green tourism behaviors. We hope to identify intrinsic and extrinsic motivations of green tourism behaviors to help providers of green tourism to understand people's needs, in addition to providing appropriate green tourism programs in the future. Therefore, we propose Hypothesis 1.

Hypothesis 1 (H1). *Motivation can positively influence people's behavior through behavioral intention.*

2.2. Knowledge, Perception, and Environmental Behaviors

Knowledge is thought to be the antecedent variable of behaviors and researchers have identified its direct and indirect influences on pro-environmental behaviors [16,26–28]. In environmental education, numerous researchers have indicated that knowledge is associated with conservation behavior [26,28]. Boubonari et al. [29] studied school teachers' knowledge, attitude, and behaviors regarding marine pollution and their findings suggested that knowledge is positively correlated with attitudes and behaviors, with the knowledge-attitude link being stronger than the knowledge-behavior link. Other researchers have identified a causal relationship between knowledge and behavior. For example, Frick, Kaiser, and Wilson [27] suggest that action-related knowledge and effectiveness knowledge (which addresses the relative effectiveness of conservation actions) have a direct effect on individuals' behavioral performance. Cheng and Monroe [16] studied children's affective attitudes toward nature and found that environmental knowledge has direct effects on children's affective attitudes, which can, in turn, influence their interests in environmentally friendly practices. Similarly, Carmi et al. [30] found that environmental knowledge can indirectly drive pro-environmental behaviors through environmental emotions. Based on the evidence of the discussed studies, environmental knowledge is a factor that is associated with the development of pro-environmental behaviors. As a result, we propose Hypothesis 2 and Hypothesis 3.

Hypothesis 2 (H2). *People's perception of sustainability can positively influence their attitudes toward green tourism*

Hypothesis 3 (H3). *People's perception of green tourism can have a positive influence on their attitudes toward green tourism.*

2.3. Attitudes, Efficacy, Intention, and Environmental Behaviors

Many researchers have explored pro-environmental behaviors to provide insights that explain, predict, and develop these behaviors [15,31–34]. Various theories have demonstrated the associations among social norms, values, attitudes, behavioral intentions, and actual behaviors [15,33,35]. These attitudes and behaviors are likely formed over time and it is possible to nurture these attitudes with environmental education programs. If programs promote environmental attitudes about behaviors, they may also succeed in increasing the intentions to perform these behaviors.

The theory of planned behavior is a classic framework that explains the relationship between predictive variables and behaviors [15]. The theory is composed of five basic concepts: Attitude toward the behavior, subjective norm, perceived behavioral control, intentions, and actual behavior, and suggests that a person's intention to perform a behavior is the direct determinant of the action. A person's intention is a function of three basic personal factors: Attitude toward the behavior, which determines a person's positive or negative evaluation of performing the behavior; subjective norm, which is a person's perception of the social pressures put on him/her to perform or not perform the behavior; and perceived behavioral control, which is a person's perception of his/her ability to perform a particular behavior. Eagly and Chaiken [36] indicated that attitude is a person's psychological inclination towards a particular entity. Numerous attitudinal studies have showed a positive relationship between environmental attitudes and behaviors. For example, studies suggest that pro-environmental attitudes were positively influential on people's willingness to pay [37,38]. Ajzen [15] indicated that perceived control is a similar form to measure one's capability to perform a certain action. Self-efficacy is considered to be an important predictor of environmentally responsible behaviors. Wood and Bandura [39] (p. 408) defined self-efficacy as the belief in one's own capacity to organize and guide the courses of action required to tackle certain situations in the immediate future. Previous studies have suggested that self-efficacy directly and indirectly influences residents' recycling behaviors in Spain [22]; self-efficacy strongly influences children's affective attitudes, as well as their intention to practice environmentally responsible behaviors [16]. The theory of plan behavior also suggests that intention can best predict a behavioral achievement. Therefore, we propose Hypothesis 4, Hypothesis 5 and Hypothesis 6.

Hypothesis 4 (H4). *People's attitudes towards green tourism can positively influence their intentions of participating in green tourism*

Hypothesis 5 (H5). *People's self-efficacy can have a positive impact on their intentions of participating in green tourism*

Hypothesis 6 (H6). *People's intention of participating in green tourism can positively influence their environmentally responsible green tourism behaviors.*

2.4. External Factors and Travel Behaviors

Some researchers have investigated the associations between the built environment and people's behaviors in residential areas. Handy, Cao, and Mokhtarian [6] studied the relationship between the built environment and travel behavior in the United States. Their finding demonstrated that, if residents were closer to their destinations and were provided with alterative travel modes, driving decreased. The results implied that the design of the built environment is influential on travel patterns in a given destination. Similarly, Titze, Stronegger, Janschitz, and Oja [18] explored the factors that influence people to use bicycles as their transportation mode in Austria. Their findings suggested that the condition of the physical environment can influence people's intention to bike. Based on the conclusions from the discussed studies, people tended to change their behaviors if there were appropriate designs. Therefore, this implied that the involvement of transportation and destination planners is critical during the planning stages of green tourism programs. Moreover, other studies suggested that nature-based recreation experiences could positively influence tourists' environmental attitudes, which further influences tourists' environmentally responsible behaviors. It is suggested that, if service providers can maintain destinations to high standards and provide positive experiences for tourists, tourists can, thus, develop positive environmental attitudes and behaviors and further contribute to the sustainable tourism industry [40].

The discussed studies present the theoretical background of factors that could influence behavioral intention and environmental behaviors. However, this study would like to examine whether there are other factors that could influence the general public's intention to participate in green tourism. Therefore, Study 1, presented hereafter, used a qualitative approach to explore motivations (both intrinsic and extrinsic factors) that could influence tourists; behavioral intentions regarding green tourism participation. Followed by Study 2, which uses a quantitative approach to explore how antecedent variables of green tourism participation influence people's green tourism behaviors.

3. Study 1

The researchers concluded that there was an insufficient understanding of factors that influence people's green tourism behaviors; therefore, it was necessary to perform an exploratory qualitative study to establish quantitative instruments that could be tested later in the quantitative stage. The specific research question for the qualitative initiative was: What are people's motivations to practice green tourism behaviors?

3.1. Study Area and Participants

The researchers selected the top five popular tourism sites that can be accessed by public transportation in New Taipei City, which are Tamsui, Jiufen, Houtung, Yingge, and Sanxia (Figure 1). The participants were 18 years or older and had travelled to these areas between March and April of 2013.

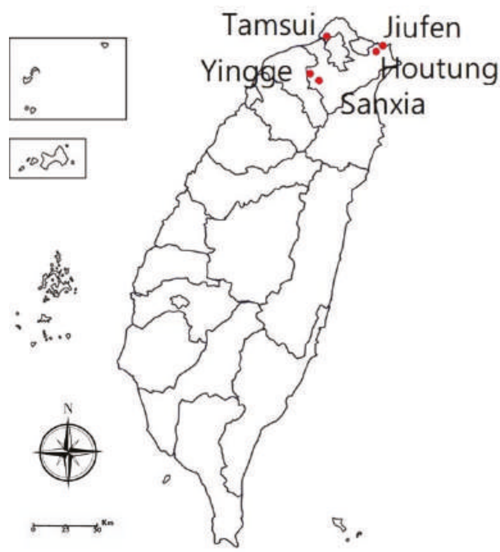

Figure 1. Interview sites.

3.2. Qualitative Initiative

During the first stage of the research, we used semi-structured interviews as the main technique to collect qualitative data. Convenience sampling was used to interview visitors. The interviewer selected the participants based on their availability. Each available participant was approached one at a time and he or she was asked of their willingness to be a research participant. After the interview with one participant was completed, the interviewer approached the next available participant. Before the interview, the researchers described the meaning of green tourism to the participants, and researchers used open-ended questions to explore the factors that could influence people's willingness of their participation in green tourism programs. The interview questions were: "Have you ever heard about green tourism?" and "What factors can influence your decision to participate in green tourism programs?" Each interview took about 8 to 10 min until the participants could not describe any new concepts.

3.3. Data Analysis

After the researchers approached 35 tourists, the data seemed saturated; therefore, we stopped the qualitative data collection. Each interview was transcribed and two researchers used Strauss and Corbin's [41] three coding steps, including open coding, axial coding, and selective coding, to explore factors that influence people's willingness to participate in green tourism.

3.4. Results

After combining items that have similar meanings and modifying the wording, two major types of factors were generated, including extrinsic factors and intrinsic factors, which are listed in Table 1.

Regarding extrinsic factors, many respondents identified an economic influence, as well as the availability of green alternatives at the destination. Some of the comments by participants were quoted below:

> It is important to have convenient public transportation. If the public transportation is not convenient or available, it is hard for people to participate in green tourism. (C6)

> If there is public transportation available between different destinations, I will take it because it is convenient. (D2)

Table 1. Factors that influence green tourism participation.

Selective Code	Axial Code	Description (Open Code)
Extrinsic factors	Economic influence	Reasonable travel costs (27)
	Destination built environment	Convenient public transportation (23) Prevalence of environmental friendly hotels (9)
	Destination experiences	The program should be interesting and attractive (16) Be close to the local environment (15) Destinations should have professional guided-services (9) To experience high quality interpretation (4)
Intrinsic factors	Social factors	To be with family and friends (10) To know people who have similar values and interests (4)
	Self-fulfilment factors	To try different types of tourism programs (11) Having environmental responsibility (8) Having environmental awareness (6) To learn new carbon reduction knowledge (5)

The participants' comments suggested that not only the availability, but also the convenience, of public transportation is critical for people to participate in green tourism. This is similar to a study presented by Larsen and Guiver [42], which reports that change towards more sustainable tourism mobility is likely to happen if tourists can value experiences at closer destinations with more available sustainable transportation.

Other respondents described the availability of environmental friendly hotels:

> If there are more green/environmental friendly hotels available, we are more likely to choose those types of hotels. (C2)

The above ideas indicate that, to promote green tourism, destinations should have sufficient facilities that could accommodate the ideas of carbon reduction. Other than destination facilities, respondents also spoke about their expectations of green tourism experiences. Their comments were as follows:

> I like traveling a lot, so if there are attractive green tourism programs or activities, I will likely participate. (A2)

> Different tourism sectors are very competitive. If you want people to participate in green tourism, the activities must be very interesting and attractive. (A4)

> I care a lot about professional guiding services, since I like to learn in-depth knowledge in the destinations. (A1)

The above quotes illustrate that, if the destinations can provide relevant services or experiences that are interesting to the visitors, people will be willing to participate in green tourism. This describes the extrinsic motivation of green tourism.

In addition to extrinsic factors, several respondents explained their motivation to participate in green tourism based on experiential factors. Some of them talked about their previous experiences. For example, one participant mentioned:

> I went to I-Lan for a green tourism program. We biked around the rice field, and had a series of in-depth environmental interpretation. The experience was memorable and interesting, so I will like to have similar experience again in the future. (C3)

From this participant, we found that experience was an important factor to attract tourists. Tourism sectors can provide memorable green tourism experiences to satisfy people. The above finding also implied that, if people have more environmental experiences, they would be more likely to participate in green tourism. Another finding was that tourists' own environmental awareness could motivate them to participate in green tourism. Some respondents pointed out:

> I am sensitive to environmental issues, so if there is a green tourism program available, I will like to participate. (A1)

> People who have interests to learn about the environment or who are having environmental responsibility will participate in these types of programs. (D2)

3.5. Discussion

We explored the factors that influence people's intentions to participate in green tourism. We found that both intrinsic and extrinsic factors can motivate people to participate in green tourism. To design and promote green tourism activities in a more effective way in the future, understanding the influential factors of green tourism behaviors is imperative. Therefore, the results of the qualitative study were used to develop a scale to reach a more general public and investigate the important factors that can influence people's willingness to participate in green tourism. Thirteen items were designed, and are listed in Table 2, based on the qualitative findings to represent intrinsic and extrinsic factors that motivate people to participate in green tourism.

Table 2. Factors that motivate people to participate in green tourism.

Items
Learning new ways of environmental conservation
Helping with environmental protection
Promotion of low carbon tourism
Awareness of environmental conservation
A skillful low carbon local tour guide
Professional low carbon guiding services
Convenient public transportation services
Attractive green tourism programs
Prevalence of green hotels
Reasonable travel cost in the destination
Diverse local cultural features
Experiencing different types of tourism
Leaving the crowed city environment

4. Study 2

The aim of Study 2 was to understand the predictors of green tourism intention and behaviors. The predictors include factors that are identified in literature review and were explored in the qualitative study. The research questions include: Can people's intention of participation in green tourism influence green tourism behaviors? Can perception, attitudes, self-efficacy, and other factors influence people's intentions to participate in green tourism?

The quantitative questionnaire included nine major sections. Section 1 included four questions that measured people's perception of sustainability. Section 2 included six questions that explored people's perceptions of green tourism. Section 3 was composed of four questions that measured people's self-efficacy, with statements such as, "I can reduce environmental impacts through participation in green tourism." Section 4 was composed of five questions that measured people's attitudes toward green tourism behaviors, with statements such as, "Green tourism can ensure the quality of the environment." Section 5 included 13 questions measuring factors that can influence people's willingness to participate in green tourism, which were developed from the qualitative study. Section 6 included one question measuring tourists' willingness to participate in green tourism in the future. The statement was, "I will follow green tourism principles when I am traveling". Section 7 included five questions that were designed following the Carbon Reduction Tourism principals provided by the Environmental Protection Agency (EPA) [43] in Taiwan. The rules included: People who participate in carbon reduction tourism should limit their footprint from transportation; they should carry light personal belongings; they should consume the local and seasonal food; they should leave no trace, etc." The example statement was, "I choose to take public transportation if available." All constructs were measured by using a 5-point Likert scale from 1, being strongly disagree, to 5, being strongly agree. The last section of the questionnaire was demographic information. Then the questionnaire was pilot tested with 60 participants to investigate the question wording and reliability. Two items from the perception of green tourism, "The carbon emission of different types of hotels is different" and "Taking public transportation can reduce carbon emission", were eliminated due to low reliability. The questionnaire items are translated in Appendix A.

4.1. Data Collection

Survey data were collected in the same five locations as visitor interviews were collected. The self-administrated questionnaire was handed to the participants. Each questionnaire took about 10 min to finish. Data were collected during June to August 2013. The study distributed 450 questionnaires and 53 were eliminated due to missing data, which left 397 surveys for data analysis.

4.2. Data Analysis

Upon completion of the data collection, data were analyzed using SPSS 20.0. Among the 397 effective samples, about 45% were men and 55% were women. The majority (78%) of tourists were from Northern Taiwan. The age distribution was 41% (20–29 years), 33% (30–39 years), 17% (40–49 years), 6% (50–59 years), and 3% (above 60 years). About 60% of visitors had a degree in college, followed by high school (19%), technical school (17%), and secondary level education (2.8%). Then data were analyzed using exploratory factor analysis to investigate factors that could predict the willingness of green tourism participation. Following the factor analysis, multiple regressions analysis was applied to discover the predictors of visitors' willingness to participate in carbon reduction tourism.

Factor analysis was used to explore the components of people's willingness to participate in green tourism behaviors. Thirteen items were factor analyzed. Researchers used the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy to evaluate the appropriateness of the factor analysis. The results showed KMO = 0.72 (Barlett's test of sphericity = 1334.51, $p < 0.01$), which allowed us to further assess factor analysis. Two items with factor loading lower than 0.4 were eliminated [44], which left 11 items for the final data analysis. Three major categories were generated to represent factors that influence people to participate in green tourism behaviors: Self-environmental awareness, destination services/features, and professional interpretation (Table 3). Self-environmental awareness belongs to intrinsic motivation, while destination green service and professional interpretation belongs to extrinsic motivation.

Table 3. Motivation of green tourism participation.

Statements	Self-Environmental Awareness	Destination Green Services	Professional Interpretation
Learning new ways of environmental conservation	0.85		
Helping with environmental protection	0.78		
Promotion of low carbon tourism	0.75		
Awareness of environmental conservation	0.66		
Convenient public transportation services		0.76	
Attractive green tourism program		0.75	
Prevalence of green hotels		0.60	
Diverse local culture and features		0.55	
Reasonable travel costs in the destination		0.41	
Skillful low carbon local tour guide			0.91
Professional low carbon guiding services			0.90
Eigen values	3.28	1.86	1.40
Percentage of variance explained	24.26	18.29	16.86
Cumulative variance explained	24.26	42.55	59.41
Cronbach's alpha	0.78	0.87	0.63

4.3. Testing of Hypotheses

After factors analysis, motivation of green tourism participation was categorized into three factors; therefore, the previous Hypothesis 1, was modified to Hypothesis 1a, Hypothesis 1b and H1c. Professional interpretation can influence people's intention of participating in green tourism. The hypothetical model of this study is explained in Figure 2. The study used the statistical package, Statistical Product and Service Solutions (SPSS), as well as Analysis of MOment Structure (AMOS), as our data analysis tool and a 95% of confidence level was implemented for the statistical analysis.

Hypothesis 1a (H1a). *Self-environmental awareness can positively influence people's intention of participating in green tourism.*

Hypothesis 1b (H1b). *Destination green service can positively influence people's intention of participating in green tourism.*

Hypothesis 1c (H1c). *Professional interpretation can influence people's intention of participating in green tourism.*

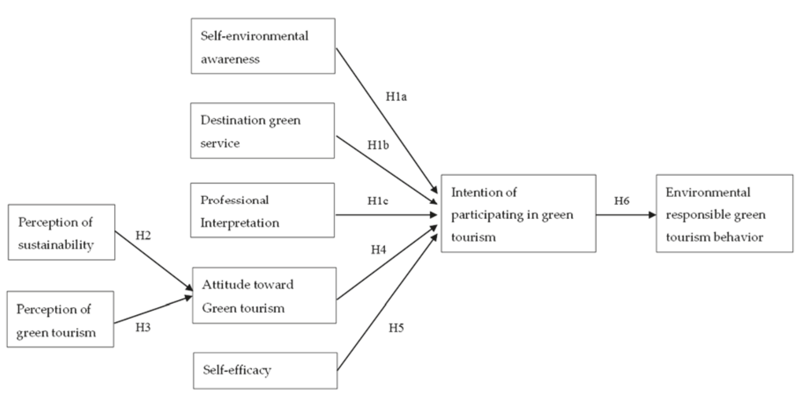

Figure 2. Proposed model of green tourism behaviors.

4.4. Results

The results were divided into two parts: The analyses of reliability and validity, and hypotheses testing. The following section shows the reliability and validity, as well as whether the results support our research hypotheses.

4.4.1. Reliability and Validity

A series of analyses were performed to test the reliability and validity of the constructs. Table 4 summarizes the descriptive statistics of the study variables. All correlations are significant at the 0.05 significance level. Besides, composite reliabilities are in italics in the diagonal. For composite reliabilities, a minimum value of 0.7 is considered acceptable.

The study also used confirmatory factor analysis (CFA) to test our measurement model. The fit indices of CFA were: χ^2/df = 2.685; NNFI = 0.801; CFI = 0.826; AGFI = 0.810; SRMR = 0.066; RMSEA = 0.065. Therefore, our research model is acceptable, indicating convergent validity [45]. The confirmatory factor analysis confirmed if the items belong to the constructs. The results demonstrate construct unidimensionality.

The study examined discriminant validity among constructs using a procedure provided by Fornell and Larcker [46], whose criterion for discriminant validity is that the variance shared by a construct with its indicators should be greater than the variance shared with other constructs in the model. As shown in Table 4, the square root of the average variance extracted (ranging from 0.574 to 0.893) was greater than almost all of the corresponding correlations, indicating adequate discriminant validity.

The diagonal values in italics to the right of the slash are the square root of the average variance extracted (AVE) for each construct; the values to the left are the composite reliabilities.

Table 4. Descriptive statistics and correlations.

Variables	Mean (SD)	1	2	3	4	5	6	7	8	9
1. Perception of sustainability	3.095 (0.790)	0.691/*0.631*								
2. Perception of green tourism	3.761 (0.699)	0.314 **	0.801/*0.681*							
3. Attitudes toward green tourism	3.695 (0.549)	0.133 **	0.388 **	0.778/*0.574*						
4. Self-efficacy	3.386 (0.750)	0.126 *	0.404 **	0.528 **	0.693/*0.644*					
5. Self-environmental awareness	3.426 (0.691)	0.180 **	0.299 **	0.463 **	0.381 **	0.834/*0.711*				
6. Destination green service	3.864 (0.619)	0.124 *	0.126 *	0.218 **	0.302 **	0.327 **	0.703/*0.589*			
7. Professional interpretation	3.731 (0.855)	0.048	0.025	0.071	0.056	0.283 **	0.061	0.896/*0.893*		
8. Intention of participating in green tourism	3.496 (0.855)	0.131 **	0.291 **	0325 **	0.271 **	0.378 **	0.303 **	0.175 **	-/-	
9. Environmental responsible green tourism behavior	2.904 (0.699)	0.339 **	0.365 **	0.379 **	0.449 **	0.482 **	0.241 **	0.121 *	0.268 **	0.748/*0.611*

Note: $N = 398$. * Correlations at the 0.05 significant level, ** Correlations at the 0.01 significant level.

4.4.2. Hypotheses Testing

Table 5 presents the AMOS estimates for our propose model. The fit indices for the proposed model were: χ^2 = 1257.926 (df = 441; $p < 0.001$); NNFI = 0.774, CFI = 0.799; AGFI = 0.797, SRMR = 0.081; RMSEA = 0.068. The fit indices suggest that the data fit our model well. The results reveal that environmental self-awareness significantly impacted on intentions of participating in green tourism (β = 0.254, $p < 0.001$). Meanwhile, destination green services are also significantly related to intentions of participating in green tourism (β = 0.155, $p < 0.001$). However, the results do not support the hypothesis that professional interpretation is positively related to intentions of participating in green tourism (β = 0.035, $p > 0.05$). Furthermore, the results show that perceptions of sustainability are not significantly related to attitudes toward green tourism (β = −0.021, $p > 0.05$). The results confirm that perceptions of green tourism are significantly related to attitudes toward green tourism (β = 0.443, $p < 0.001$). The results reveal that attitudes toward green tourism are significantly related to intentions of participating in green tourism (β = 0.169, $p < 0.05$). The results support the conclusion that self-efficacy is significantly related to intentions of participating in green tourism (β = 0.307, $p < 0.001$). Moreover, the results confirm that intentions of participating in green tourism significantly impacts on environmentally responsible green tourism behavior (β = 0.966, $p < 0.001$).

Table 5. Path estimates for the hypothesized model**.**

Path	Path Estimates
H1a: Environmental self- awareness➔Intentions of participating in green tourism	0.254 ***
H1b: Destination green service➔Intentions of participating in green tourism	0.155 ***
H1c: Professional interpretation➔Intentions of participating in green tourism	0.035
H2: Perception of sustainability➔Attitudes toward green tourism	−0.021
H3: Perception of green tourism➔Attitudes toward green tourism	0.443 ***
H4: Attitudes toward green tourism➔Intentions of participating in green tourism	0.169 *
H5: Self-efficacy➔Intentions of participating in green tourism	0.307 ***
H6: Intentions of participating in green tourism➔Environmentally responsible tourism behavior	0.966 ***

Note: * $p < 0.05$, *** $p < 0.001$. The fit indices: χ^2/df = 2.852; NNFI = 0.774, CFI = 0.799; AGFI = 0.797, SRMR = 0.081; RMSEA = 0.068.

After hypotheses testing, we have several major findings. First, the perception of green tourism can significantly predict attitudes toward green tourism. Second, attitudes toward green tourism, self-efficacy, self-environmental awareness, and destination services can significantly predict intentions of participating in green tourism. Third, intentions of participating in green tourism can significantly predict environmentally responsible tourism behaviors.

4.5. Discussion

This study used both factors that were identified from the literature and the factors generated from qualitative results to predict people's willingness to participate in green tourism. Our study explored people's actual tourism behaviors and found that people who have stronger intentions to participate in green tourism are more likely to perform environmentally responsible travel behaviors. This finding is consistent with previous studies that intention is one of the strongest predictors of behaviors [15,47]. Also consistent with previous literature, perception, attitudes, and self -efficacy are also predictors of behavioral intentions [15,16,39].

One interesting finding of our study is that destination services, which is an external factor, can significantly influence people's intention to participate in green tourism. While previous literature has focused on people's internal motives of performing certain behaviors, our study explained that external factors can play an important role for people to perform certain behaviors. One possible explanation is that, if the destinations are attractive and have services that can be convenient or easy to use, people will be more willing to participate in green tourism, which is similar to previous suggestions in the literature, which indicate that external factors, such as economic, social, and cultural, and design of the built environment might influence people's behavioral decisions [6,17,18,28]. However, we further investigated the predictability of other independent variables of people's willingness to participate in green tourism programs and found that professional interpretation is not a significant predictor. The reason may be because people who want to participate in green tourism programs are more interested in local resources rather than professional guides and interpretation services.

5. Conclusions and Implications

This exploratory study used both qualitative and quantitative methods to find out factors that can influence people's willingness to participate in green tourism, as well as the factors that influence people's responsible green tourism behaviors. The findings show that people's own environmental awareness and destination services are influential on people's willingness to participate in green tourism. These findings provide suggestions for government agencies, tourism sectors, NGOs, and city planners and developers that want to promote green tourism programs in the future. We suggest that government agencies should emphasize environmental education regarding the relationships between climate change and people's lives; in doing so, people will increase their environmental awareness regarding the urgent conditions of the environment and will support green tourism efforts, as well as being more responsible in their tourism behaviors. For the tourism sectors or NGOs that are interested in promoting green tourism, it is critical to consider factors, such as destination services and educational elements, during the program developmental process, since our findings suggest that, if the destination can provide more green tourism services, people are more likely to participate in green tourism in the future. We also suggest that city planners and developers provide opportunities for public involvement and consider environmentally friendly designs during their planning processes so that they will know the actual demands for the users. For example, different stakeholders are able to participate in the planning stage and make it possible to have more convenient public transportation for green tourism promotion.

The quantitative results suggested that self-environmental awareness, self-efficacy, and destination services, as well as their attitudes toward green tourism, are critical factors for people to make decisions about participating in green tourism. The results are consistent with previous studies, which indicate that both intrinsic and extrinsic motivations were associated with environmental behaviors [48,49]. We suggest future research should use more in-depth qualitative research methods to explore people's motivations and thoughts regarding green tourism participation; therefore, countries that want to promote green tourism may benefit from these findings. This study was conducted in sub-urban areas in Taiwan, and, thus, we also suggest researchers should explore how these factors influence people to participate in green tourism programs in different cultures and countries. More diverse data could be beneficial for green tourism promotion all over the world.

6. Limitations

This study has several contextual and design limitations that may affect the results. The qualitative study used convenient sampling on site. Although, after interviewing 35 people, the data had been saturated, on-site interviews may have several limitations. First, people do not have a large period of time to explain their thoughts. Second, people do not have detailed ideas regarding green tourism so their responses may be limited. Therefore, we suggest further in-depth interviews can be conducted to explore the factors that influence people's decision to participate in green tourism programs. Third, this study investigated the general public's green tourism behaviors; some participants might not have in depth knowledge regarding green tourism, which might result in scoring low in the actual green tourism behaviors. A more precise questionnaire can be designed to investigate green tourism participants in the future.

Author Contributions: J.C.-H.C. led coordinated the research; M.-Y. Huang and Y.Y. reviewed relevant literatures and developed implications; J.C.-H.C. and A.-H.C. analyzed the data; All Authors contributed to the manuscript preparation.

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Appendix A

Section 1: Perception of sustainability	**Mean**	**SD**
I understand carbon footprint	2.86	1.17
I understand carbon cycle	2.77	1.15
I understand green consumption	3.14	1.01
I understand sustainable development	3.61	0.96
Section 2: Perception of green tourism		
Consuming local food helps reduce carbon emission	3.61	1.01
Reducing use of disposable products helps reduce carbon emission	3.93	0.83
Wearing lightweight clothing helps reduce carbon emission	3.60	0.91
Carrying your own toothbrush and towels helps reduce carbon emission	3.89	0.89
Taking public transportation can reduce carbon emission	4.01	0.82
The carbon emission of different types of hotels is different	3.90	0.73
Section 3: Self-efficacy		
I can reduce environmental impacts through participation in green tourism	3.74	0.89
I have a responsibility to reduce carbon emission during my travel journey	3.35	0.94
I have a responsibility to persuade those who are damaging natural resources	3.08	1.07
Carbon emission reduction from green tourism cannot be neglected	3.55	1.05
Section 4: Attitudes toward green tourism		
Green tourism can ensure the quality of the environment	3.60	0.83
Green tourism can promote the local tourism industry	3.51	0.79
Green tourism has educational meaning	3.87	0.91
Green tourism can enhance my travel experiences	3.72	0.75
Green tourism can enhance my knowledge of resource conservation	3.77	0.83
Section 5: Influencing factors of willingness of participation in green tourism		
Self-environmental awareness		
Learning new ways of environmental conservation	3.54	0.93
Helping with environmental protection	3.43	0.87
Promotion of low carbon tourism	3.40	0.80
Awareness of environmental conservation	3.33	0.95
Destination green service		
Convenient public transportation services	3.99	0.83
Attractive carbon reduction tourism program	3.91	0.89
Prevalence of green hotels	3.73	0.90
Diverse local cultural and features	3.82	0.90
Reasonable travel cost in the destination	3.85	0.96
Experience different types of programs (eliminate due to low factor loading)	3.65	0.83
Escaping from urban areas (eliminate due to low factor loading)	3.69	0.93

Professional interpretation		
Skillful low carbon local tour guide	3.66	0.94
Professional low carbon guiding services	3.80	0.88
Section 6: Intention of participation in green tourism		
I will follow green tourism principles when I am traveling	3.50	0.85
Section 7: Environmental responsible tourism behaviors		
I choose to take public transportation if available	3.10	1.06
I carry my own water bottles when traveling	2.85	1.08
I carry my own shopping bags when traveling	2.55	0.98
I carry my own toothbrush and towels when traveling	2.69	1.02
I choose to purchase souvenirs with less packaging	3.33	0.85

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Article

Analysis of the Land Use and Cover Changes in the Metropolitan Area of Tepic-Xalisco (1973–2015) through Landsat Images

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Abstract: Land use and cover changes (LUCC) have been identified as one of the main causes of biodiversity loss and deforestation in the world. Fundamentally, the urban land use has replaced agricultural and forest cover causing loss of environmental services. Monitoring and quantifying LUCC are essential to achieve a proper land management. The objective of this study was to analyze the LUCC in the metropolitan area of Tepic-Xalisco during the period 1973–2015. To find the best fit and obtain the different land use classes, supervised classification techniques were applied using Maximum Likelihood Classification (MLC), Support Vector Machines (SVMs) and Artificial Neural Networks (ANNs). The results were validated with control points (ground truth) through cross tabulation. The best results were obtained from the SVMs method with kappa indices above 85%. The transition analysis infers that urban land has grown significantly during 42 years, increasing 62 km^2 and replacing agricultural areas at a rate of 1.48 km^2/year. Forest loss of 5.78 km^2 annually was also identified. The results show the different land uses distribution and the dynamics developed in the past. This information may be used to simulate future LUCC and modeling different scenarios.

Keywords: Maximum Likelihood Classification; Support Vector Machines; Artificial Neural Networks; significant transitions; urban growth; Nayarit (Mexico)

1. Introduction

Terrestrial ecosystems are important components of nature since they have biological and functional effects on climate regulation, the hydrologic cycle and as a source of natural resources to satisfy human needs. However, during the last 300 years, the planet has suffered big transformations [1]. The ecosystems have been subject to accelerated processes of land use and cover changes (LUCC) [2], which have been identified as one of the main factors contributing to global environmental change [3–5], as a result of major current environmental problems [6] such as land loss and degradation, climate change, biodiversity loss, deforestation [7] and ecosystems fragmentation [4,8,9], which in turn cause loss of associated environmental services [10] to such a degree that more than half of the world's forest cover has been lost, and around 30% of these ecosystems face degradation processes. Anthropogenic activities are one of the main elements that contribute to land use changes [11].

Mexico is known as a megadiverse country, consisting of large diversity of organisms, landscapes and terrestrial ecosystems [12]. Forests, jungles and other natural vegetation are distributed all over the country [13] covering 74% of the national territory [14], about 146 million hectares [12]. The distribution of natural vegetation has been studied for monitoring LUCC, but most of the research conducted at a regional scale has focused on the analysis of losses in natural vegetation and deforestation [15,16]. The deforestation rates recorded show a difference from 260,000 ha/year to 775,000 ha/year (i.e., 2600 km^2/year to 7760 km^2/year) [15]. Since local scale studies on LUCC have been scarce [14], the present work was centered on monitoring LUCC locally, paying particular attention to the urban land use in the metropolitan area of Tepic-Xalisco as a starting point for further research on urban growth simulation and future scenarios design.

The advance in using Geographic Information Systems (GIS) and remote sensing techniques has proven to be very useful to get accurate and coherent information according to the spatial reality [16]; these tools are widely used to analyze the distribution, patterns and trends of the LUCC processes via different methods to obtain several land use classes in the territory, as well as diverse approaches to detect temporary differences, such as the traditional method of cross tabulation [17,18].

In this context, the objective of this study was to analyze the dynamics on urban LUCC at local scale. The methodology was developed through the analysis and processing of four Landsat satellite images corresponding to the years 1973, 1985, 2000 and 2015. To find the best fit and obtain the different land use classes, three supervised classification methods were applied: Maximum Likelihood Classification (MLC), Support Vector Machines (SVMs) and Artificial Neural Networks (ANNs). The results were validated with control points (ground truth). Then, to identify the significant transitions between different land uses—especially in the urban land use changes—losses, gains, changes and interchanges were obtained through the cross-tabulation matrix and according to the methodology of Pontius [19].

The remainder of the paper is organized into four sections. Section 2 describes the study area and the satellite images that were used to obtain different classes of cover and land use. Section 3 outlins the procedure that was followed to classify the satellite images using two supervised classification methods and LUCC analysis. Section 4 describes and discusses the results obtained with respect to other similar works. Finally, the conclusions are presented in the Section 5.

2. Materials and Methods

2.1. Study Area

The metropolitan area of Tepic-Xalisco is located in the central part of the state of Nayarit (Mexico), as presented in Figure 1. The study area comprises two of the main localities of the state that are linked by commercial and administrative activities through the Tepic-Xalisco highway, which in turn provoked a conurbation process that was formalized as metropolitan area in 2006 by the National Institute of Statistics and Geography (INEGI, for its abbreviation in Spanish), the National Population Council (CONAPO, for its abbreviation in Spanish) and the Ministry of Social Development (SEDESOL, for its abbreviation in Spanish).

The study area was delimited through a 900 km^2 quadrant (30 km $\times$ 30 km polygon) including the metropolitan area, a polygon wide enough to locally observe and analyze the processes of LUCC during a 42 year-period.

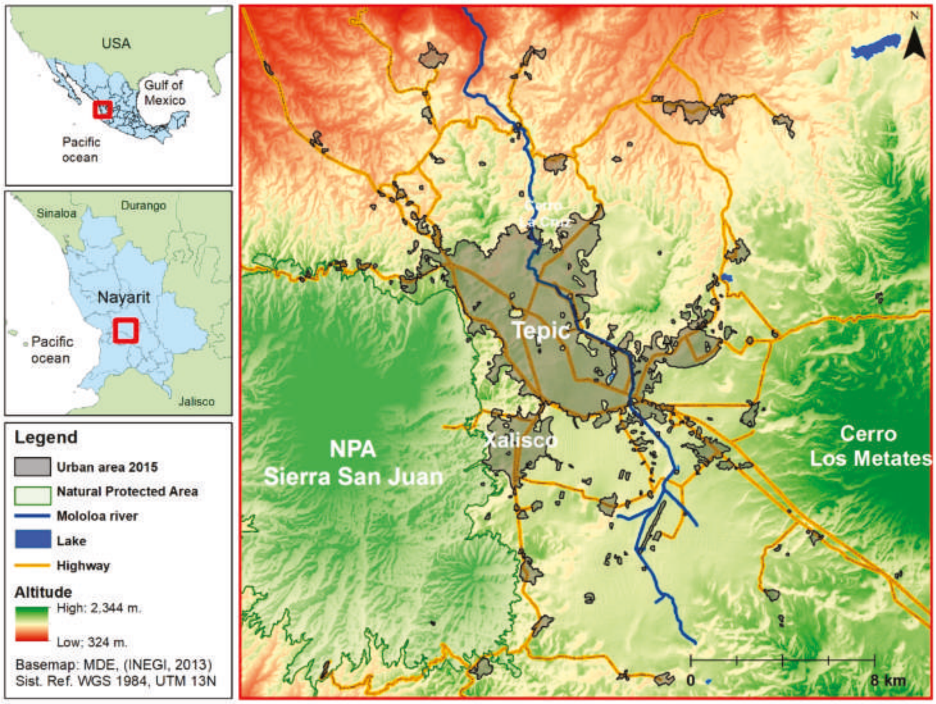


Figure 1. Localization and delimitation of the study area. Source: Own elaboration based on INEGI's data.

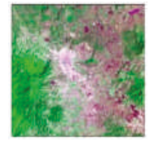
The surrounding zone of the study area contains a diversity of land use where are predominant intensive agricultural activities—mainly devoted to sugarcane, maize, mango and jicama crops—as well as farming activities. To the West of the study area is located the Natural Protected Area (NPA) Sierra de San Juan with over 50% of cover consisting of pine trees and live oaks forest, a great variety of natural resources that provide diverse environmental services susceptible of exploitation.

The metropolitan area has suffered important changes in land use as a result from urban growth. The forest is endangered by the indiscriminate clearcutting activities and mining performed in the east of the mountain, at the boundaries of the locality of Xalisco. Therefore, a historical analysis is necessary to show the distribution of land use and the change processes during a period of 42 years. Such information may be used to simulate future land use changes, such as the urban growth and modeling several scenarios.

2.2. Data

To set a temporary standardized thematic nomenclature for the analysis of the different land use, the four Landsat satellite images described in Table 1 were used. The images were taken from the United States Geological Survey (USGS) official website (http://glovis.usgs.gov).

Table 1. Landsat images used for mapping land uses in the study area.

Description	Image	Description	Image
Landsat 1 (1973) Multispectral Scanner System (MSS) Sensor LM10320451973043GDS03 Scene Spatial resolution 60 m Acquisition date 12 February 1973 Composition V-A-R		Landsat 5 (1985) Thematic Mapper (TM) Sensor LT50300451985139AAA03 Scene Spatial resolution 60 m Acquisition date 5 May 1985 Composition NIR-SWIR-R	
Landsat 7 (2000) Enhanced Thematic Mapper (ETM) Sensor LE70300452000045EDC00 Scene Spatial resolution 30 m Acquisition date 14 February 2000 Composition NIR-SWIR-R		Landsat 8 (2015) Operational Land Imager (OLI) Sensor LO80300452015062LGN01 Scene Spatial resolution 30 m Acquisition date 3 April 2015 Composition NIR-SWIR-R	

Source: United States Geological Survey (USGS) official website.

2.3. Methodology

Figure 2 shows the methodological process that was followed to analyze urban land use changes in the metropolitan area during a period of 42 years. First, supervised classification techniques were applied through Maximum Likelihood Classification (MLC), Support Vector Machines (SVMs) and Artificial Neural Networks (ANNs); from the preparation of the images (pre-processing) to the application of three supervised classification methods (processing), and validation of classifications (post-processing). Then, to detect changes between different land uses, the periods 1973–1985, 1985–2000, 2000–2015 and 1973–2015 were analyzed using cross tabulation. Finally, to identify significant changes, transitions analysis was conducted using the method of Pontius [19]. All processes were performed using GIS with ENVI 5.3, Arcgis 10.3 and Focus (PCI Geomatics, 2015) applications.

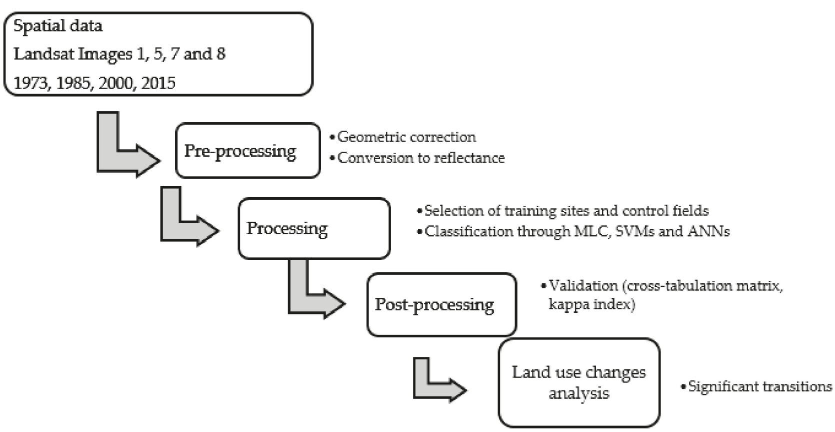


Figure 2. Landsat images classification methodology for LUCC analysis. Source: Own elaboration.

3. Satellite Images Classification

3.1. Pre-Processing

The scenes of Landsat images 1, 5, 7 and 8 were pre-processed to classify the different types of land use during the identification of changes in the urban areas for each analyzed period. Prior to images processing, the study area was cropped for each satellite image by means of a layer (30 km × 30 km polygon) wide enough to visualize urban land use changes in the metropolitan area during a 42-year period; the polygon was measured from the center of the urban land of the metropolitan area.

In the region of interest, it was necessary to verify and standardize the pixel size and the dimensions of each image by means of geometric correction in the WGS-1984 reference system, UTM projection in the zone 13 N. The validation of the geometric correction was obtained with the Mean Squared Error (MSE) for the control points, using one of the images as reference and comparing it (in pairs) to get the best geometric adjustment. To standardize a spatial resolution to 30 m, the four Landsat images were standardized by resampling the pixel size, especially the 1 and 2 Landsat images.

Spectral bands were selected for each image, in particular the ones with optical spectrum, Near Infrared (NIR) and Short-Wave Infrared (SWIR); the panchromatic bands were omitted due to high atmospheric influence, as well as the thermal bands, especially in the 7 and 8 Landsat images. To easily visualize the several classes of covers and land uses, a RGB composition in false color was used, highlighting the strong green areas with the NIR, SWIR and R combination; in addition, 2% of linear contrast highlighting was applied to enhance the visualization and identification of the training sites.

The conversion to reflectance was performed to obtain the terrestrial area spectral reflectance values for the different covers and land uses, giving the spectral value to each pixel. The conversion to reflectance was conducted considering the method of Chavez [20] through the following equation (Equation (1)).

$$\rho_k = \frac{d^2 * \pi * \partial_{1,k} * (ND_k - ND_{min,\,k})}{E_{0,k} * sin\ \theta_e * \tau_{k,i}} \tag{1}$$

where ρ_k is the reflectance for the ***k*** band; d is the factor that considers the solar variation from the Earth–Sun distance, calculated from the Julian Day; $\partial_{1,k}$ is the conversion to radiance multiplicative coefficient; θ_e is the solar elevation angle; and $E_{0,k}$ is the solar irradiance in the top of atmosphere for the ***k*** band. The data to make the conversion to reflectance were obtained from the header files of each satellite image.

3.2. Processing

For processing the images, spectral signatures were created from selecting training sites based on the identification of similar areas in different covers and land uses, combining the knowledge of the area for a proper selection of the regions of interest (ROI). To identify the different land use classes, some visual patterns such as tone, texture and the influence areas were used.

During the identification of the training sites, the separability of the spectral signatures was verified for the five land use classes described in Table 2.

Table 2. Description of identified covers and land uses.

Class No.	Class	Description
1	Urban	Includes urban and industrial areas.
2	Agricultural	Periodic and temporary irrigation agriculture.
3	Water bodies	Water bodies, lakes and rivers.
4	Secondary vegetation	Includes arbustive (scrub and grassland) and arboreal vegetation of low or scarce density.
5	Forest	High density arboreal vegetation.

Source: Own elaboration.

While selecting the training sites, control fields verified in situ were also set for validation of each classified image (post-processing).

To obtain the different land use classes, three supervised classification methods were used. First, the Maximum Likelihood Classification (MLC) method, as the most widely used in the scientific literature, is fast, easy to apply and enables a clear interpretation of the results [21]. This algorithm can obtain a spectral image of each land use class through variance and covariance statistics of the set of training sites identified in the image and calculates the probability of belonging to each class according to the spectral signature; this method has been proven in works such as those of [22–25], with satisfactory results.

The Support Vector Machines (SVMs) algorithm was the second method applied. This automatic learning algorithm trains linear and non-linear learning functions by transforming the original data into a different space with a function (kernel) to obtain the hyperplane which maximizes the margin of separation between two or more classes to be classified [26]. Currently, the SVMs algorithm is among the most reliable methods; therefore, it is used in many works [27–29] with satisfactory results. For the classification of images the Radial Basis Function (RBF) for not-linearly separable data was used.

Finally, the third method applied was the Artificial Neural Networks (ANNs), an automatic learning method that predicts a complex behavior from a sample of observed inputs and outputs. The network structure is based on a simplified model of the human brain consisting of three layers: input, hidden and output. This structure is trained to recognize the result from input values and classify the rest according to the given rules [30,31]. Neural networks have been applied to classify satellite images with good results [32,33].

The ANNs classification was applied with a hidden layer of standard backpropagation for supervised learning by means of the logistic activation function for non-linear classification.

3.3. Post-Processing

To obtain a better representation of the land use mapping, each classified image was subject to a series of auxiliary processes: a process of majority filtering (3 × 3 pixels) and a method of generalization of polygons less than one hectare—as they are few representatives with respect to the minimum mapping unit—were applied, which reduced the image noise and eliminated the isolated polygons, resulting in the land use mapping for each year of analysis. Finally, to standardize and confirm the location of urban areas, a visual inspection of the mapped urban localities and the population census with historical data from INEGI for the same analyzed periods was carried out.

To validate the obtained results, the classified images were compared against the control fields through a cross-tabulation matrix for the different dates. At the same time the following were obtained: the kappa index, which shows the degree of similarity between a set of control fields and the classified image; the general accuracy, which indicates the percentage of pixels properly classified; the percentage of producer's accuracy, which sets the percentage of a kind of particular land use change correctly classified in the image; and the percentage of user's accuracy, which provides the percentage of a land use class in the image that matches with the class that corresponds in the land.

The model validated as the one with higher accuracy was used to represent the cover and land use mapping for the years 1973, 1985, 2000 and 2015.

3.4. Analysis of Land Use and Cover Changes

The analysis of LUCC was conducted through the cross-tabulation matrix to obtain losses, gains and interchanges between the different covers and land uses and after that, the significant transitions analysis was conducted according to the methodology proposed by [19]. For each cover and land use the cross-tabulation matrix enables to obtain, through the diagonal values, the stable areas between two dates, as well as the losses (below the diagonal) and the gains (above the diagonal). Such significant transitions on each cover and land use were obtained by comparing the gains and/or real losses against the gains and/or expected losses randomly, divided by the gains and/or expected losses. This comparison gave as a result the transition index where the values less than one indicated non-significant changes among covers and land uses, while the positive values more than one, indicated significant transitions.

4. Results and Discussion

4.1. Satellite Images Classification

Figure 3 shows the mapping of covers and land uses obtained for each classified Landsat image. The urban land use has mainly replaced agricultural land use where the productive activities has been focused on sugarcane, maize, mango and jicama crops at rate of 1.48 km^2/year.

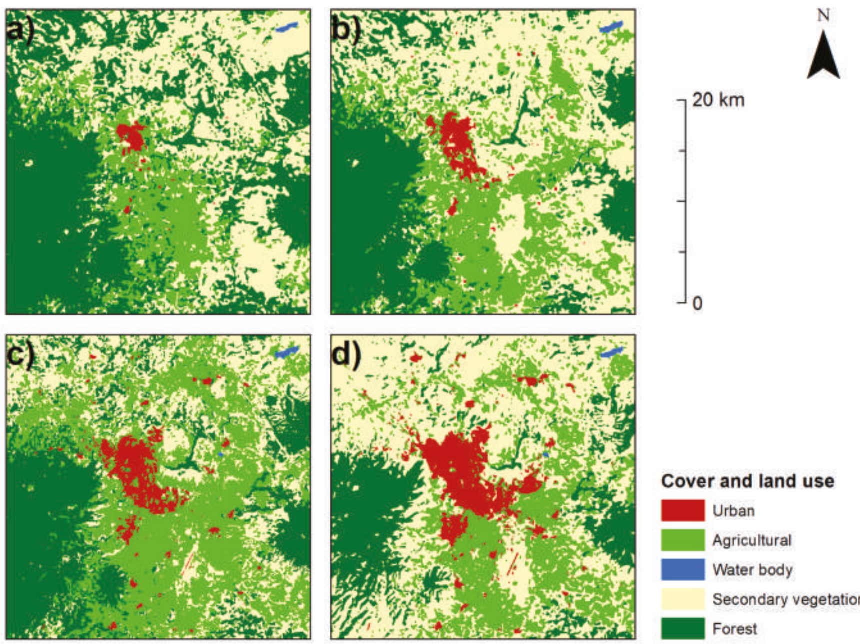


Figure 3. Image classified from Landsat images 1, 5, 7 and 8 with SVMs; Cover and land use: (**a**) 1973; (**b**) 1985; (**c**) 2000; and (**d**) 2015. Source: Own elaboration from Landsat images 1, 5, 7 and 8.

4.2. Classification Validation

Table 3 shows the results from the process of classified images validation through the cross-tabulation matrix and the parameters obtained: kappa index, general accuracy, producer's accuracy and user's accuracy. Validation statistics show better results when using the SVMs classification method, from which general accuracy above 85% is recorded for the four classified Landsat images 1, 5, 7 and 8, unlike the maximum likelihood classification and the artificial neural networks methods.

Table 3. Classified images validation.

Year Evaluated	SVMs		MLC		ANNs	
	General Accuracy	Kappa Index	General Accuracy	Kappa Index	General Accuracy	Kappa Index
1973	98.7%	0.98	97.7%	0.96	97.7%	0.96
1985	89.0%	0.85	92.5%	0.90	96.5%	0.95
2000	89.3%	0.85	82.1%	0.76	92.7%	0.90
2015	90.4%	0.87	86.1%	0.81	86.1%	0.81

Source: Own elaboration.

When selecting training fields, separability problems were identified between the secondary vegetation and the agricultural land use classes, which is reflected in the producer's accuracy percentage with values below 90%. The best fit was recorded when using the SVMs classification method, where the accuracy percentages average 96% for the user, and 95% for the producer; as shown in the Table 4.

Table 4. Percentages of producer's accuracy and user's accuracy.

Classified Image	Class	SVMs		MLC		ANNs	
		Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)	Producer's Accuracy (%)	User's Accuracy (%)
Landsat 1 MSS (1973)	Urban	100	100	100	100	100	100
	Agricultural	97	100	96	99	95	100
	Water body	100	100	100	100	100	100
	Secondary vegetation	100	95	100	93	100	98
	Forest	99	100	96	100	98	94
Landsat 5 TM (1985)	Urban	100	100	100	100	83	199
	Agricultural	100	100	100	100	100	98
	Water body	100	100	100	100	100	90
	Secondary vegetation	68	100	82	100	99	94
	Forest	100	74	100	83	93	100
Landsat 7 ETM (2000)	Urban	100	100	100	56	100	39
	Agricultural	100	100	93	100	89	98
	Water body	100	100	100	100	100	100
	Secondary vegetation	56	100	63	100	86	100
	Forest	100	67	100	71	100	89
Landsat 8 OLI (2015)	Urban	100	100	100	100	94	89
	Agricultural	100	80	100	94	95	84
	Water body	100	100	100	100	100	95
	Secondary vegetation	72	100	44	100	71	69
	Forest	100	96	100	76	83	93
Mean		95	96	94	94	94	96

Source: Own elaboration.

4.3. Analysis of Land Use Changes

Table 5 shows the changes in area for each class of cover and land use occurred during 1973–2015. The urban land use has increased 7% from the overall analyzed area with an annual rate of 1.48 km^2/year. At the same time, the forest cover has lost 28% of area in 42 years, with an annual rate of 5.78 km^2/year.

Table 5. LUCC during 1973–2015 according to the SVMs method.

Classification Method	Class	Description	1973		1985		2000		2015		Annual Rate (km^2)
			Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	
SVMs	1	Urban	6.8	1	19.2	2	40.0	4	68.8	8	1.48
	2	Agricultural	151.1	17	215.1	24	342.8	38	211.3	23	1.43
	3	Water body	1.1	0	1.4	0	1.5	0	1.4	0	0.01
	4	Secondary vegetation	322.7	36	383.7	43	243.7	27	442.8	49	2.86
	5	Forest	418.3	46	280.6	31	272.1	30	175.7	20	5.78 *
MLC	1	Urban	6.8	1	19.2	2	39.9	4	68.6	8	1.47
	2	Agricultural	179.5	20	258.1	29	234.7	26	218.5	24	0.93
	3	Water body	1.2	0	1.7	0	1.4	0	1.5	0	0.01
	4	Secondary vegetation	396.0	44	319.6	36	372.7	41	401.7	45	0.13
	5	Forest	316.4	35	301.3	33	251.3	28	209.7	23	2.54 *
ANNs	1	Urban	6.8	1	19.2	2	39.9	4	68.8	8	1.48
	2	Agricultural	140.1	16	221.3	25	314.2	35	331.1	37	4.55
	3	Water body	1.1	0	2.6	0	2.1	0	1.8	0	0.02
	4	Secondary vegetation	281.2	31	413.4	46	283.6	32	284.4	32	0.08
	5	Forest	470.8	52	243.6	27	260.2	29	213.9	24	6.12 *

* Loss. Source: Own elaboration.

The annual rates of change for each class of cover and land use are shown in Figure 4. Differences were identified depending on the classification methods applied. When applying the SVMs and ANNs methods, the urban land use presented a similar trend of 1.48 km^2/year of change. The three methods recorded differences regarding agricultural land use, where the ANNs method registered a rate of 4.55 km^2/year, while the SVMs method obtained rates of 1.43 km^2/year. The secondary vegetation cover also presented important differences; while the SVMs method registered a rate of 2.86 km^2/year, the results of the MLC and ANNs methods presented a rate below 0.13 and 0.08 km^2/year, respectively. With regard to the forest, the methods SVMs and ANNs obtained similar annual rates of 5.78 and 6.12 km^2/year; the negative rate of change is due to the loss of surface.

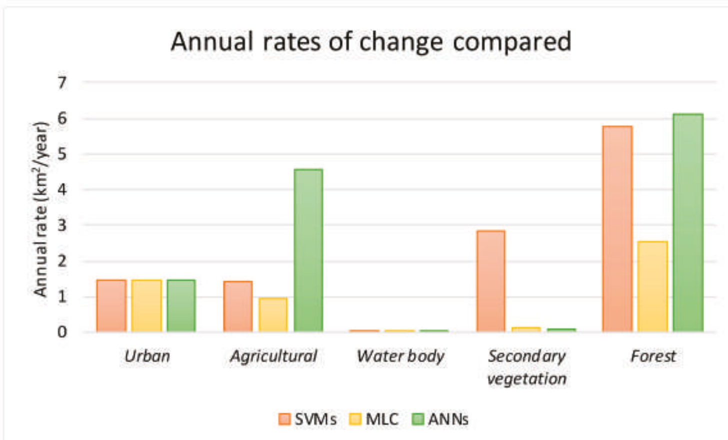


Figure 4. Annual rates of change according to the classification methods applied. Source. Own elaboration.

Since the SVMs method proved the best fit, the results from applying this method were used to analyze significant transitions and land use changes in the metropolitan area.

The changes occurred in this same period due to losses and gains are shown in Table 6. The main results show that the urban land use in the metropolitan area has increased 62 km^2 since 1973. The agricultural area and the secondary vegetation present most of the interchanges due to crop rotation, which is confirmed when observing the losses and gains of these same land use classes.

Table 6. Land use losses, gains and interchanges between periods with SVMs.

Period	Class	Area (km^2)							
		Total (t1)	Total (t2)	Steady (E)	Gains (G)	Losses (L)	Interchanges (I)	Net Change (NT)	Total Change (CT)
1973–1985	Urban	6.8	19.2	6.8	12.4	0.0	0.0	12.4	12.4
	Agricultural	151.1	215.1	86.6	128.5	64.5	129.0	64.0	193.0
	Water body	1.1	1.4	1.0	0.4	0.0	0.1	0.3	0.4
	Secondary vegetation	322.7	383.7	229.0	154.7	93.7	187.4	61.0	248.4
	Forest	418.3	280.6	263.0	17.6	155.3	35.2	137.7	172.9
1985–2000	Urban	19.2	40.0	19.2	20.8	0.0	0.0	20.8	20.8
	Agriculture	215.1	342.8	171.3	171.5	43.8	87.6	127.7	215.3
	Water body	1.4	1.5	1.3	0.2	0.1	0.2	0.1	0.3
	Secondary vegetation	383.7	243.7	185.2	58.5	198.5	116.9	140.1	257.0
	Forest	280.6	272.1	227.1	45.0	53.6	90.1	8.5	98.6
2000–2015	Urban	40.0	68.8	40.0	28.9	0.0	0.0	28.9	28.9
	Agricultural	342.8	211.3	182.3	29.0	160.5	58.1	131.5	189.5
	Water body	1.5	1.4	1.3	0.1	0.3	0.2	0.2	0.4
	Secondary vegetation	243.7	442.8	203.7	239.1	40.0	79.9	199.1	279.1
	Forest	272.1	175.7	161.8	13.9	110.3	27.8	96.4	124.2
1973–2015	Urban	6.8	68.8	6.8	62.0	0.0	0.0	62.0	62.0
	Agriculture	151.1	211.3	64.4	146.9	86.7	173.4	60.3	233.6
	Water body	1.1	1.4	1.0	0.3	0.0	0.0	0.3	0.3
	Secondary vegetation	322.7	442.8	194.2	248.6	128.5	257.0	120.1	377.1
	Forest	418.3	175.7	166.4	9.3	251.9	18.5	242.7	261.1

Source: Own elaboration.

The transitions analysis for each cover and land use is summarized in Table 7. Significant transitions for the analyzed periods are registered particularly in the agricultural land use change to urban land use and secondary vegetation. The increase of urban area and secondary vegetation is because the agricultural area is being replaced. During a 42-year period, 33.1 km^2 of agricultural use transformed into urban areas and 53.3 km^2 into secondary vegetation. The forest also has been affected with transitions, although non-significant. They recorded ecological changes of 49.1 km^2 to agricultural land and 195.3 km^2 to secondary vegetation.

Table 7. Significant transitions analysis.

From	Area (km^2)				To
	1973–1985	1985–2000	2000–2015	1973–2015	
Agricultural	8.9 *	7.6 *	24.7 *	33.1 *	Urban
	0.0	0.1	0.1	0.0	Water body
	51.3 *	29.6	133.2	53.3	Secondary vegetation
	4.2	6.5	2.5	0.2	Forest
Water body	0.0	0.0	0.0	0.0	Urban
	0.0	0.0	0.1	0.0	Agricultural
	0.0	0.0	0.2	0.0	Secondary vegetation
	0.0	0.0	0.0	0.0	Forest
Secondary vegetation	2.7	12.8	3.9	21.4	Urban
	77.3	147.2	24.6	97.8	Agricultural
	0.4	0.1	0.0	0.2	Water body
	13.3	38.5	11.4	9.0	Forest
Forest	0.7	0.4	0.2	7.5	Urban
	51.2	24.3	4.4	49.1	Agricultural
	0.0	0.1	0.0	0.1	Water body
	103.4	28.8	11.4	195.3	Secondary vegetation

* Significant transition. Source: Own elaboration.

The methodology applied in this study is similar to the one used by Aguayo et al. [1], Lopez and Plata [25] and Antillón et al. [34], who applied the maximum likelihood algorithm to get the different land use classes of the study area and analyzed LUCC through cross-tabulation method or confusion matrix. The results of said investigations have had the same trend as obtained in the present study as regards to urban areas replacing agricultural lands, as well as a decrease in the forest area.

According to the scientific literature, the SVMs method has been used in several studies such as those developed by Mountrakis et al. [27]; Lu et al. [28]; and Xie et al. [29] with good results on image classification, similar to the results obtained in this work where the SVMs method registered the best fit. Some works have compared different supervised classification methods; for example, Pal and Mather [35] used the same three classification methods that were applied in this study (MLC, ANNs and SVMs), obtaining the best fit results through SVMs. On the other hand, Otukei and Blaschke [36] compared three methods of classification, MLC, SVMs and Decision Trees (DT), and affirmed that the best results were obtained when applying SVMs. In addition, Mondal et al. [37] compared the SVMs and MLC methods, and concluded that when preparing land use maps, the SVMs method is more appropriate than the MLC. Finally, in a more recent study, Wu et al. [38] compared the SVMs, ANNs and DT methods; although radial base and polynomial functions were used for SVMs, this method obtained better results with kappa indices (0.72 and 0.79 for each function, respectively). Both the results in the above mentioned research and in this work obtained the best fit applying the SVMs method; therefore, the results from applying this method were used for the LUCC analysis in the study area.

In Mexico, several studies on LUCC have been conducted to achieve a better understanding on the dynamics and processes of land use change (e.g., [2,8,14,24,25,34,39–43]). These studies have been oriented to identify forest areas loss rates, unlike this research that was focused on analyzing the urban land use during three periods with the intention of identifying the historical dynamics of urban growth to be able to build urban growth simulation models and development of future scenarios.

Particularly, Cano et al. [44] analyzed urban land use in Hidalgo State (Mexico). From satellite images, they identified urban growth of 72.3 km^2 in a 14-year period, equivalent to an annual growth rate of 1.8%. On the other hand, by means of digital and visual techniques classification, Lopez and Plata [25] analyzed LUCC in the metropolitan area of Mexico City regarding urban expansion detecting an urban growth of 202 km^2 equivalent to 16% in a 10-year period. In comparison with the present work, in the metropolitan area of Tepic-Xalisco it was possible to quantify an urban growth of 62 km^2 during a 42-year period, with an annual rate of 1.48 km^2, which means a relatively low growth regarding to the metropolitan area of Mexico City.

For the study area, the research on cover and land use analysis conducted by Nájera et al. [45] was identified for the Mololoa River watershed, which determined natural vegetation losses of 41.67 ha/year with deforestation rates of 0.1% and urban growth of 74.86 ha/year, which is nearly half that obtained by this study that registered an increase of urban land of 148 ha/year (1.48 km^2/year). These results may be attributed to the difference in the boundaries set for the study areas, and to the methodology used to obtain the different land use classes.

5. Conclusions

The validation results from the classifications developed suggest that the SVMs method gives the best fit and offers greater certainty on the distribution and quantification of the different classes of cover and land use obtained.

The urban land use in the metropolitan area of Tepic-Xalisco has experienced an important increase within a period of 42 years, exceeding ten times the urban area recorded in 1973, with a rate of 1.48 km^2/year. This growth has produced significant changes in land use with transitions towards agricultural and secondary vegetation land use. The forest cover also has been affected, since it has experienced considerable losses of area with transformation trends towards secondary vegetation. In addition, the agricultural land use has been replaced as a result of urban growth. This situation has caused functional implications on ecosystems and to date losses of agricultural productive area are present, as well as deforestation processes.

The applied methodology enabled learning about the historical dynamics and quantifying the LUCC during a 42-year period, identifying the transitions between each land use. This information will help to establish land planning strategies, promote management and develop land use conservation policies.

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