



Relationship between land urbanization and the ecosystem service value of land: evidence from Chinese land use

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Abstract

The connection between land urbanization (LU) and the ecosystem service value (ESV) from land is studied theoretically and empirically in this research. Firstly, an optimization model with constraints in which the externality of land development and construction is internalized into decision-making behavior of local governments is established to theoretically find out the potential link between urbanization and ecosystem value; then, an empirical analysis using cross-section dataset of 280 cities in mainland China in 2010 is conducted to verify the theoretical results. It could be concluded that the influence of LU on ESV of land depends on phase of economic development. When the unit conveyance fee's marginal effect of requisitioned land is greater than the unit compensation's marginal effect of this land, LU exerts a negative impact toward ESV of land and vice versa. An empirical analysis indicated a U-shaped curve between LU and the ESV of land, biodiversity, carbon sequestration, soil retention, and water retention. However, the effect of LU on ESV is currently still negative. These results held up significantly after endogeneity tests and some robustness tests. Finally, we suggest that Chinese government should promote innovations in terms of the pattern of land use as well as institutions.

Keywords Land urbanization · Ecosystem service value · Land use · An optimization model with constraints · China

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1 Introduction

The reform and opening up in China have brought the country significant strides in economic development, which greatly accelerated the urbanization process. However, this has come at the expense of ecosystem services, which include products or services gained from ecosystems. These services include physical products like food, raw materials, and intangible services like carbon storage and biodiversity preservation (Costanza, 2020). The rapid urbanization has resulted in variations in land use types, with agricultural or inactive land becoming urban construction areas, a phenomenon referred to as "land urbanization (LU)." This shift in land use patterns affects the allocation structure, intensity, and efficiency of land use, ultimately impacting ecosystem services such as habitats, biodiversity, energy cycles, water cycles, geochemical cycles, and climate (Chuai et al., 2015; Lam & Conway, 2018). Moreover, human activities conducted on land, such as population growth, industrial development, energy consumption, and technological advancements, have additional feedback effects on the ecosystem processes, further affecting the functions of environmental services (Chuai et al., 2016; Jantz & Manuel, 2013; Lai et al., 2016). The variations in environmental service functions, areas, and spatial distribution patterns led by land use variation and its derived human activities are important reasons for changes in environmental service functions (Xie et al., 2021).

The effects of land utilization variation on environmental services during LU are embodied in the following aspects:

Initially, the rise in the scale of city construction land undermines biodiversity and leads to the fragmentation in natural habitat. The acceleration of urbanization in turn accelerates the change in land use structure. With the accelerating LU, huge amounts of agricultural land are converted towards construction land. Chinese urban construction land area grew by 164% from 20,877 square kilometers in 1999 to 55,155.5 square kilometers in 2017 (Ji, 2023). The expansion of urbanization destroys natural vegetation and hydrological systems among others, which leads to the fragmentation of natural habitat, the simplification and homogeneity of species composition, and a decline in biodiversity (Fricke & Svenning, 2020). Simultaneously, variation in energy flow and nutrient cycling reduces the environmental adaptability of species.

Secondly, the change in land allocation structure will profoundly affect the ecological process of the ecosystem, thus, changing the ecosystem service function by exerting biophysical and social influences (Grimm et al., 2008). The rapid LU has created a sequence of problems, like variation in land use/cover as well as an unreasonable form for land allocation. In China, the percentage for industrial land at construction area is normally about 20%. In Pearl River Delta or other cities with developed manufacturing industries, the percentage of industrial land is generally above 40%. In the same period, the international ratio was only 5–8%; in most developed area, the figure is normally smaller than 10% (Xie et al., 2016). Too much industrial land results in the slow transformation and upgrade of industrial structure and the discharge of a large number of pollutants during the process of industrial production, which has negatively affects the self-circulation as well as other functions of the ecosystem. Variations in the structure of land allocation affect environmental processes, like energy, water, as well as geochemical cycles and the renewal of soil, by changing the environmental structure and function; this results in additional variations in ecosystem service functions and ecological effects (Chuai et al., 2013; Shu & Xiong, 2019).

Third, the high intensity of land development will disturb the balance of the ecosystem, destroy the mutual connection between biological populations, and thus, reduce the supply of ecosystem services (Fang et al., 2022; Li et al., 2014; Smith et al., 2019). Considering China's national conditions, the development intensity of inland land should not exceed 10% in general, and that of coastal areas should not exceed 20%. Currently, China's major cities have substantially exceeded this proportion. A high intensity of land development would seriously undermine the balance between urban landscapes and ecosystems. It affects the landscape, interfere with the balance of the ecosystem, destroy the mutual connection between biological populations, directly change the supply of environmental services, and indirectly affect the environmental service functions by changing the social and economic system. Pollutants emitted during the process of economic production will also greatly disrupt the balance of the ecosystem and reduce its ability to provide ecological services (Allan et al., 2014, 2015).

Finally, land use efficiency influences the improvement of ecological energy conversion efficiency, thus, changing the land use processes on environmental services. (Bateman et al., 2013). In early stage of economic development, the economy was based on an extensive development model. The Chinese central government evaluated local governments based on gross economic development indicators, such as GDP and tax revenue. To attract investment, local governments sell industrial land cheaply to increase local GDP and tax revenue (Tao et al., 2009). Industrial land is usually less efficient, which results in a large amount of inefficient, idle industrial land, and serious pollution. This reduces the ESV. When the economy enters a phase of high-quality development, land utilization efficiency should be improved; impact from land variation on environmental services should be reduced through innovation in land systems (Costanza, 2020).

Ecosystem service is important in improving human welfare, and can be regarded as the direct as well as indirect contributions of environment to human welfare (Costanza et al., 2017). According to exclusive characteristics of environmental services and products, they can be divided into general private goods, club products, public resources, and pure public goods. The payment and transaction methods are determined by ecosystem services, in turn influencing realization of ESV (Xie et al., 2021; Yang et al., 2020). Generally, the realization mechanism of ESV mainly includes government administrative mechanism, market mechanism, and multi-center governance mechanism (Gao et al., 2019). In terms of general private and club ecosystem service goods, they mainly rely on the market and price mechanisms to realize their value. However, market-based approaches fail in some instances such as imperfect as well as asymmetric information. In terms of pure public goods, their value is mainly realized through administrative mechanisms, including transfer payments, ecological compensation, and taxation. The 18th National Congress of China unveiled a series of significant progress in ecological compensation, resource product price mechanism, energy use right trading, water use right trading, emission right trading, carbon Emissions trading, green finance and related policies to improve ESV (Gu et al., 2019). The 19th National Congress motivated more ecological-friendly products and the Fifth Plenary Session from Central Committee stressed "establishing ecological product value realization mechanism." However, the effective utilization of land spatial planning policies by the Chinese government, the full integration of synergistic and balancing effects of government administrative and market mechanisms, and the use of market mechanisms for property rights transactions to protect the ecosystem, are still lacking. Therefore, there is a need to design a reasonable mechanism for realizing the ESV.

LU and environmental services are a comprehensive system of mutual influence. Establishing a dual objective system of optimizing land resource allocation and enhancing ESV

will help to coordinate economic development and ecological protection. LU is decided by nature, society, economy, as well as other factors. Among them, the natural condition is the basic part that leads to LU, like climate, soil, as well as hydrology among others (Bateman et al., 2013; Cavender-Bares et al., 2015). Changes in land type and usage will influence the types, intensities, and functions of ecosystem services supply, thus, leading to changes in ESV (Eichner and Pethig, 2009; Chuai et al., 2013, 2015, 2016; Cumming et al., 2014; Chen et al., 2020). Therefore, there may be a nonlinear relationship between LU and ESV, which merits further study.

Existing research on the influence of LU on ESV could be categorized into three aspects. The first type is based on spatial statistics methods, which utilize hotspot analysis or spatial autocorrelation models to analyze the spatial relationship. The second type combines land use econometric models with simulations of spatial patterns of LU to analyze the influence of LU on ESV. The third type employs land utilization simulation models to simulate the spatial patterns of land utilization and their impact on ESV. Examples of such models include CLUE-S model adopted by Verburg et al. (2002), FLUS model used by Liu et al. (2017), as well as Plus model. However, current research primarily relies on quantitative or simulation methods to examine the connection between LU and ESV. Notably, there exists a reciprocal relationship and feedback loop between the economic utilization of land and the ecosystem. Unfortunately, existing research has not thoroughly explored the connection between LU and ESV, thereby failing to uncover the underlying mechanisms through which land use impacts ESV.

This study theoretically and empirically examined the correlation between LU and the ESV of land. As Lichtenberg and Ding (2009) and Turnbull (2004) did, we began with constructing a theoretical model for a constrained optimization model in which the externality of local government's land development and construction is endogenous to its decision-making behavior to demonstrate the nonlinear relationship between LU and ESV of land. We then used a Chinese prefecture-level panel data to verify the results we have obtained in the theoretical model; in this way, the study should be more convincing both theoretically and empirically. Finally, we drew a conclusion through analysis of the results and suggested some policy recommendations.

2 Literature

During the process of LU, land development activities affect the land surface material cycle and life processes, which causes changes in the surface structure. High-intensity land development will affect the balance of the biosphere (Mendoza-Gonzalez et al., 2012; Peters et al., 2019). Because of low land utilization efficiency, a large number of pollutants are discharged to the outside world during the process of production and living, which will affect the regional atmospheric environment, water environment and soil resources among others (Costanza, 2020; Wang et al., 2018). In summary, LU caused by human activities can change the ecological habitat area, ecosystem structure, and ecosystem cycle process. This further affects the conversion and transformation of material, energy, and information flows in ecosystems, resulting in the fragmentation of habitats, homogenization of species composition, destruction of hydrological systems, and variations in energy as well as nutrient cycling. Finally, the environmental service functions are degraded, which results in the decline of ESV (Cumming et al., 2014; Oliver & Morecroft, 2014; Wan et al., 2015).

Some of the existing literature has studied the interaction between economic systems and ecosystems by establishing a dynamic general equilibrium model that combines economic systems and ecosystems (Zhu et al., 2019), while there are also studies on the internalization of ecosystem externalities through transfer payments or property rights transactions between the two regions (Eichner & Pethig, 2019). Some existing literature empirically analyzed the negative relationship between LU and ESV based on Environmental Kuznets Curve (EKC), mentioned by Grossman and Krueger (1995). Newbold et al. (2015) studied how land utilization influenced biodiversity and concluded the changes in land use harmed biodiversity. Ye et al. (2018) showed a net 4.4% (201.5 million USD) decline in ESV owing to land utilization changes in the rapidly developing Guangfo metropolitan area in China. Wang et al. (2018) asserted that the energy ESV declined by 10.89% during LU in Yellow River Delta. Du and Huang (2017) found that during the process of rapid LU, the ESV in Hangzhou declined significantly. Chuai et al. (2016) showed that LU reduced the ESV in Jiangsu Province of China by 43.2 million USD between the 1980s and 2010. Peng et al. (2017) pointed out the negative correlation between LU and total ESV in the suburban areas of Beijing. Cao et al. (2018) asserted a sharp decrease of 15.06% ESV from RMB 35.278 billion to 29.964 billion in Zhejiang Province between 1990 and 2010; Hu et al. (2019) studied the scenario in Anhui province and found the ESV fell from $30,015.58 \times 10^7$ RMB in 2000 to $29,683.74 \times 10^7$ RMB in 2015, indicating a 1.11% decline. Furthermore, as shown by Song et al. (2015), LU caused a net loss of 880 million USD in ESV from 2000 to 2008, and the expansion of urbanized areas accounted for 84.61% of the loss in ESV. Su et al. (2014) studied change of ESV in suburbs within Shanghai and its relationship with land utilization, concluding that from 1994 to 2006, the total ESV decreased by 30.8%.

Furthermore, there are also many studies investigating the influence of land resource allocation optimization in different regions on ESV. Examples of substantial analyses include the following: (1) land utilization optimization as well as environmental impacts in typical areas of an agro-pastoral ecotone within northeast China (Yang et al., 2020); (2) the influence of LU on the ESV in the northeast transect (Wang et al., 2022); (3) spatial autocorrelation pattern analysis in terms of land utilization and ESV in northeastern Hainan (Lei et al., 2019); and 4) impacts of LU on ESV in the Sanjiang Plain, Zhejiang, Kunshan City in Jiangsu Province and Mingguang City in Anhui Province (Hasan et al., 2020; Qiao & Huang, 2022).

However, China's central and local governments have different incentive goals in land use, which leads to different mechanisms of LU on the ESV. While attaching importance to land utilization efficiency, the central government also examines various economic, social, and ecological environmental goals, such as coordinated regional development, food security, environmental protection, and public services. Local governments have the motivation for distortion behaviors, like investment impulse, performance appraisal, and land finance. As a result, local governments may have conflicts in the principle of land utilization with central governments. Local governments strive for more allocation of land resources within framework set by central government responsibility and participate in horizontal competition among regions (Chen et al., 2020). Local government officials use land disposal rights to strategically set land transfer prices and scale in the monopolized land market (Wang et al., 2018). Therefore, industrial land is transferred by low-price agreement as a means of attracting investment (Zhang et al., 2017). Alternatively, the government sells commercial or residential land at a much higher price in the way of recruitment, auction, and hanging, an enormous amount of land transfer fee is obtained, namely, "generating wealth from land" (Zheng Siqi et al., 2014). The development mode of "land management"

and “regional competition” of local governments leads to inefficient utilization, idle waste, and the serious environmental pollution of industrial land (Tao Ran et al., 2009). The conflict of behavioral goals between central and local governments in land resource allocation leads to land resource mismatch (Wang et al., 2018, 2021). As a result, the land ecological function degrades, and there is a decline in ecological efficiency (Teulings et al., 2018). In addition, land allocation, industrial, and energy consumption structures; and technology level and other characteristics are heterogeneous, which leads to a nonlinear relationship on the impact of land utilization on ESV. Previous literature did not investigate the nonlinear relationship and mechanism of LU affecting ESV from the reality in China. This is also the exact innovation of this study.

3 Theoretical model

China adopts public ownership on all land. The State owned land in urban areas; ‘collectives’ owned land in rural areas which could only be utilized for agriculture. The Chinese central government controls the supply of new construction land. These new construction land mainly comes from the government’s expropriation or requisition of agricultural land, which is generated through the government’s non-agricultural land conversion behavior (Deng et al., 2008, 2011). With the promotion of farmland conversion, the scale of urban construction land rises, negatively affecting ecosystem service system increases accordingly (Wan et al., 2015). The local governments aims to pursue economic growth and increase employment, focusing on the acquisition of construction land indicators required for industrialization (Wang et al., 2021). At this time, the central government should use the land utilization planning as well as control system. Based on theoretical models of Lichtenberg and Ding (2009) and Turnbull (2004), this study attempts to establish an optimization model with constraints in which the externality of land development and construction is internalized into the decision-making behavior of local governments to demonstrate the nonlinear relationship between LU and ESV of the land.

It is first necessary to make some assumptions to construct an accurate theoretical model. In China, the land area of one city is designed for agricultural or urban use. The total land area is assumed to be unit one for simplicity. The scale of urban land is denoted as $N(t)$. Accordingly, the scale of agricultural land is $1 - N(t)$. The unit output of urban land is assumed to be $R(N(t))$, and it satisfies $R(\cdot) > 0$, $R'(\cdot) < 0$, i.e. the output of urban land meets the law of diminishing returns to scale; similarly, the unit output of agricultural land is assumed to be $r(1 - N(t))$. As LU progresses, the change of area from agricultural use to urban use would be $X(t)$ during period t , and land conversion $X(t)$ should be less than the planned land quota X_0 , which is issued by central government:

$$\dot{N}(t) = X(t) \quad (1)$$

$$X(t) \leq X_0 \quad (2)$$

where $X(t)$ represents how much land gets transformed from non-urban into urban use during period t .

It is imperative to recognize that agricultural land can bring positive externalities, as it could perform as a place like watershed or wetlands (Turnbull, 2004). Unused land could also create value as a sanctuary for endangered animal. As suggested by Turnbull (2004),

unused land can be considered to be a source of a positive externality, which is shown in Eq. (3).

$$E(t) = \epsilon e^{\gamma t} \tag{3}$$

Local government decides how much land would be transformed from non-urban use to urban use by requesting non-urban use land. In China, local government has to compensate for the land it requisitions; $\phi(\cdot)$ can be used to indicate unit compensation on agricultural land. Meanwhile, local government gains a unit conveyance fee $v(\cdot)$ by leasing land use rights. GDP, representing economic behaviour in urban area, increases owing to the concave function for stock on urban land, $R(N(t))$. ρ can be considered as the discount rate, i.e., the local government's time preference for gaining outcomes.

The local government tries to maximize the gain from land development under the control of central government. Therefore, land transformation $X(t)$ is picked to maximize its total output, but they should factor in environmental quality in this study. The current value of the social benefits from agricultural land conversion is shown in Eq. (4); the total benefit should be GDP created by non-urban and urban area plus positive externalities brought by agricultural land, minus compensation plus conveyance fee of transitioned land.

$$W = \int_0^\infty \left\{ \int_0^{N(t)} R(z)e^{\gamma t} dz + \int_{N(t)}^1 r(1-z)e^{\gamma t} dz + \epsilon e^{\gamma t}(1-N(t)) - \int_0^{X(t)} \phi(z)e^{\gamma t} dz + \int_0^{X(t)} v(z)e^{\gamma t} dz \right\} e^{-\rho t} dt \tag{4}$$

Subject to Eq. (1), Eq. (2) and a restriction on the amount of land for urban usage, $N(0) = N_0$.

This is a dynamic optimization problem whereas local government chooses $X(t)$; therefore, it would be reasonable to use its Hamilton function:

$$H(N(t), X(t), \lambda(t), \mu(t)) = \int_0^{N(t)} R(z)e^{\gamma t} dz + \int_{N(t)}^1 r(1-z)e^{\gamma t} dz + \epsilon e^{\gamma t}(1-N(t)) - \int_0^{X(t)} \phi(z)e^{\gamma t} dz + \int_0^{X(t)} v(z)e^{\gamma t} dz + \lambda(t)X(t) \tag{5}$$

We obtained the following equations by solving this problem.

- (1) (1) Control equation: for all t , we have $\partial H / \partial X = 0$, i.e.

$$\lambda(t) - \phi(X(t))e^{\gamma t} + v(X(t))e^{\gamma t} = 0 \tag{6}$$

- (2) The state equation: $\dot{N}(t) = \frac{\partial H}{\partial \lambda}$, and thus, we have $\dot{N}(t) = X(t)$.

- (3) The co-state equation: $\dot{\lambda}(t) = \rho \lambda(t) - \partial H / \partial N$, and therefore we have

$$\dot{\lambda}(t) = (\rho - \gamma)\lambda(t) - [R(N(t)) - r(1 - N(t)) - \epsilon] \tag{7}$$

- (4) The transversality condition is as follows:

$$\lim_{t \rightarrow \infty} \lambda(t)e^{(\gamma - \rho)t} = 0 \tag{8}$$

$$\lim_{t \rightarrow \infty} H(X(t), N_1(t), \lambda(t))e^{(\gamma-\rho)t} = 0 \tag{9}$$

Through the use of Eqs. (6) and (7), we can solve the expression of the price of requisitioned land as Eq. (10).

$$\lambda(t) = \int_t^\infty [R(N(s)) - r(1 - N(s)) - \epsilon]e^{-(\rho-\gamma)(s-t)} ds \tag{10}$$

As shown in Eq. (10), the shadow price of requisitioned land has three components: (a) the effect of further economic growth $R(N(s))$; (b) the unit output from urban land exceeding that of agricultural land; (c) the effect of unit value of ecological land ϵ .

Next, we derive some results about optimal land transformation $X(t)$. We define shifters from the urban land value as α and compensation from land conversion as β ; they both have original value of one:

$$v(X(t))e^{\gamma t} - \varphi(X(t))e^{\gamma t} + \int_t^\infty [R(N(s)) - r(1 - N(s)) - \epsilon]e^{-(\rho-\gamma)(s-t)} ds = 0 \tag{11}$$

By differentiating Eq. (11) with respect to ϵ when holding N fixed, we can obtain Eq. (12):

$$\frac{\partial \epsilon}{\partial X} = (\rho - \gamma)(v'(X(t)) - \varphi'(X(t)))e^{\gamma t} \tag{12}$$

From Eq. (12), it is apparent that when $v'(X(t)) > \varphi'(X(t))$, we have $\partial \epsilon / \partial X < 0$ (we assume that $\rho < \gamma$), while when $v'(X(t)) < \varphi'(X(t))$, we have $\partial \epsilon / \partial X > 0$. This means that if the marginal rate of unit conveyance fee is greater than that of the unit compensation from requisitioned land, LU has a negative effect toward the ESV of land. This result means that the benefits from land development by local governments are greater than their costs, because the negative externality of land development cannot be internalized. At this time, local governments tend to develop more land to promote local economic growth, and do not care about the improvement of land utilization efficiency. Accordingly, a negative relationship between land use and ESV exists. However, if the marginal rate from unit conveyance fee is smaller than that of the unit compensation from requisitioned land, LU positively affects ESV of land. This result indicates that when the benefits of land development are less than their costs, local governments are forced to promote land utilization efficiency and cannot utilize land extensively. At this time, the central government and residents are also paying more attention to the ESV of land, which further leads to local governments being more cautious in developing land and increasing investment in ecological environment protection. Accordingly, a positive correlation between land use and the ESV exists.

We can also analyze the stages of the impact of LU on the ESV of land through economic theory. In general, the influence of LU on ESV of land presents a flat ‘‘S’’ curve. During the early stage of urban expansion, the population and economy grow slowly; also, the urban consumption of land and its impact on the ESV of land is relatively small. During the middle period of urban expansion with significant industrialization development urban population rise, and quick spread of the urban scale, the urban land consumption and its impact on the ESV of land encounters a period of rapid growth. During the later period

of urbanization, the urban land consumption and its impact on the ESV of land tends to decrease with change in urban industrial structure and more attention to connotation. In the mature phase of urbanization, impact of LU on ESV is primarily connected with consumer demand. Land consumption will decline, but it will remain at a relatively high level.

We can draw the following hypothesis through the research describe above.

Hypothesis. The correlation between LU and the ESV of land relies on phase of economic development. When marginal effect from unit conveyance fee brought by requisitioned land is greater than that from the unit compensation brought by requisitioned land on its area, LU negatively affects the ESV of land. When marginal rate of unit conveyance fee is less than that of the unit compensation from requisitioned land, LU positively affects the ESV of land.

The connection between LU and the ESV of land is depicted in Fig. 1.

4 Data, variables, and empirical model

4.1 Data

A cross-sectional data of 280 Chinese cities in 2010 is used to examine how LU affects ESV. Data of dependent variable “ESV” originated from Zhang (2018). To overcome the influence of land scale, we divided total ESV of each city by the number of population to obtain the dependent variable “per capita ESV” (denoted by “aESV”). It also includes six important sub-ecosystem services value. Similarly, each sub-ecosystem services value was divided by the number of people to get per capita value to soil retention (denoted by “asret”), water retention (denoted by “awret”), biodiversity (denoted by “abiod”) and carbon sequestration (denoted by “acarseq”). We pick data from the Statistical Yearbook of Chinese cities (2011). The data of ESV used in this study is derived from the Chinese High-Resolution Emission Gridded Database (CHRED 3.0). This dataset is particularly noteworthy as it employs a bottom-up approach to spatialize greenhouse gas emissions at a resolution of 1 km. It takes into account emissions from point sources, line sources, and area sources, providing detailed and accurate information on emissions distribution across the city. Based on research hypothesis, we consider the area of land leasing to be an independent variable that represents LU and the ESV as the dependent variable. Moreover, a series of macroeconomic variables and characteristic variables that affect the ESV were selected as control variables. Based on these variables, we empirically analyzed how LU

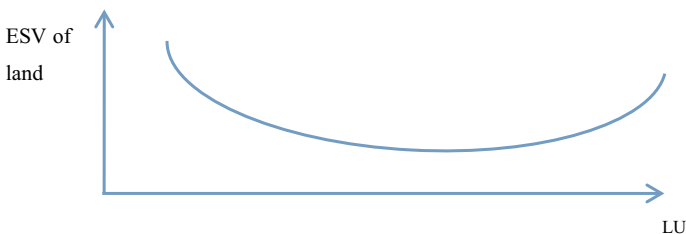


Fig. 1 The relation between LU and the ESV of land

affects ESV. Furthermore, different land use structure were used as an intermediate variables to study the mechanism of LU on ESV.

Endogeneity between LU and ESV may exist due to reverse causality or omitted variables issue (Zhang et al., 2017; Wang et al., 2021). Therefore, the relief degree for land surface acts as an instrumental variable of LU; that variable could represent regional altitude as well as surface cutting degree, that is commonly used in current analyses on land use. The dataset, which was obtained from You et al. (2018), contains spatial distribution dataset on relief degree for land surface at 1 km that covers China and statistics of the average degree of relief of the land surface in Chinese provinces, cities, or counties.

The measurement methods and datasets of each variable are presented in Tables 1, 2 presents descriptive statistics for the variables. The outcome in Table 2 shows primary distribution trend from data of each variable.

4.2 Specification and assessment of econometric model

The econometric model that is specified to study the connection between LU and the ESV of land is expressed in Eq. (13).

$$aESV_i = c + \alpha landurban_i + \beta X_i + \varepsilon_i \quad (13)$$

where $aESV_i$ presents the per capita ESV of city i . $landurban_i$ is a core explanatory variable that represents LU, denoted by area of land leasing of city i . X_i indicates a number of control variables (e.g., $pergdp$, $bupgrate$, $pwater$, $emis$, $hindustr$, and rd). ε_i presents the standard error terms. The linear models of the influence of LU on biodiversity, carbon sequestration, retention for soil, and retention for water are established as the same in Eq. (13).

The nonlinear model between LU and ecological value of land presents as follows:

$$aESV_i = c + \alpha landurban_i + \gamma landurban_i^2 + \beta X_i + \varepsilon_i \quad (14)$$

where $landurban_i^2$ denotes quadratic term of LU.

In Eqs. (13) and (14), α represents the influence of LU on ESV of land. β represents the coefficients for control variables. γ is the coefficient for quadratic term for LU. The nonlinear models depicting the influence of LU on biodiversity, carbon sequestration, retention for soil, and retention for water were established as the same in Eq. (14).

4.3 Estimation results

The benchmark regression results based on Eq. (1) between LU and ESV are in Table 3. The outcome in column (1) and (2) of Table 3 indicates LU significantly and negatively affects ESV of land with or without control variables. When the quadratic term for LU is added, the outcomes in columns (3) and (4) of Table 3 suggest the U-shaped curve between LU and ESV of land with or without control variables. This result verifies the conclusion that a U-shaped relationship exists between LU and the ESV of land in hypothesis of Sect. 3. Figure 2 presents a quadratic fitting curve between LU and ESV of land, which further proves the U-shaped curve relationship between the two. However, the influence of LU on land ESV is still currently negative. With the advancement in LU, the confluence of population and industry leads to the conversion of ecological and agricultural land towards urban construction land, which resulted in fragmentation, damage to connectivity among

Table 1 Variables and data descriptions

Variables	Definition	Notation	Unit	Description and Calculation Method
Explained variable	Ecosystem service value	aESV		Taken from ecosystem classification data in 2010, the key fitting parameters were obtained by integrating multivariate data, such as remote sensing, monitoring sites and statistical literature, and a model system was created to represent the spatial dataset of ecosystem services in China
	Soil Retention	asret	t/a	Soil retention originates from general soil loss equation
	Water retention	awret	m ³ /a	Water retention originates from water balance equation
	Biodiversity	abiod	the number of species	Biodiversity is measured by the recorded number of indicator species
	Carbon sequestration	acarseq	t/a	It is measured using the total weight of the sequestered carbon
	Land Urbanization	landurban	ha	It is measured by the area of land leasing
Explanatory variable	Population	population	10,000 people	It is picked from Statistical Yearbook of Chinese cities
Control variables	Economic growth level	pergdp	yuan	It is assessed by gross regional product per capita in urban districts
	Greening level	bupgrate	%	It generates from green coverage for urban built-up areas
	Water Pollution emissions	pwater	10,000 ton	It is measured by the amount of industrial wastewater discharged
	Air Pollution emissions	semis	ton	It indicates the industrial emissions of sulfur dioxide in each prefecture-level city
	Advanced industrial structure	hindustr	none	It generates from the ratio of output value between tertiary sector and the secondary sector of each city
	R&D expenditure	rd	million yuan	It generates from provincial R&D expenditure data

Table 2 Descriptive statistics of variables

Variable	Mean	SD	Min	Max	N
aESV	906.1933	879.9325	36.4068	4663.808	280
abiod	0.7429	0.8529	0.0131	10.0634	280
afprod	0.0777	0.0797	0.0001	0.5443	280
asret	5.4412	7.877	0	43.6729	280
awret	30.2095	45.9754	0	278.8333	280
awsfix	9.228	46.6721	0	612.1422	280
acarseq	0.3885	0.5263	2.08e-06	3.1182	280
linten	5320.776	6356.417	27.89	48,099.95	280
population	136.2609	169.8884	15.23	1542.77	280
pergdp	44,815.78	28,927.26	6222	249,040	276
bupgrate	39.66121	22.24251	0.6	386.64	280
pwater	7916.373	9953.612	23	80,468	279
semiss	59,724.46	59,793.25	12	572,747	278
hindustr	0.9139	0.5597	0.11	4.01	280
rd	28,117.76	25,980.12	702.04	85,794.91	280
IV1	2.6703	1.5736	0.1562	13.2613	279
IV2	8.5804	9.3979	0.22	58.73	280

Table 3 Regression outcomes between LU and ESV of land

Variables	(1) aESV	(2) aESV	(3) aESV	(4) aESV
landurban	-0.2565*** (0.000)	-0.2723* (0.000)	-0.4761*** (0.000)	-0.568*** (0.000)
linten ²			5.03*E-05*** (0.002)	6.41E-05*** (0.002)
pergdp		8.887*E-04 (0.604)		0.0016 (0.351)
bupgrate		-0.8083 (0.552)		-0.8138 (0.587)
pwater		0.0093* (0.093)		0.0112** (0.046)
semiss		-0.0027** (0.043)		-0.0028** (0.024)
hindustr		112.2612 (0.211)		121.0411 (0.171)
rd		0.0027 (0.302)		0.0032 (0.220)
_cons	1157.271*** (0.000)	1063.829*** (0.000)	1275.689*** (0.000)	1171.651*** (0.000)
Observations	279	273	279	273
R-squared	0.0796	0.1103	0.0918	0.1290
F-value	40.52*** (0.0000)	5.38*** (0.0000)	28.24*** (0.0000)	6.79*** (0.0000)

The value in parentheses represent the *p*-value of each coefficient. **P* < 0.10, ***P* < 0.05, ****P* < 0.01

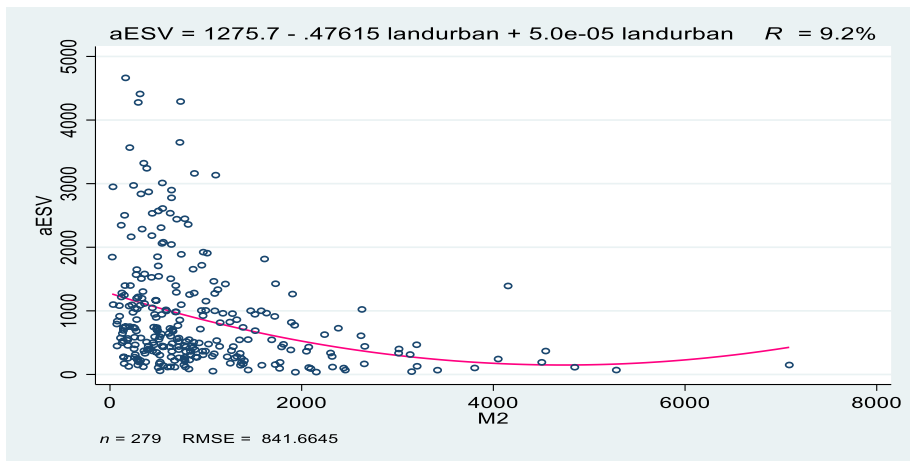


Fig. 2 The quadratic fitting curve between LU and the ESV of land

landscapes, and a deterioration in quality of habitat (Ouyang et al., 2021; Wan et al., 2015). Consequently, the existing LU negatively affects the ecological process and reduces the ecosystem function and ESV. The Chinese government should carry out further policies and measures to seek optimization for optimal utilization structure, reasonably control the land use intensity, and stress land use efficiency, aiming to make the positive mutual promotion relationship between LU and the ESV of land as soon as possible.

Furthermore, we carried out a regression analysis of LU on sub-ESV of land and presented the results in Table 4. It shows the impacts of LU on soil retention, carbon sequestration, biodiversity, and water retention are all significantly negative with or without the control variables. With the advancement in LU and land utilization structure, intensity as well as efficiency has undergone profound changes. This will further profoundly affect the ecological process of the ecosystem, ecosystem service function and ecosystem energy conversion efficiency; disturb the balance of the ecosystem; and destroy the mutual connection between biological populations. Accordingly, the correlation between LU and the sub-ESV of land were all negative. Furthermore,

The quadratic fitting curves between LU and biodiversity, carbon sequestration, soil and water retention are shown in Figs. 3, 4, 5 and 6, respectively. A U-shaped curve between LU and biodiversity, carbon sequestration, soil retention, and water retention exists. However, most of the existing sample data are on the left side of that curve. The Chinese government should also boost the enhancement of ecological functions, like biodiversity, carbon sequestration, as well as soil and water retention, through optimization of land utilization.

Endogeneity between LU and ESV of land may exist due to reverse causality or omitted variables issue (Zhang et al., 2017; Wang et al., 2021). To execute a robustness check, we picked an instrumental variables (IV) of LU and applied 2SLS methods (Xu et al., 2021; Nepal et al., 2021; Safiullah et al., 2021). We chose topographic relief of the city as the IV for LU to remain consistent with the current studies. The degree of topographic relief can be used to reflect the.

Complexity of local terrain, which influences the land transfer behavior of local government. In general, agricultural land with a lower slope and better quality is more suitable for

Table 4 Regression outcomes between LU and the sub-ESV of land

Variables	(1) abiod	(2) abiod	(3) acarseq	(4) acarseq	(5) asret	(6) asret	(7) awret	(8) awret
landurban	-2.692*E-04*** (0.000)	-2.252*E-04*** (0.000)	-1.592E-04*** (0.000)	-1.371E-04*** (0.000)	-0.0023*** (0.000)	-0.0024*** (0.000)	-0.0111*** (0.000)	-0.0115*** (0.000)
pergdp	2.13E-06 (0.320)	2.13E-06 (0.320)		-4.85E-07 (0.616)		-4.11*E-06 (0.773)		5.8E-05 (0.483)
bupgrate		-0.0011 (0.214)		-4.122E-04 (0.532)		-0.0047 (0.715)		0.03 (0.785)
pwater		-2.65E-06 (0.530)		2.06E-06 (0.491)		6.09*E-05 (0.259)		4.405E-04* (0.097)
semis		-1.87E-06* (0.073)		-1.23E-06** (0.033)		-2.14*E-05*** (0.013)		-1.568E- 04*** (0.002)
hindustr		0.1322 (0.248)		0.0646 (0.262)		1.6028** (0.055)		4.6471 (0.337)
rd		-2.44E-06 (0.228)		1.28E-07 (0.931)		2.6*E-05 (0.288)		1.128E-04 (0.418)
_cons	1.0057*** (0.000)	0.9895*** (0.000)	0.5437*** (0.000)	0.5517 (0.000)	7.7193*** (0.000)	6.6902*** (0.000)	41.0324*** (0.000)	35.5781*** (0.000)
R-squared	0.0932	0.1204	0.0855	0.1027	0.0823	0.1196	0.0544	0.0849
F value	23.90*** (0.0000)	4.88*** (0.0000)	39.10*** (0.0000)	5.26*** (0.0000)	39.76*** (0.0000)	5.26*** (0.0000)	33.62*** (0.0000)	4.15*** (0.0002)

The value in parentheses represent p-value of each coefficient. * $P < 0.10$. ** $P < 0.05$. *** $P < 0.01$

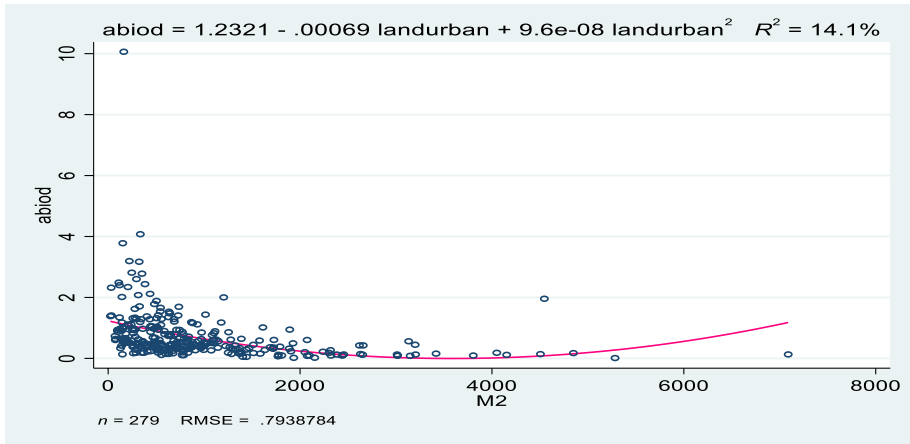


Fig. 3 The quadratic fitting curve between LU and biodiversity

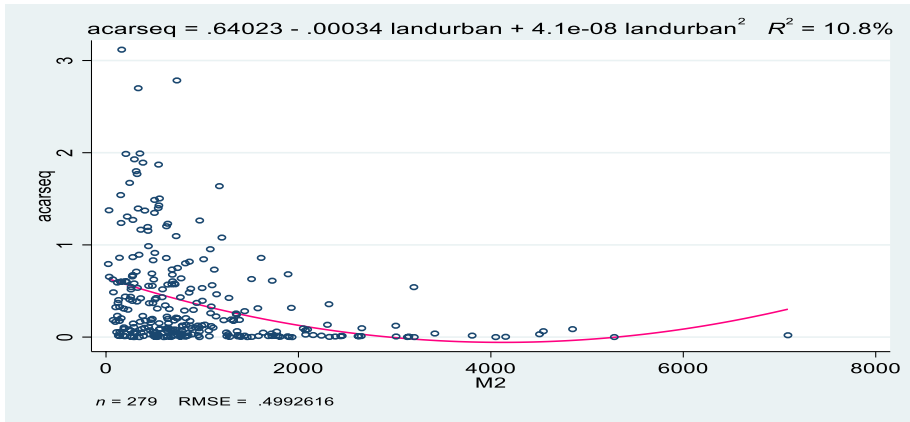


Fig. 4 The quadratic fitting curve between LU and carbon sequestration

transformation into urban and industrial land, and it is less expensive to expand onto this type of land use. However, the cost of urban construction is too high for land with a high slope to be developed into urban land, which limits the supply of land resources in urban expansion to some extent. Therefore, the degree of topographic relief meets the correlation condition as an IV. However, as a natural factor, topographic relief would not be directly connected with other economic factors and satisfies the exogeneity condition as an instrumental variable. The regression results between LU and ESV of land based on IV analysis are presented in column (1) on Table 5. It suggests that the influence of LU on ESV of land was still significantly negative, which means the benchmark regression outcomes on Table 3 are robust. Also, we use the area of land leasing per plot (denoted by “alandurban”) to replace the core explanatory variable “landurban”, and the regional GDP per unit of land area (denoted by “linten”) to execute a robustness test. Regression outcomes are presented in columns (2) and (3) on Table 5. The outcomes further prove that benchmark regression results are robust.

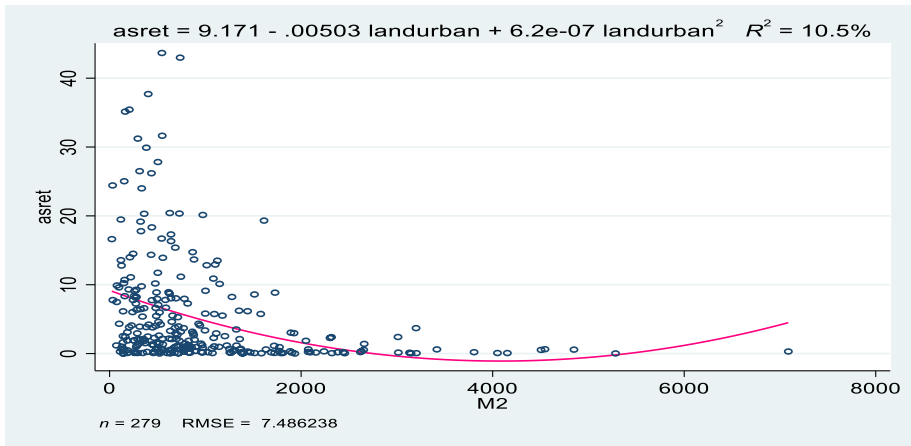


Fig. 5 The quadratic fitting curve between LU and soil retention

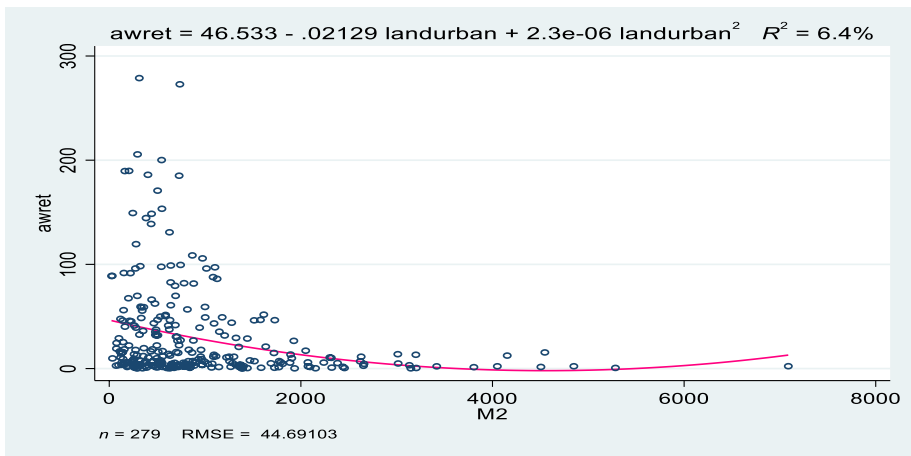


Fig. 6 The quadratic fitting curve between LU and water retention

Table 5 Regression outcomes between LU and ESV of land generated by instrumental variable analysis and substituting core explanatory variable

Variables	(1) Instrumental variable analysis	(2) substituting core explanatory variable	(3) substituting core explanatory variable
landurban	0.7007* (0.074)		
alandurban		-105.9193*** (0.005)	
linten		-4.58E-04** (0.735)	-0.0257*** (0.000)
pergdp	0.0052 (0.243)	0.2281 (0.846)	8.90E-06 (0.995)
bupgrate	-2.1029 (0.443)	3.7571 (0.127)	0.5289 (0.638)
pwater	0.0177* (0.079)	0.0022 (0.704)	0.0073 (0.201)
semis	-0.0010*** (0.598)	-0.0033** (0.020)	-0.0033*** (0.000)
hindustr	182.0443 (0.117)	92.9373 (0.301)	89.8921 (0.307)
rd	0.0063 (0.113)	9.912E-04 (0.703)	0.0010 (0.699)
_cons	1007.848*** (0.000)	1255.333*** (0.000)	1041.868*** (0.000)
Observations	273	273	274
Wald chi2	18.63*** (0.0094)	13.73** (0.0561)	
R-squared		0.0881	0.0819
F-value		3.74*** (0.0007)	4.84*** (0.0000)

The value in parentheses represent the *p*-value of each coefficient. **P* < 0.10, ***P* < 0.05, ****P* < 0.01

5 Conclusions

With the development of LU, the expanding urban construction land resulted in fragmentation of natural habitats and a decline in biodiversity. Additionally, LU has implications for land use structure, intensity, as well as utilization efficiency. Variations in land use structure can significantly impact ecological processes within an ecosystem, while high-intensity land development can disrupt the delicate balance in ecosystem. Furthermore, land utilization efficiency could greatly enhance efficiency of energy conversion. Consequently, LU exerts an influence on the ecosystem service system and its associated value. Furthermore, in different phases of economic development, variations in land use structure, intensity, as well as efficiency arise, resulting in diverse government policies concerning land use planning. Simultaneously, residents' demand for and willingness to pay for ESV differ accordingly. As a result, a nonlinear relationship emerges between LU and ESV. This study takes an important step in exploring this relationship by considering how decisions are made by central as well as local governments.

To investigate the connection between LU and ESV of land, we developed an optimization model with constraints that internalized the externalities of land development and

construction into the decision-making process of local governments. This model aimed to demonstrate the nonlinear correlation between LU and the ESV of land, drawing on theoretical frameworks proposed by Lichtenberg and Ding (2009) and Turnbull (2004). The theoretical analysis revealed that the connection between LU and ESV of land is contingent upon the phase of economic development. When the marginal effect of the unit conveyance fee of requisitioned land on its area surpasses the marginal effect of the unit compensation of requisitioned land on its area, LU negatively impacts the ESV of land. Conversely, when marginal rate from the unit conveyance fee is lower than that of the unit compensation from requisitioned land, LU positively affects the ESV of land. To validate theoretical findings, we conducted an empirical analysis adopting cross-sectional dataset from 280 cities in mainland China in 2010. The empirical analysis confirmed a U-shaped curve between LU and the ESV of land. However, it is important to note that the influence of LU on land ESV in China remains predominantly negative at present. Similarly, a U-shaped curve is observed between LU and indicators like biodiversity, carbon sequestration, and soil as well as water retention. However, it is worth mentioning that the majority of the available sample data is concentrated on left side of that U-shaped curve. These findings have been robustly supported by conducting endogeneity tests and various robustness tests.

6 Policy recommendations

Based on our study's major findings, we propose the following policy recommendations. Even though most of the cities in China are excessively urbanized, the influence of LU on ESV is still currently negative; that is to say, it is extremely hard to get into the right side of U-shaped curve and improve ESV in the early stage of urbanization. For those undeveloped area in China or the developing countries embarking on urbanization, it indicates that it is crucial to control the pace and extent of urbanization, as well as population influx, to prevent excessive urbanization that could harm ESV. For areas in China that has completed urbanization, it is imperative to strive for a harmonious balance between economic development and environmental protection. This calls for innovative approaches to land use patterns and institutional frameworks, considering the potential negative impacts of urbanization on ecosystems. The Chinese government should actively promote the realization of the ESV by increasing investment in ecological infrastructure. Additionally, the introduction of policies and measures such as ecological compensation, resource taxes, and environmental taxes, as well as the establishment of trading mechanisms and platforms for ecological property rights, can contribute to this goal. Finally, the Chinese government should prioritize the tertiary as well as high-tech industries related with land and industrial policies and introduce environmental regulation policies to control the level of environmental pollution.

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Data availability Data included in this study will be made available on reasonable request.

Declarations

Conflict of interest The author declare no conflicts of interest in this article.

References

- Allan, E., Bossdorf, O., Dormann, C. F., Prati, D., Gossner, M. M., Tschardt, T., et al. (2014). Interannual variation in land-use intensity enhances grassland multidiversity. *Proceedings of the National Academy of Sciences*, *111*, 308–313.
- Allan, E., Manning, P., Alt, F., et al. (2015). Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. *Ecology Letters*, *18*, 834–843.
- Bateman, I. J., Harwood, A. R., Mace, G. M., et al. (2013). Bringing ecosystem services into economic decision-making: Land use in the United Kingdom. *Science*, *341*(6141), 45–50.
- Baumgartner, S., Jost, F., & Winkler, R. (2009). Optimal dynamic scale and structure of a multi-pollution economy. *Ecological Economics*, *68*, 1226–1238.
- Cao, L., Li, J., Ye, M., Pu, R., Liu, Y., Guo, Q., & Song, X. (2018). Changes of ecosystem service value in a coastal zone of Zhejiang province, China, during rapid urbanization. *International Journal of Environmental Research and Public Health*, *15*(7), 1301.
- Cavender-Bares, J., Polasky, S., King, E., & Balvanera, P. (2015). A sustainability framework for assessing trade-offs in ecosystem services. *Ecology and Society*, *20*(1), 84–138.
- Chen, G., Li, X., Liu, X., et al. (2020). Global projections of future urban land expansion under shared socioeconomic pathways. *Nature Communications*, *11*, 537.
- Chuai, X. W., Huang, X., Lai, L., et al. (2013). Land use structure optimization based on carbon storage of terrestrial ecosystems in different regions of China. *Environmental Science & Policy*, *25*, 50–61.
- Chuai, X., Huang, X., Wang, W., et al. (2015). Spatial simulation of land use based on terrestrial ecosystem carbon storage in coastal Jiangsu. *China Scientific Reports*, *4*, 5667.
- Chuai, X. W., Huang, X. J., Wu, C. Y., et al. (2016). Land use and ecosystem services value changes and ecological land management in coastal Jiangsu, China. *Habitat International*, *57*, 164–174.
- Costanza, R. (2020). Valuing natural capital and ecosystem services toward the goals of efficiency, fairness, and sustainability. *Ecosystem Services*, *43*, 101096.
- Costanza, R., De Groot, R., Braat, L., Kubiszewski, I., Fioramonti, L., Sutton, P., & Grasso, M. (2017). Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosystem Services*, *28*, 1–16.
- Cumming, G., Buerkert, A., Hoffmann, E., et al. (2014). Implications of agricultural transitions and urbanization for ecosystem services. *Nature*, *515*, 50–57.
- Deng, X. Z., Huang, J., Rozelle, S., & Uchida, E. (2008). Growth, population and industrialization, and urban land expansion in China. *Journal of Urban Economics*, *63*, 96–115.
- Deng, X. Z., Huang, J. K., Rozelle, S., & Uchida, E. (2011). Economic growth and the expansion of urban land in China. *Urban Studies*, *47*(4), 813–843.
- Du, X. J., & Huang, Z. H. (2017). Ecological and environmental effects of land use change in rapid urbanization: The case of Hangzhou, China. *Ecological Indicators*, *81*, 243–251.
- Eichner, T., & Pethig, R. (2019). Coaseian biodiversity conservation and market power. *Environmental & Resource Economics*, *72*, 849–873.
- Fang, Z., Ding, T., Chen, J., Xue, S., Zhou, Q., Wang, Y., & Yang, S. (2022). Impacts of land use/land cover changes on ecosystem services in ecologically fragile regions. *Science of the Total Environment*, *831*, 154967.
- Fricke, E. C., & Svenning, J. C. (2020). Accelerating homogenization of the global plant–frugivore meta-network. *Nature*, *585*, 74–78.
- Gao, X., Cheng, H., Zheng, H., & Ouyang, Z. (2019). Research on the policy instruments for the value realization of ecological products. *Acta Ecologica Sinica*, *39*, 8746–8754.
- Grossman, G., & Krueger, A. (1995). Economic growth and the environment. *Quarterly Journal of Economics*, *110*(2), 353–377.
- Gu, S., Xie, M., & Zhang, X. (2019). *Green transformation and development*. Palgrave Macmillan.
- Hu, S., Chen, L., Li, L., Wang, B., Yuan, L., Cheng, L., & Zhang, T. (2019). Spatiotemporal dynamics of ecosystem service value determined by land-use changes in the urbanization of Anhui Province, China. *International Journal of Environmental Research and Public Health*, *16*(24), 5104.
- Jantz, C. A., & Manuel, J. J. (2013). Estimating impacts of population growth and land use policy on ecosystem services: A community-level case study in Virginia, USA. *Ecosystem Services*, *5*, 110–123.
- Ji, Q. (2023). *Managing climate risk in the global economic system in the post-COVID-19 era*. Frontiers Media SA.
- Lai, L., Huang, X., Yang, H., et al. (2016). Carbon emissions from land-use change and management in China between 1990 and 2010. *Science Advances*, *2*(11), e1601063.

- Lam, S. T., & Conway, T. C. (2018). Ecosystem services in urban land use planning policies: A case study of Ontario municipalities. *Land Use Policy*, *77*, 641–651.
- Lei, J., Chen, Z., Wu, T., & Li, Y. (2019). Spatial autocorrelation pattern analysis of land use and the value of ecosystem services in northeast Hainan island. *Acta Ecologica Sinica*, *39*(7), 2366–2377.
- Li, F., Wang, R., Hu, D., Ye, Y., Yang, W., & Liu, H. (2014). Measurement methods and applications for beneficial and detrimental effects of ecological services. *Ecological Indicators*, *47*, 102–111.
- Lichtenberg, E., & Ding, C. R. (2009). Local officials as land developers: Urban spatial expansion in China. *Journal of Urban Economics*, *66*, 57–64.
- Liu, X. P., Liang, X., Li, X., Xu, X. C., Ou, J. P., Chen, Y. M., Li, S. Y., Wang, S. J., & Pei, F. S. (2017). A future land use simulation model (FLUS) for simulating multiple land use scenarios by coupling human and natural effects. *Landscape and Urban Planning*, *168*, 94–116.
- Mendoza-González, G., Martínez, M. L., Lithgow, D., Pérez-Maqueo, O., & Simonin, P. (2012). Land use change and its effects on the value of ecosystem services along the coast of the Gulf of Mexico. *Ecological Economics*, *82*, 23–32.
- Nepal, R., Musibau, H. O., & Jamasb, T. (2021). Energy consumption as an indicator of energy efficiency and emissions in the European union: A GMM based quantile regression approach. *Energy Policy*, *158*, 112572. <https://doi.org/10.1016/j.enpol.2021.112572>
- Newbold, T., Hudson, L. N., Hill, S. L. L., et al. (2015). Global effects of land use on local terrestrial biodiversity. *Nature*, *520*(7545), 45–60.
- Oliver, T. H., & Morecroft, M. D. (2014). Interactions between climate change and land use change on biodiversity: Attribution problems, risks, and opportunities. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(3), 317–335.
- Ouyang, X., Tang, L., Wei, X., & Li, Y. (2021). Spatial interaction between urbanization and ecosystem services in Chinese urban agglomeration. *Land Use Policy*, *109*, 105587.
- Peng, J., Tian, L., Liu, Y. X., et al. (2017). Ecosystem services response to urbanization in metropolitan areas: Thresholds identification. *The Science of the Total Environment*, *607–608*(31), 706–714.
- Peters, M. K., Hemp, A., Appelhans, T., et al. (2019). Climate-land-use interactions shape tropical mountain biodiversity and ecosystem functions. *Nature*, *568*, 88–110.
- Qiao, W., & Huang, X. (2022). The impact of land urbanization on ecosystem health in the Yangtze River delta urban agglomerations. *China. Cities*, *130*, 103981.
- Shu, H., & Xiong, P. (2019). Reallocation planning of urban industrial land for structure optimization and emission reduction: A practical analysis of urban agglomeration in China's Yangtze River Delta. *Land Use Policy*, *81*, 604–623.
- Smith, P., Adams, J., Beerling, D. J., Beringer, T., Calvin, K. V., Fuss, S., & Keesstra, S. (2019). Land-management options for greenhouse gas removal and their impacts on ecosystem services and the sustainable development goals. *Annual Review of Environment and Resources*, *44*, 255–286.
- Song, W., Deng, X. Z., Yuan, Y. W., et al. (2015). Impacts of land-use change on valued ecosystem service in rapidly urbanized North China Plain. *Ecological Modelling*, *318*, 245–253.
- Su, S. L., Li, D. L., & Hu, Y. N. (2014). Spatially non-stationary response of ecosystem service value changes to urbanization in Shanghai, China. *Ecological Indicators*, *45*, 332–339.
- Teulings, C. N., Ossokina, I. V., & de Groot, H. L. F. (2018). Land use, worker heterogeneity and welfare benefits of public goods. *Journal of Urban Economics*, *103*, 67–82.
- Turnbull, G. K. (2004). Urban growth controls: Transitional dynamics of development fees and growth boundaries. *Journal of Urban Economics*, *2004*(55), 215–237.
- Verburg, P. H., Soepboer, W., Veldkamp, A., et al. (2002). Modeling the spatial dynamics of regional land use: The CLUE-S model. *Environmental Management*, *30*(3), 391–405.
- Wan, L., Ye, X., Lee, J., Lu, X., Zheng, L., & Wu, K. (2015). Effects of urbanization on ecosystem service values in a mineral resource-based city. *Habitat International*, *46*, 54–63.
- Wang, H., Lu, S., Lu, B., & Nie, X. (2021). Overt and covert: The relationship between the transfer of land development rights and carbon emissions. *Land Use Policy*, *108*, 105665. <https://doi.org/10.1016/j.landusepol.2021.105665>
- Wang, X., Pan, T., Pan, R., Chi, W., Ma, C., Ning, L., Wang, X., & Zhang, J. (2022). Impact of land transition on landscape and ecosystem service value in northeast region of China from 2000 to 2020. *Land*, *11*, 696. <https://doi.org/10.3390/land11050696>
- Wang, Z., Chen, J., Zheng, W., & Deng, X. (2018). Dynamics of land use efficiency with ecological inter-correlation in regional development. *Landscape and Urban Planning*, *177*, 303–316.
- Xie, H., Wang, W., Yang, Z., & Choi, Y. (2016). Measuring the sustainable performance of industrial land utilization in major industrial zones of China. *Technological Forecasting and Social Change*, *112*, 207–219.

- Xie, X., Fang, B., Xu, H., He, S., & Li, X. (2021). Study on the coordinated relationship between Urban land use efficiency and ecosystem health in China. *Land Use Policy*, *102*, 105235.
- Xu, L., Fan, M., Yang, L., & Shao, S. (2021). Heterogeneous green Innovations and carbon emission performance: Evidence at China's city level. *Energ. Econ.*, *99*, 105269. <https://doi.org/10.1016/j.eneco.2021.105269>
- Yang, Y., Wang, K., Liu, D., Zhao, X., & Fan, J. (2020). Effects of land-use conversions on the ecosystem services in the agro-pastoral ecotone of northern China. *Journal of Cleaner Production*, *249*, 119360.
- Ye, Y. Q., Bryan, B. A., Zhang, J. E., et al. (2018). Changes in land-use and ecosystem services in the Guangzhou-Foshan Metropolitan area, China from 1990 to 2010: Implications for sustainability under rapid urbanization. *Ecological Indicators*, *93*, 930–941.
- You, Z., Feng, Z., & Yang, Y. (2018). Relief degree of land surface dataset of China (1km) [J/DB/OL]. *Digital Journal of Global Change Data Repository*. <https://doi.org/10.3974/geodb.2018.03.16.V1>
- Zhang, W., & Xu, H. (2017). Effects of land urbanization and land finance on carbon emissions: A panel data analysis for Chinese provinces. *Land Use Policy*, *63*, 493–500. <https://doi.org/10.1016/j.landusepol.2017.02.006>

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