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Assessment and driving factor of housing vacancies in Shandong Peninsula urban agglomeration based on multi-source remote sensing data

Dong Yang [a,b], Bing Xiao [a], Xinjie Lu [a], Xuexiu Jia [c], Xin Li [a], Feng Han [a], Lingwen Sun [a], Feng Shi [d,e,*], Kronnaphat Khumvongsa [f], Jinping Li [b], Xianyin Duan [g]

[a] Institute of Science and Technology for Development of Shandong, Qilu University of Technology (Shandong Academy of Sciences), Jinan, 250014, China
[b] Research Center of SCO Countries, Qilu University of Technology (Shandong Academy of Sciences), Jinan, 250014, China
[c] Sustainable Process Integration Laboratory-SPIL, NETME Centre, Faculty of Mechanical Engineering, Brno University of Technology-VUT Brno, Technická 2896/2, 616 69, Brno, Czech Republic
[d] School of Environmental Science and Engineering, Qilu University of Technology (Shandong Academy of Sciences), Jinan, 250014, China
[e] Institute of Carbon Circulation Advanced Technology Industry, Zhengzhou, 450001, China
[f] Graduate School of Environmental Studies, Nagoya University, D2-1(510), Furo-cho, Chikusa-ku, Nagoya, 464-8603, Japan
[g] Xintai Economic Development Zone Management Committee, Taian, 271000, China

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ABSTRACT

As the urbanization rate in the world has increased rapidly, the housing vacancy problem has become serious and attracting more attention. Calculating and analyzing vacant housing can help reduce the wasteful use of resources. This paper measures the housing vacancy rate and housing vacancy stock in the Shandong Peninsula urban agglomeration using night-time lighting and land use data. The results show that the average housing vacancy rate in the Shandong Peninsula urban agglomeration rose rapidly from 14.68% in 2000 to 29.71% in 2015 before declining slowly to 29.49% in 2020. Since urban population growth is lower than the housing construction rate, the average annual growth of housing vacancy stock between 2000 and 2020 exceeds 3 million square meters in megacities and is around 1–2 million square meters in large and medium-sized cities. The vacant housing has caused considerable waste of housing resources. The driving factors of the housing vacancy were further analyzed using the LMDI decomposition method. Results indicate that the economic development level is the most significant driving factor of the vacant housing stock. In addition, the value effect of unit floor areas is the major driving factor inhibiting the growth of vacant housing stock, while the decline of unit floor area value is conducive to the reduction of this stock.

1. Introduction

Currently, the world's urban population accounts for 56.20% of the world's total population, and this proportion will reach 60.40%

* Corresponding author. School of Environmental Science and Engineering, Qilu University of Technology (Shandong Academy of Sciences), Jinan, 250014, China.
E-mail address: shifeng1224cn@126.com (F. Shi).

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by 2030, of which 96.00% of this growth is mainly from developing countries in East Asia, South Asia, and Africa [1]. As the largest developing country in the world, China has been keeping a great pace in urbanization, with its increased rate about three times since the reform and opening up (around the year 1978). The high-paced improvement in urbanization has been both the outcome and the driver of the economic development of China [2]; however, the social and environmental issues along with the fast urban development cannot be ignored [3]. For example, in 2010, *Time* magazine published an article titled "*Ordos, China: A Modern Ghost City*", reporting the over-development issues in the housing market in the city of Ordos, Inner Mongolia, China. Since then, the term "*Ghost city*" has been used to describe cities with over-developed residential and commercial housing projects that are left empty due to low real-world demand [4]. "*Ghost city*" reflects a series of social, economic, and environmental issues related to the over-development of land, loss of urban population, and vacant housing in the process of urbanization construction. Therefore, it is necessary to focus on the problems due to the housing vacant in the stage of rapid urbanization in developing countries, especially in China.

In recent years, vacant housing has become one of the most important issues for the Chinese government and residents [5]. Although the per capita housing area has been increasing, there are problems of unbalance between supply and demand. Namely, in some cities, a large number of residential and commercial housing has been developed during the rapid urbanization process to meet the expected living and developing demand, but due to the unbalanced development between urbanization and population, a large number of houses are left vacant, resulting in a waste of construction resources and space [6].

Many extensive research works have been carried out to discuss the urban housing vacancy issue. Two indicators, Housing Vacancy Rate (HVR) and Housing Vacancy Stock (HVS), have been proposed and widely used for urban housing vacancy evaluation. A comprehensive housing vacancy statistical system has been constructed through nationwide research and data collection. The analysis and discussion on the driving factors [7]and the economic [8], social [9,10], and environmental [11]impacts of the housing vacancy have facilitated healthy and sustainable urban development in the process of urbanisation. For example, Cozens [12]studied the effect of vacant and poorly maintained housing on crime, and the results showed that reducing vacant housing and improving the housing environment have important implications for crime prevention. Segú [13]developed a model to assess the impact of vacancy taxation on housing vacancies in France. The results showed that the vacancy rate decreased by 13.00% with the application of vacancy tax between 1997 and 2001, indicating that taxation can be an effective tool to reduce housing vacancy and the waste of resources.

China's housing vacancy issues have attracted extensive attention from researchers as it has increased along with urban expansion and economic growth [14]. Some studies have attempted to analyze vacant housing in China using statistical research methods proposed and applied to cases in Europe and the United States. For example, Zhang et al. [15]empirically investigated the impact of income inequality on the housing price-to-income ratio and the housing vacancy rate in various cities based on the 2002–2009 China Urban Household Survey (CUHS) database provided by the National Bureau of Statistics of China (NBS). Their research showed that the development of the capital and housing rental markets could help alleviate the issues of inequality in the housing price-to-income ratio and vacancy rate to a certain extent. Wang et al. [16]applied average sales price data of commercial housing in 35 major cities in China from 2007 to 2016 to construct a fixed influence variable coefficient model and analyze the impact of housing vacancy rate and control variables on housing price fluctuations. Results indicate that vacancy rate is the major driving factor of housing price fluctuations and the main reason for the differences in housing price fluctuations in cities of different scales. These studies have preliminarily explored the housing vacancy situation in China based on statistical data. However, due to the need of more sufficient vacant housing statistics in China [17], it is challenging to investigate up-to-date housing vacancy issues on a large scale.

Satellite night light (NTL, night-time light) data, as one type of typical remote sensing data, has been proven to have a high correlation with the intensity of human activities and has been widely used in the study of human activities [18,19]. As night lights can indicate house-using rates, high-resolution night light remote sensing data has been increasingly used for vacant housing-related studies with the further development of remote sensing technology. Vacancy housing evaluation methods with NTL have been continuously improved and achieved better research results. There has been a shift in NTL applications from the simple identification of "ghost cities" to the detailed calculation of housing vacancy rates [20,21]. For example, Chen et al. [20]estimated the HVR of 15 metropolitan areas in the United States based on NPP-VIIRS (Nation Polar-Orbiting Partnership satellite with the Visible Infrared Imaging Radiometer Suite) data, illustrating the strong correlation between HVR values and statistical data. Niu [22]estimated the housing vacancy rate in Qingdao (China) using NPP-VIIRS data and identified different regional characteristics of housing vacancy in the city. Using remote sensing data, Li et al. [23]divided the housing vacancy grades into 2430 counties in China. Identifying urban housing vacancies is claimed to provide insightful scientific guidance for the balanced development of the cities. For example, in 2018, Wang et al. [24]carried out a detailed calculation of housing vacancy in 31 provincial capital cities in China based on night light data and auxiliary data, indicatingthat the housing vacancy rate decreases with the city development level. The average housing vacancy rate is 23.30% in third-tier cities, 20.40% in second-tier cities, and only 18.90% in first-tier cities. These studies proved that housing vacancy rate evaluation using night light data has high accuracy and can be effectively used for housing vacancy in large-scale cities. Nevertheless, this method have never been combinedly used with the LMDI for analyzing and evaluating the vacant house situation and the driving force of this vacant house situation.

An urban agglomeration is the highest form of spatial organization in the mature stage of urban development [25]. Research on the issues related to housing vacancy in the urban agglomeration development process can provide guiding information to monitor housing vacancy and the related economic, social, and environmental problems from a macro perspective. The Shandong Peninsula Urban Agglomeration (geographical coordinates: 114.48°48′ E – 122°42′ E, 34°23′ N - 38°24′ N) is a crucial area for the development of Shandong Province (the third largest economy in China), and also one of the critical urban dense areas in East China. Shandong Peninsula Urban Agglomeration is also the estuary of thevast hinterland of the middle and lower reaches of the Yellow River in China andis the only urban agglomeration in the mature stage among the seven major urban agglomerations [26]. The agglomeration includes 16 cities in Shandong Province, and according to China's official urban city size categories, two are mega cities (with an urban population of more than 5 million), 8 are large cities (with an urban population of 1–5 million), and 6 are medium-sized cities (with an urban population of 0.5–1 million), as shown in Fig. 1. The urbanization rate of Shandong Province rose significantly from only 13.40% in 1978 [27] to 63.10% [28] in 2020 (approximately more than 1.00% annual increase), making the population of Shandong reach 101.5 million. This trend is possible to continue, as claimed in the "*Shandong Province New Urbanization Plan (2021–2035)*" that with the progressing development of Shandong Peninsula urban agglomeration, the urbanization rate of the permanent population is expected to reach about 68.00% by 2025 and 75.00% by 2035 respectively [29]. According to the plan, there is still significant potential for the future urbanization construction of the Shandong Peninsula urban agglomeration. However, the rapid population expansion and economic growth have resulted in excessive energy consumption and pollution, brought enormous environmental pressure, and challenged this region's sustainable development. Due to the fact that people in Shandong will migrate to other region to seek better job, the vacant house is expected to increase and become an obstacle for the socio-economic development in this region, but rarely do studies investigate this region's housing vacancy and resource waste issues. There is a need to systematically evaluate the housing vacancy condition and estimate the related environmental issues to provide guiding insights for the sustainable development of the Shandong Peninsula urban agglomeration.

To fill in the research gap, this paper serves as an initial attempt to investigate the housing vacancy and related building stock in the Shandong Peninsula urban agglomeration from 2000 to 2020. Night light data and land use data are combinedly used to analyze and assess the housing vacancy situation in each city in this region. In addition, the driving factors of the housing vacancy stock in the Shandong Peninsula urban agglomeration have been discussed based on the existing research results and the actual situation of this research area. The ultimate goal of this study is to propose an urban housing vacancy measurement method targeted for the large-scale area and long-term applications, identify the main driving factors of housing vacancy, and put forward policy recommendations to reduce housing vacancy stock and facilitate sustainable and healthy development of the city on the basis of the evaluation and identification.

2. Methods and data

2.1. Residential housing vacancy estimation

In this study, housing vacancy refers to the whole or part of the housing that is not currently used, or the housing that is waiting to be sold or rented [30]. The housing vacancy rate is defined as the ratio of vacant house area to the total area of built housing. The unit of housing vacancy stock is m^2 [31]. Existing studies mostly use the housing vacancy rate as the main indicator for the housing vacancy situation. To further analyze housing vacancy and related issues, this study calculates the housing vacancy stock based on the calculated housing vacancy rate combined with statistical data. Therefore, the two indicators, i.e., the housing vacancy rate and the

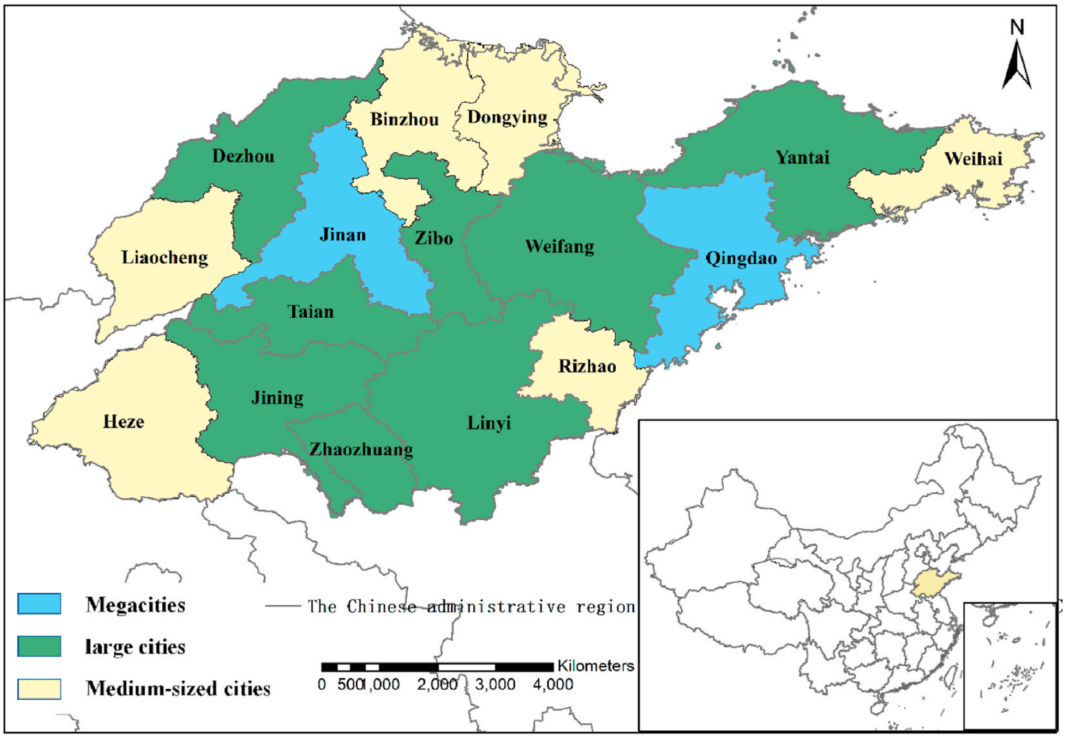

Fig. 1. Location map of Shandong Peninsula urban agglomeration.

housing vacancy stock, are used in this study to analyze and discuss the housing vacancy situation in the Shandong peninsula urban agglomeration.

2.1.1. Calculation of housing vacancy rate

The HVR calculation method is developed based on the night-light-based method from existing studies [20,24], using the night light data with a resolution of 500 m and the land use data with a resolution of 30 m. The night light dataset is the annual NPP-VIIRS-like nighttime light data [32] from 2000 to 2020, obtained from Harvard University's official data website [33]. This dataset was pre-processed before being used for the evaluation in this study. First, the minimum light intensity value in areas without lights is set as 0, and the negative pixel values were replaced with zero in this study. Then, for pixels with exceedingly large values, the annual brightest light intensity value in the central studied urban area is used as the upper bound threshold value, which can effectively remove outliers in the dataset. Finally, to better fit the need of this research, the night light data of the research area is cropped according to the administrative division's data obtained from the National Basic Geographic Information Centre [34].

The land use data is obtained from the Chinese land use dataset with a resolution of 30 m from 2000 to 2020 produced by Wuhan University [35]. This data is freely available from the open scientific data repository Zenodo [36]. The land use type used in this study is the impervious surface, it is an important artificial surface in the city, which can prevent groundwater infiltration into the soil, cut off the connection between the city surface and underground hydrology, mainly composed of buildings in the city. Therefore, the land use data is binarized, meaning that the artificial surface is assigned the value of 1, and other land use types are assigned the value of 0. The data were then resampled to 10 m resolution and cropped according to the administrative divisions of the study area. The processed night light data and land use data are then overlaid to construct the 500 m × 500 m data grid, as shown in Fig. 2 (a)-(c).

In Fig. 2, (a) is the land use data resampled to a 10 m resolution, (b) is the night light data grid with a 500 m resolution, and (c) is the overlay data.

In each 500*500 grid, there are light intensity values and land use intensity values. The night light data in the original dataset includes both the lights in the residential and non-residential areas (roads, parks, etc.). As the lights in the non-residential area may affect the lights in the residential area, therefore, the non-residential lights in the residential area have been removed. The thresholds are set mainly from the two aspects of lighting intensity and land use intensity to determine the lighting in residential areas. Firstly, the POI (point of interest) points that only contain roads are obtained from the internet and projected into grid pixels to extract the light intensity data of the non-residential areas. The average value of these light intensities is then set as the minimum threshold of the residential area light intensity, which is used to eliminate the influence of the non-residential area. During the POI points selection, it is found that the light intensity of the bustling commercial area is mostly higher than that of the residential area. Therefore, the POI points covering only the bustling commercial area are selected and projected into the grid pixels to obtain the light intensity of these sample points. The average value of the light intensity is set as the highest threshold (DN, night intensity digital number) for the residential area. It is possible that only using the highest and lowest light threshold to identify the residential area can be greatly affected by light. Therefore, the indicator of the green space rate is further introduced. The green space rate is a mandatorily required indicator listed in the national standard in China's housing construction. That is, the ratio of the total area of various types of green space within the newly-built residential area must be at least 30.00% and at least 20.00% within the old residential areas. Considering the actual situation, the land used for construction in the studied residential area is much higher than the relevant standards. The

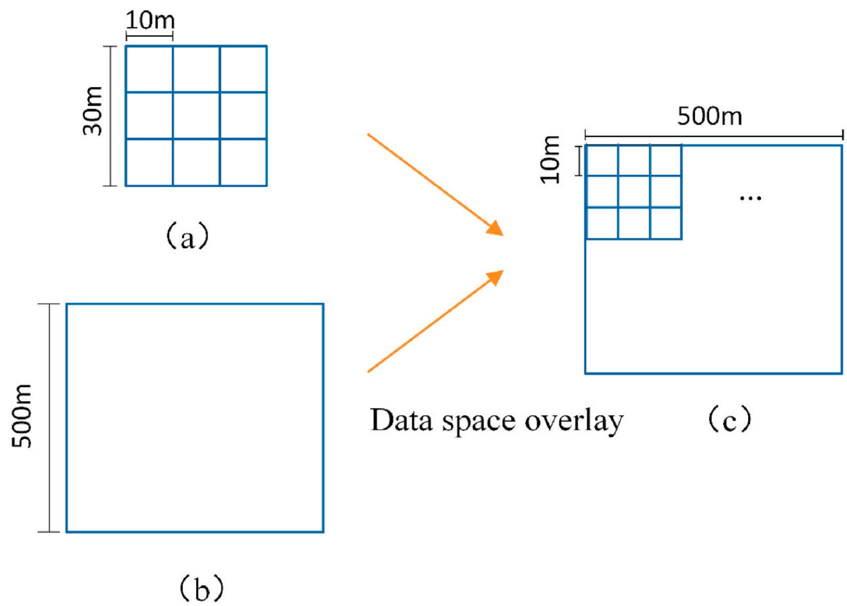

Fig. 2. Overlay of light data and land use data.

proportion of the Urban Area Reserve (UAR) of 70% is set as the maximum threshold of the land use intensity of the residential area to screen out the pixels that are most likely to be a residential area. In this case, the residential area identification accuracy can be improved by setting the light intensity and land use intensity thresholds. The residential area night light intensity can be calculated as follows:

$$ALI = \frac{\sum_{k=1}^{N_{non-resi}} NTL_k}{N_{non-resi}} \tag{1}$$

$$NTL_{MA} = \begin{cases} \mathrm{F}(NTL, ALI), \text{if UAR} \geq 0.7 \\ \text{NULL, otherwise} \end{cases} \tag{2}$$

$$\mathrm{F}(NTL, ALI) = \begin{cases} NTL_{UAR\geq 0.7} - ALL * (1 - \mathrm{UAR}), \text{if } DN > NTL_{UAR\geq 0.7} > ALL \\ 0, otherwise \end{cases} \tag{3}$$

$$UAR = \frac{N_d}{N_t} \tag{4}$$

where ALI is the average light intensity of the non-residential area; NTL_k is the light intensity in the k-th pixel of the non-residential area; $N_{non-resi}$ denotes the N-th pixel of the non-residential area; NTL_{MA} represents the light intensity of each mixed pixel after removing the influence of the non-residential area, $NTL_{UAR\geq 0.7}$ is the light intensity of a single pixel of mixed pixels in each residential area before removing the influence of non-residential area; DN is the highest threshold of light intensity in the residential area; UAR is the proportion of Urban Area Reserve in each light pixel; N_d represents the number of impervious surface pixels in the binarized land use image; N_t indicates the number of all pixels that overlap with the NTL pixel in the binarized land use image (Overlay of 500 m resolution nighttime lighting data and 10 m resolution land use data, $N_t = 2500$).

The light intensity of residential areas with almost no vacancies is selected as the reference value for non-vacant houses (*LINV*). According to the field study, expert interviews, and literature research, the housing vacancy rate in school district housing areas (refer to the housing areas with free access to better public schools and better education resources) is very low and tends to be at a zero-vacancy level. Therefore, the average value of the top 30.00% light intensity value of the POI points of the school district housing is selected as the reference value for no vacant housing (LINV), which is used to calculate the housing vacancy rate of each residential area pixel. The calculation is as follows.

$$ULI_{i,t} = NTL_{MA}^{i} / UAR_i \tag{5}$$

$$\mathrm{HVR}_{i,t} = 1 - ULI_{i,t} / LIN\mathrm{V}_t \tag{6}$$

$$\text{If } ULI_{i,t} > LIN\mathrm{V}_t, \mathrm{HVR}_{i,t} = 0 \tag{7}$$

where $ULI_{i,t}$ is the correction value of the light intensity of the i-th residential pixel in year t, NTL_{MA}^{i} is the light intensity of each mixed pixel after removing the influence of non-residential area, UAR_i is the ratio of Urban Area Reserve of the i-th residential pixel; $\mathrm{HVR}_{i,t}$ is the housing vacancy rate of the i-th residential district pixel in year t, $LIN\mathrm{V}_t$ is the reference value in the residential area without housing vacancy in year t.

2.1.2. Estimated vacant housing stock

To investigate the resource waste caused by vacant housing, this study also calculates the housing vacancy stock based on the statistical data of the permanent resident population of each city, per capita living area, as well as the housing vacancy rate results obtained in this study. The statistical data is extracted from the 2000–2020 Shandong Provincial Statistical Yearbook [37], including the total population, urban population, regional GDP, urban per capita living area, etc. The entire residential building area can be calculated using Equation (8), and the vacant housing stock can then be calculated with Equation (9).

$$\mathrm{S}_{sum,n,t} = \mathrm{S}_{avr,t} * P_{n,t} \tag{8}$$

$$\mathrm{S}_{hvr,n,t} = \mathrm{S}_{sum,n,t} * HVR_{n,t} \tag{9}$$

where $\mathrm{S}_{sum,n,t}$ is the total residential building area of the studied city n in year t, $\mathrm{S}_{avr,t}$ is the per capita living area in year t, $P_{n,t}$ is the number of permanent residents in city n in year t; $\mathrm{S}_{hvr,n,t}$ is the vacant housing stock of city n in year t, and $HVR_{n,t}$ is the housing vacancy rate of city n in year t.

2.2. Decomposition analysis of the driving factors of vacant housing stock

Logarithmic Mean Divisia Index (LMDI) decomposition method is one of the exponential decomposition analysis methods (For more information about the LMDI method, please see the Annex S1). The LMDI method has been widely used due to its advantages of reversible factors, no residuals, wide application range, and the consistency between addition decomposition and multiplication decomposition methods [38]. Existing studies showed that housing vacancy is mainly affected by a few factors, such as population [39, 40], economy [41,42], income [16], and urban development level [43]. In this paper, the construction of a factor decomposition analysis model follows the principle of Kaya identity [44], the existing results, and the actual situation of the selected study. Changes in vacant housing stock are decomposed into five driving factors: the housing vacancy rate, economic value of unit floor area, economic development level, urbanization level, and urban population. Thereby the vacant housing stock in the Shandong Peninsula urban agglomeration can be expressed as shown in Equation (10):

$$S = \frac{S}{S_0} * \frac{S_0}{GDP} * \frac{GDP}{P} * \frac{P}{CP} * CP = SS * SG * GP * PCP * CP \tag{10}$$

where S is the regional housing vacancy stock, S_0 is the regional total housing stock, $SS = \frac{S}{S_0}$ represents the housing vacancy rate level; GDP is the regional Gross Domestic Product and $SG = \frac{S_0}{GDP}$ represents the economic value of the unit building area; P is the regional total population, $GP = \frac{GDP}{P}$ represents the economic development level; CP is the resident population in urban areas, and $PCP = \frac{P}{CP}$ represents the urbanization level.

Using the additive form of the LMDI model, each factor that affects the vacant housing stock can be decomposed, and their impact on the changes in housing stock can be quantitatively analyzed, as shown in Equation (11):

$$\Delta S = \Delta SS + \Delta SG + \Delta GP + \Delta PCP + \Delta CP \tag{11}$$

where ΔS represents the changes in housing vacancy stock, ΔSS represents the impact of the housing vacancy rate on the changes in housing vacancy stock; ΔSG represents the impact of unit floor area value; ΔGP represents the impact of the level of economic development level; ΔPCP represents the impact of the urbanization level; ΔCP represents the impact of the urban population level on the vacant housing stock;

Based on the IMDI model, the contribution value of each decomposition factor is expressed as shown in Equation 12–16:

$$\Delta SS = \frac{S^T - S^0}{Ln\, S^T - LnS^0} Ln \frac{SS^T}{SS^0} \tag{12}$$

$$\Delta SG = \frac{S^T - S^0}{Ln\, S^T - LnS^0} Ln \frac{SG^T}{SG^0} \tag{13}$$

$$\Delta GP = \frac{S^T - S^0}{Ln\, S^T - LnS^0} Ln \frac{GP^T}{GP^0} \tag{14}$$

$$\Delta PCP = \frac{S^T - S^0}{Ln\, S^T - LnS^0} Ln \frac{PCP^T}{PCP^0} \tag{15}$$

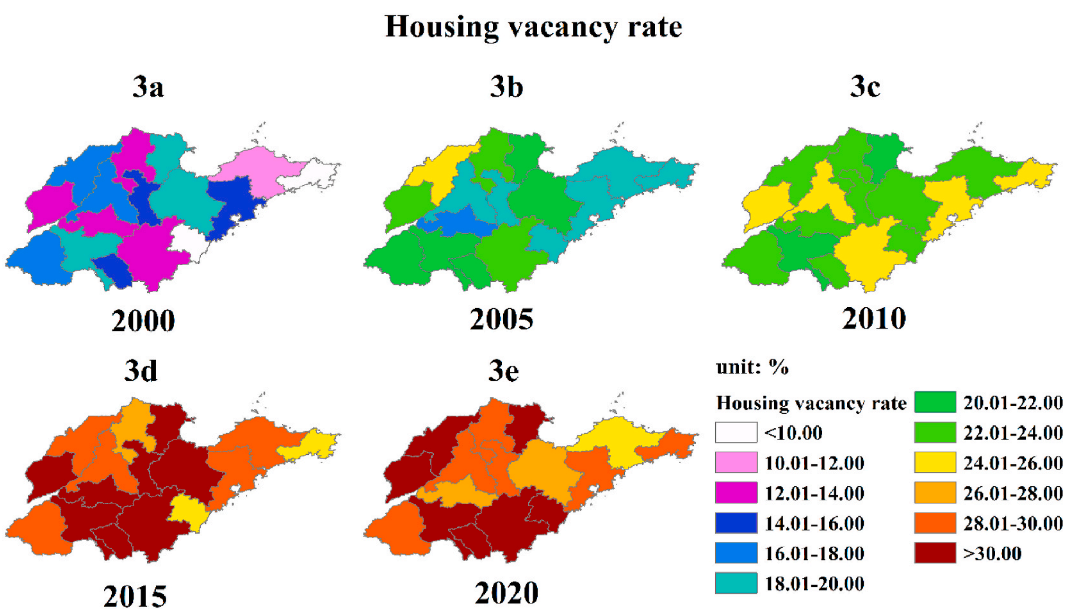

Fig. 3a–e. The housing vacancy rate of each city in the Shandong Peninsula urban agglomeration from 2000 to 2020.

$$\Delta CP = \frac{S^T - S^0}{Ln\,S^T - LnS^0} Ln \frac{CP^T}{CP^0} \tag{16}$$

where, ΔSS, ΔSG, ΔGP, ΔPCP and ΔCP represents the change in the vacant housing stock caused by the factors, and the superscripts T and 0 represent the end and the start of the studying period. These five indicators can be used to measure the contribution of each factor to the changes in the vacant housing stock in a certain period.

The cumulative contribution rate can more effectively indicate the contribution of each factor at different stages of urbanization development. The accumulative contribution rate (ACR) can be calculated as shown in Equation (17):

$$ACR_{F_i} = \frac{\sum_t \Delta F_i}{\sum_t (\Delta SS + \Delta SG + \Delta GP + \Delta PCP + \Delta \mathrm{P})} \times 100\% \tag{17}$$

where, ACR_{F_i} is the accumulative contribution rate of factor i (i = SS, SG, GP, PCP, and CP), ΔF_i is the variation of factor i (i = SS, SG, GP, PCP, and CP) from the reference year (year 0) to year t.

3. Results

3.1. Evolution of housing vacancy rates

The results of the calculated housing vacancy rate of each city in the Shandong Peninsula urban agglomeration from 2000 to 2020 are shown in Fig. 3a and b. The overall housing vacancy level was not high in 2000, and the housing vacancy rate in most cities in the Shandong Peninsula urban agglomeration was below 10.00%. By 2005, the housing vacancy rate in nearly half of the cities increased between 20.00% and 25.00%, (even exceeded 25.00% in some cities). Fig. 3c and d illustrate that housing vacancy has become a common phenomenon in the Shandong Peninsula urban agglomeration, and the housing vacancy rates in all cities are above 20.00% in 2010. The housing vacancy rate peaked in 2015 at around 30.00% in about half of the cities. A regional aggregation phenomenon can also be detected in cities with high housing vacancy rates. Despite the slight decrease in the housing vacancy rate in 2020 (Fig. 3e), the overall housing vacancy rate is still at a higher level.

3.2. Spatial and temporal changes in housing vacancy stock

Fig. 4a–e presents the calculated vacant housing stock of the Shandong Peninsula urban agglomeration from 2000 to 2020. The housing vacancy stock in the Shandong Peninsula urban agglomeration showed a fluctuating upward trend during the studied years. The vacant housing stock in 2000 in the whole studied region was at a low level (<10%) (Fig. 4a), and this value in most cities decreased significantly from 2005 to 2010 (Fig. 4b and c). Only five cities, i.e., Jinan, Qingdao, Zibo, Yantai, and Weihai, experienced an increase in the vacant housing stock. Among them, the vacant housing stock in the two megacities, i.e., Jinan and Qingdao, rose continuously from 2000 to 2020 with an average annual increase of over 3 MSM (Million Square Metres). In this recent year, the vacant housing stock in these megacities was the largest in the entire Shandong Peninsula urban agglomeration, exceeding 80 MSM. With this

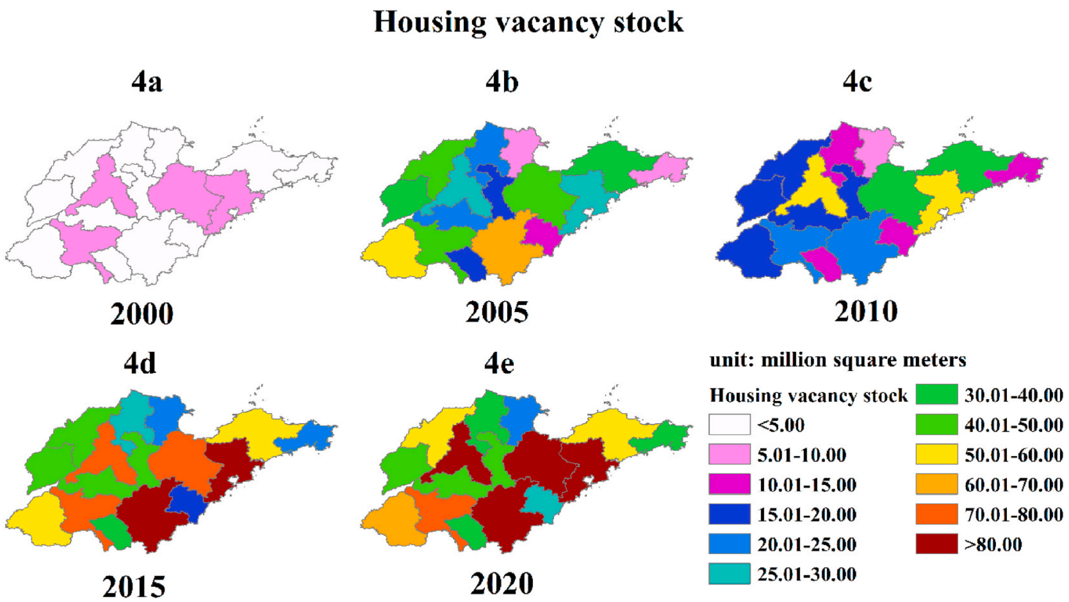

Fig. 4a–e. The vacant housing stock of each city in the Shandong Peninsula urban agglomeration from 2000 to 2020.

vacant housing stock, about two million people can be accommodated based on the theoretical calculation of per capita living area of that year. In large and medium cities, urban vacant housing stock growth averaged 1–2 MSM per year during 2000–2020. The vacant housing stock in these cities experienced a significant decline in 2010 but rebounded sharply from 2010 to 2015 until it started to slow down from 2015 to 2020.

3.3. Driving factors analysis of the vacant housing stock

A decomposition analysis with the LMDI method has been carried out to analyze the contribution and contribution rate of the five main factors to the housing vacancy stock during the study period. According to the results presented in Tables 1 and 2, ΔSS, ΔGP, and ΔCP are the main factors that promote the increase of vacant housing stock, whereas ΔSG and ΔPCP have a negative contribution to this stock's growth. In particular, ΔSS showed a positive driving effect during 2000–2015 but then turned into a negative inhibitory effect from 2015 to 2020 with a contribution rate of −2.01%. It indicates that the increase in the housing vacancy rate can promote the rise in the vacant housing stock, and reducing the housing vacancy rate can facilitate the reduction in the vacant housing stock to a certain extent. The changes in ΔSG showed a U-shaped trend during 2000–2020, illustrating a positive driving effect on vacant housing stock during 2000–2005 and 2010–2020, and a negative effect during 2005–2015, with the minimum contribution rate of - 32.48% and maximum rate of 330.10%. This implies that ΔSG is a sensitive factor to the vacant housing stock. During 2000–2020, ΔGP had a positive driving effect on the increase in the vacant housing stock, and the average contribution and average contribution rate of ΔGP are the largest among all factors. At the same time, ΔPCP had a negative inhibitory effect on the growth of vacant housing stock, with an average contribution rate of −37.82%. In this study, however, the urbanization level is defined as the ratio of the total population to the urban population, which is the reverse of the conventional definition of urbanization level. Therefore, the results indicated that rapid urbanization is also a major driver of the increase in the vacant housing stock. ΔCP showed a positive driving effect on the increase in vacant housing stock with an average contribution rate of 44.47%, indicating that the excessive growth of the urban population will also facilitate the increase of vacant housing stock.

The factor decomposition results of the housing vacancy stock in the cities of Shandong Peninsula urban agglomeration from 2000 to 2020 are shown in Fig. 5. On the whole, there are five influencing factors: ΔSS, ΔGP, ΔCP, ΔSG, and ΔPCP, which have a positive driving effect on the growth of the vacant housing stock in each city. In most prefectures and cities, the growth of vacant housing stock has a negative inhibitory effect. In the Shandong Peninsula urban agglomeration, ΔGP is the largest positive driving factor affecting the vacant housing stock in all cities. Although ΔSG has a negative inhibitory effect on the growth of the vacant housing stock, its impact is only in the two megacities. In contrast, the impact on other cities is relatively small, indicating that ΔSG is a relatively sensitive factor in megacities. ΔPCP has a significant effect in the Shandong Peninsula urban agglomeration, but in this study, the definition of urbanization level is total population/urban population, indicating that rapid urbanization will promote an increase in vacant housing stock in all cities.

In Fig. 5, ΔSS represents the impact of the housing vacancy rate on the changes in housing vacancy stock; ΔSG represents the impact of unit floor area value; ΔGP represents the impact of the level of economic development level; ΔPCP represents the impact of the urbanization level; ΔCP represents the impact of the urban population level on the vacant housing stock.

4. Discussion

4.1. Comparison of housing vacancy rate results with other studies

This paper calculates the housing vacancy rate of each city in the Shandong Peninsula urban agglomeration from 2000 to 2020. As relevant statistical data in China has not yet been available, the results from previous studies are used to compare with the results from this study in order to verify the accuracy. As shown in Table 3, the Research Center for China Household Finance Survey (CHFS) of the Southwestern University of Finance and Economics is the representative institution for calculating the housing vacancy in China [45], providing investigation and analysis of urban housing in China every two years. It can be seen from the table that the average housing vacancy rate in Chinese cities is between 15.00% and 25.00%, and the housing vacancy rate in first-tier cities is relatively low. Wang et al. [24]evaluated the vacant housing level in 2015 in 31 provincial-level cities with different development levels in China based on the NPP-VIIRS night-time light data and OpenStreetMap data. The research showed that the average vacancy rate in first-tier cities is 18.90%, second-tier cities are 20.40%, and third-tier cities are 23.30%. The results are similar to the housing vacancy rate of large cities in China in 2018 from Tang et al. [14]calculated using night light data. The May 2015 National Urban Housing Market Survey Report [46] jointly released by Tencent.com, Tencent Real Estate Research Institute, China Real Estate News, and Tencent Wisdom

Table 1
Factor decomposition (Contribution) of housing vacancy stock in Shandong Peninsula urban agglomeration from 2000 to 2020 (million m2).

Year	ΔSS	ΔSG	ΔGP	ΔPCP	ΔCP	ΔS
2000–2005	54.61	140.34	108.72	−89.52	87.63	301.77
2005–2010	39.11	−375.47	211.22	−31.52	42.91	−113.75
2010–2015	100.31	−69.61	170.63	−55.28	68.23	214.29
2015–2020	−4.81	194.26	29.63	−66.33	86.56	239.31
Average	47.30	−27.62	130.05	−60.66	71.33	160.41

Table 2
Factor decomposition (contribution rate) of vacant housing stock in Shandong Peninsula urban agglomeration from 2000 to 2020 (%).

Years	Δ*SS*	Δ*SG*	Δ*GP*	Δ*PCP*	Δ*CP*
2000–2005	18.10	46.51	36.03	−29.67	29.04
2005–2010	−34.39	330.10	−185.69	27.71	−37.72
2010–2015	46.81	−32.48	79.63	−25.80	31.84
2015–2020	−2.01	81.18	12.38	−27.72	36.17
Average	29.49	−17.22	81.08	−37.82	44.47

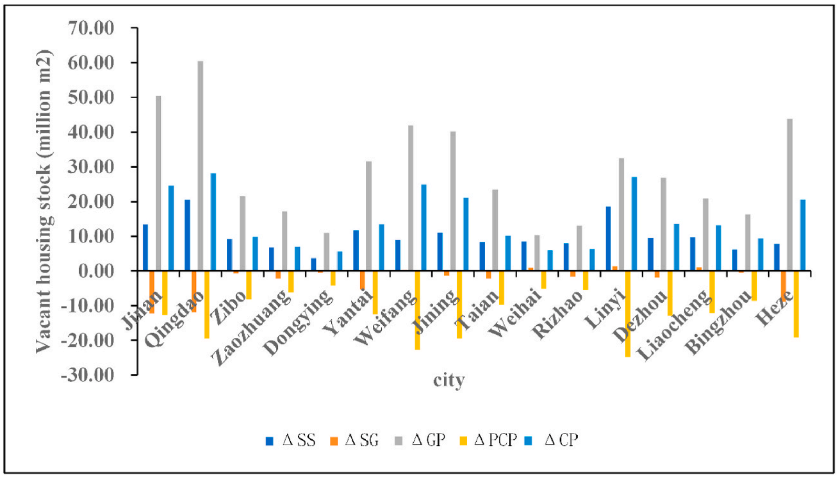

Fig. 5. Factor decomposition results of housing vacancy stock in Shandong Peninsula urban agglomeration from 2000 to 2020.

Table 3
Comparison of housing vacancy rates in different studies.

Sources	Study area	HVR (%)				
This study	Shandong peninsula urban agglomeration	**2000**	**2005**	**2010**	**2015**	**2020**
	Qingdao	14.31	19.67	24.37	29.45	28.95
	Jinan	17.06	19.38	25.75	28.40	28.13
	Linyi	13.63	23.34	24.72	30.63	31.44
	Yantai	11.93	18.91	22.45	28.34	24.87
	Zibo	14.73	19.09	22.86	30.19	28.14
	Weifang	18.06	21.30	22.02	31.12	27.04
	Jining	18.53	21.92	21.64	33.49	31.13
	Zaozhuang	15.13	20.35	22.39	31.43	30.36
	Taian	13.86	16.21	23.24	30.86	26.44
	Dezhou	17.55	25.43	22.85	28.22	35.35
	Weihai	9.38	18.67	25.57	24.58	30.02
	Heze	17.60	21.01	23.14	29.11	28.55
	Dongying	18.51	21.82	21.67	31.69	31.23
	Liaocheng	12.41	22.32	24.15	35.70	30.09
	Rizhao	9.02	18.18	23.61	25.10	31.54
	Bingzhou	13.17	22.58	23.08	27.00	28.55
CHFS		**2011**	**2013**	**2015**	**2017**	
	First-tier cities	17.90	17.90	17.50	16.80	
	Second-tier cities	17.80	19.60	20.30	22.20	
	Third-line cities	19.00	19.70	21.30	21.80	
[a]Report				**2015**		
	First-tier cities			22.00		
	Second-tier cities			24.00		
	Third-line cities and Four-tier cities			26.00		
Wang et al., 2019	Nationwide			**2015**		
				20.78		
Tan et al., 2020	Nationwide					**2018**
						20.51

[a] *Report: the data is extracted from the May 2015 National Urban Housing Market Survey report* (Tencent, Tencent Real Estate Research Institute, China Real Estate News, 2015.).

showed that the overall housing vacancy rate in major Chinese cities was between 22.00% and 26.00%.

Compared with the housing vacancy rate results from other studies in the same period, the housing vacancy rate values of some cities obtained in this paper are slightly higher. Nonetheless, the calculated results are close to those of previous studies, indicating that the calculated results in this paper are relatively accurate, and therefore, can be used to estimate the stock of housing vacancies and analye the driving factors. Moreover, this paper calculates the housing vacancy rate of various cities in the Shandong Peninsula urban agglomeration from 2000 to 2020. Compared with other studies that focus on the regional vacancy data at a single time node, this study can further analyze the regional housing situation and its influencing factors from the time and space perspectives. It can further facilitate the formulation of a more scientific urban construction and development plan and promote the healthy and sustainable development of the city.

4.2. Analysis of the potential for reducing the vacant housing stock

The decomposition analysis of the housing vacancy driving factors showed that, at the macro level, ΔSS, ΔGP, ΔCP are the positive driving factors triggering the increase of vacant housing stock,. In contrast, ΔSG and ΔPCP are the negative driving factors limiting the increase of vacant housing stock. Therefore, to mitigate this issue, the following suggestions are proposed. i) Reduce the housing vacancy rate in each city. As shown in Fig. 3, significant differences are observed in the housing vacancy rates in cities of different grades and different cities within the same grade. The "policy by city" principle should be continuously implemented to reduce the housing vacancy rate when adjusting the housing market of different cities. For each city, the housing market monitoring policy should be tailor-made in congurance with the specific driving factors of housing vacancy in this city and the particular conditions of the housing vacancy levels and their distributions in the city. ii). Improve the level of economic development in the region and reduce the economic value of unit construction areas. As shown in Table 2, ΔGP has the greatest impact on the stock of vacant housing. Therefore, when monitoring the vacant housing stock, it is important to strictly control the housing investment from enterprises and individuals, suppress behaviours that maliciously raise the housing value levels, and stabilize economic growth and improve the purchasing power of residents. iii). Formulate appropriate urban planning schemes and steadily improve the level of urbanization. It can be seen from the decomposition analysis results that excessive urbanization can increase urban housing vacancies. Therefore, the growth of the urban population and the correlation between housing supply and demand should be fully considered to prevent excess housing supply during the process of city construction and development.

As shown in Fig. 4, the vacant housing stock in the Shandong Peninsula urban agglomeration is gradually increasing over time at the city level, and the spatial distribution has been constantly changing. Combined with the decomposition analysis results of the vacant housing stock at the city level in the Shandong Peninsula urban agglomeration (Fig. 5), the following suggestions are proposed to reduce the vacant housing stock in the future. First, the two megacities: Jinan and Qingdao have almost the largest vacant housing stock over the studied years. During the development of such megacities, the urban expansion speed should match the growth rate of the urban population. Reducing the investment property of housing and making sure that the real needs of residents for housing are met could reduce the generation of vacant housing stock from its origin. For cities with existing vacant stock, the development and construction of new projects should be limited, and urban population introduction should be strengthened to digest the existing large amount of vacant stock. Such as, implementing the talent introduction policy, and provide housing security and purchase discounts for talents who settle in the local area. In nine large cities, including Linyi, Zibo, and Weifang etc., and six medium-sized cities including Heze, Rizhao, and Binzhou etc. The level of economic development is the main driving factor for the increase in the vacant housing stock. Therefore, the focus of city development should be placed on increasing the residents' income, enhancing the resident's purchasing power, and lowering the economic value of unit housing. Meanwhile, with the siphoning effect of the two megacities of Jinan and Qingdao on the population, large cities and medium-sized cities surrounding Jinan and Qingdao should vigorously develop the education system and provide better development opportunities for scientific researchers. In addition, these cities should also promote the development of advantageous regional industries, with the effort to attract populations from other cities and retain the local population, and finally, reduce housing vacancies.

By analyzing the population and vacant housing stock in the Shandong Peninsula urban agglomeration from 2000 to 2020, it is found that more than 50.00% of the population and vacant housing stock in the Shandong Peninsula urban agglomeration are concentrated in the large cities. In response, the government could consider reducing the construction of new housing and using incentives such as home purchase subsidies to encourage residents to purchase the existing housing stock. In addition, the analysis also show that the vacant housing stock and the vacant housing stock per capita in the city both growth with the expansion of cities. For example, the share of vacant housing stock in mega-cities is over 30.00%, although only about 20.00% of the population. The main reason is quite likely that many houses are purchased were not for living. Some studies have shown that housing is a good investment product in some Chinese cities [47–50] [47–50] [47–50]. The government could consider introducing housing policies that reduce the investment attributes of housing and return housing to its use attributes, thereby fundamentally reducing housing vacancy.

4.3. Limitations and uncertainties

This paper uses nighttime light and land use data to quantitatively estimate the urban housing vacancy level, which can quickly obtain the housing vacancy situation on a large regional scale. However, the results of this paper have certain limitations and uncertainties due to the limitations of data, methods, and the influence of topography and urban layout as follows: 1) The best spatial resolution of long-term series night light data that is currently available is 500 m × 500 m, which is not a high resolution and can be easily affected by many background noises such as light intensity, firelight, and exhaust gas burning in urban areas. 2) The land use data adopted in this study is the integrated products on the global scale with an overall classification accuracy of 79.30%, and the interpretation accuracy is low corresponding to the real situation, which can, in a way, affect the estimation accuracy of housing vacancies. 3) In this study, the selected lighting thresholds for non-residential and non-vacant housing might affect the accuracy of the calculation of the housing vacancy rate in the study area. Meanwhile, statistical data is used for the calculation of housing vacancy stock, which can also affect the accuracy of the results. 4) Although the method and approach of studying housing vacancy based on remote sensing data in this study can be effectively extended to other countries and regions. However, the selection of certain key values needs to take into account the actual situation of the research results more accurate. For example, the selection of lighting intensity thresholds for non residential and non vacant housing needs to be determined based on the actual situation of the region, which is also in line with the differences in housing development in different countries and regions.

5. Conclusions

Accurate and objective measurement of housing vacancy data is crucial for predicting housing market demand, reducing resource waste, and ensuring the stable development of the national economy. It can provide guiding information for policymakers to formulate effective housing market regulation policies and measures. However, at present, authoritative housing vacancy data in China has yet to be available, which makes it difficult to conduct further research on the waste of housing resources caused by vacant housing and its driving factors. Therefore, this study used night light data and land use data to analyze the vacant housing situation and its driving factors in the Shandong Peninsula urban agglomeration. The study is carried out based on existing research on vacant housing and combined with the actual situation in China, which is when it is difficult to obtain statistical data. The main conclusions are as follows:

1) The housing vacancy rate in the Shandong Peninsula urban agglomeration increased from 14.68% in 2000 to 29.71% in 2015 and dropped to 29.49% in 2020. Compared with the results in previous research, it showed that the housing vacancy rate calculation results using nighttime light data and land use data are more accurate. At the same time, the research results also show that a large number of housing vacancies can appear in the process of excessively rapid urbanization.
2) The total vacant housing stock in the Shandong Peninsula urban agglomeration rose from 49.84 million m^2 in 2000 to 696.62 million m^2 in 2020, with an average annual increase of 32.34 million m^2. There was a brief dip in vacant housing stock during 2010 but followed by a rapid increase since then. Research showed that in the process of rapid urbanization, high vacancy of housing could lead to a rapid increase in vacant housing stock, resulting in a great waste of housing resources.
3) ΔSS, ΔGP, and ΔCP, which represent the housing vacancy rate, economic development level and urban population have a positive drive on the vacant housing stock, ΔSG and ΔPCP, which represent unit floor area value and urbanization level have a negative impact. Among them, ΔGP has the greatest impact on the vacant housing stock and can promote the growth of vacant housing stock. ΔSG is more sensitive to the vacant housing stock, and the vacant housing stock can be effectively reduced by reducing the unit floor area value.

Author contribution statement

Dong Yang: conceived and designed the experiments; performed the experiments; wrote the paper.
Bing Xiao: conceived and designed the experiments; performed the experiments; wrote the paper.
Feng Han: conceived and designed the experiments; contributed reagents, materials, analysis tools or data; wrote the paper.
Jinping Li: conceived and designed the experiments; analyzed and interpreted the data; wrote the paper.
Xinjie Lu: conceived and designed the experiments; analyzed and interpreted the data; wrote the paper.
Lingwen Sun: performed the experiments; contributed reagents, materials, analysis tools or data.
Feng Shi: performed the experiments; contributed reagents, materials, analysis tools or data.
Xuexiu Jia: performed the experiments; analyzed and interpreted the data.
Xin Li: performed the experiments; analyzed and interpreted the data.
Kronnaphat Khumvongsa: analyzed and interpreted the data; contributed reagents, materials, analysis tools or data; wrote the paper.
Xianyin Duan: analyzed and interpreted the data; contributed reagents, materials, analysis tools or data.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] United Nations Human Settlements Programme (UN-Habitat), World Cities Report 2020: the Value of Sustainable Urbanization, 2020. https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf. (Accessed 15 February 2022).
[2] Y. Chen, Y. Cai, C. Zheng, Efficiency of Chinese real estate market based on complexity-entropy binary causal plane method, Complexity (2020) 2020, https://doi.org/10.1155/2020/2791352.
[3] S. Cao, Y. Lv, H. Zheng, X. Wang, Challenges facing China's unbalanced urbanization strategy, Land Use Pol. 39 (2014) 412–415, https://doi.org/10.1016/j.landusepol.2013.12.004.
[4] W. Shepard, Geographical reviews, in: Ghost Cities China Story OfCities without People World's Most Popul. Ctry., Zed Books, London, 2015, https://doi.org/10.1111/j.1931-0846.2009.tb00449.x.
[5] I.C. Tsai, Price rigidity and vacancy rates: the framing effect on rental housing markets, J. R. Estate Finance Econ. 63 (2021) 547–564, https://doi.org/10.1007/s11146-020-09791-4.
[6] X. Fang, X. Shi, T.K. Phillips, P. Du, W. Gao, The coupling coordinated development of urban environment towards sustainable urbanization: an empirical study of Shandong peninsula, China, ecol, Indic 129 (2021), 107864, https://doi.org/10.1016/j.ecolind.2021.107864.
[7] G. Wood, J. Yates, M. Reynolds, Vacancy rates and low-rent housing: a panel data analysis, J. Hous. Built Environ. 21 (2006) 441–458, https://doi.org/10.1007/s10901-006-9059-0.
[8] R.M. Silverman, L. Yin, K.L. Patterson, Dawn of the dead city: an exploratory analysis of vacant addresses in buffalo, ny 2008-2010, J. Urban Aff. 35 (2013) 131–152, https://doi.org/10.1111/j.1467-9906.2012.00627.x.
[9] C. Vakili-Zad, J. Hoekstra, High dwelling vacancy rate and high prices of housing in Malta a Mediterranean phenomenon, J. Hous. Built Environ. 26 (2011) 441–455, https://doi.org/10.1007/s10901-011-9232-y.
[10] A. Harrison, D. Immergluck, The Battle of the Belts : Comparing Housing Vacancy in Larger Metros in the Sun Belt and the Rust Belt since the Mortgage Crisis, 2020, 2012 to 2019.
[11] G. Newman, R.J. Lee, D. Gu, Y. Park, J. Saginor, S. Van Zandt, W. Li, Evaluating drivers of housing vacancy: a longitudinal analysis of large U.S. cities from 1960 to 2010, J. Hous. Built Environ. 34 (2019) 807–827, https://doi.org/10.1007/s10901-019-09684-w.
[12] T. Cozens, Paul, Exploring housing maintenance and vacancy in Western Australia, Property Manag. 34 (2016) 1–5, https://doi.org/10.1108/PM-06-2015-0027.
[13] M. Segú, The impact of taxing vacancy on housing markets: evidence from France, J. Publ. Econ. 185 (2020), 104079, https://doi.org/10.1016/j.jpubeco.2019.104079.
[14] Z. Tan, D. Wei, Z. Yin, Housing vacancy rate in major cities in China: perspectives from nighttime light data, Complexity (2020) 2020, https://doi.org/10.1155/2020/5104578.
[15] C. Zhang, S. Jia, R. Yang, Housing affordability and housing vacancy in China: the role of income inequality, J. Hous. Econ. 33 (2016) 4–14, https://doi.org/10.1016/j.jhe.2016.05.005.
[16] J. Wang, J. Zhang, The influence of vacancy rate on housing price： Based on panel data of 35 key cities, Resour. Sci. 42 (2020) 1135–1147, https://doi.org/10.18402/resci.2020.06.11.
[17] J. Wu, J. Gyourko, Y. Deng, Evaluating the risk of Chinese housing markets: what we know and what we need to know, China Econ, Rev 39 (2016) 91–114, https://doi.org/10.1016/j.chieco.2016.03.008.
[18] L. Tan, Y. Zhou, L. Bai, Human activities along southwest border of China: findings based on DMSP/OLS nighttime light data, SSRN Electron. J. (2017) 1–10, https://doi.org/10.2139/ssrn.3027885.
[19] J. Yang, Y. Wang, C. Xiu, X. Xiao, J. Xia, C. Jin, Optimizing local climate zones to mitigate urban heat island effect in human settlements, J. Clean. Prod. 275 (2020), 123767, https://doi.org/10.1016/j.jclepro.2020.123767.
[20] Z. Chen, B. Yu, Y. Hu, C. Huang, K. Shi, J. Wu, Estimating house vacancy rate in metropolitan areas using NPP-VIIRS nighttime light composite data, IEEE J. Sel. Top. Appl. Earth Obs. Rem. Sens. 8 (2015) 2188–2197, https://doi.org/10.1109/JSTARS.2015.2418201.
[21] Q. Zheng, Y. Zeng, J. Deng, K. Wang, R. Jiang, Z. Ye, Ghost cities" identification using multi-source remote sensing datasets: a case study in Yangtze River Delta, Appl. Geogr. 80 (2017) 112–121, https://doi.org/10.1016/j.apgeog.2017.02.004.
[22] X. Niu, Estimating housing vacancy rate in Qingdao City with NPP-VIIRS nighttime light and geographical national conditions monitoring data, Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. - ISPRS Arch. 42 (2018) 1319–1326, https://doi.org/10.5194/isprs-archives-XLII-3-1319-2018.
[23] H. Li, C. Zeng, W. Wan, Y. Cui, Y. Hong, W. Fan, A remote sensing-based vacancy area Index for estimating housing vacancy and ghost cities in China, Int. Geosci. Remote Sens. Symp. (2019) 7518–7521, https://doi.org/10.1109/IGARSS.2019.8898197.
[24] L. Wang, H. Fan, Y. Wang, An estimation of housing vacancy rate using NPP-VIIRS night-time light data and OpenStreetMap data, Int. J. Rem. Sens. 40 (2019) 8566–8588, https://doi.org/10.1080/01431161.2019.1615655.
[25] C. Fang, X. Yu, X. Zhang, J. Fang, H. Liu, Big data analysis on the spatial networks of urban agglomeration, Cities 102 (2020), 102735, https://doi.org/10.1016/j.cities.2020.102735.
[26] H. Xian-yin, W. Ren, The route selection of Shandong peninsula urban agglomeration to play the leading role under the background of yellow river national strategy, Urban Environ. Stud. 21 (2020) 1–9.
[27] National Bureau of statistics, China statistical Yearbook 1999, China statistics press, beijing, China. http://www.stats.gov.cn/yearbook/indexC.htm, 1999. (Accessed 14 February 2022).
[28] Office of the seventh national census LeadingGroup of the state council., major figures on 2020 population census of China., (n.d.). http://www.stats.gov.cn/tjsj/pcsj/rkpc/d7c/202111/P020211126523667366751.pdf. (Accessed 14 February 2022).
[29] People's government of Shandong province., new urbanization planning of Shandong province (2021-2035)., (n.d.). http://www.shandong.gov.cn/art/2022/1/21/art_107851_117039.html. (Accessed 14 February 2022).
[30] S. Yu, Z. Siqi, L. Hongyu, International Comparison of residential vacancy statistics and implications, Stat. Res. 8 (2005) 8–12, https://doi.org/10.19343/j.cnki.11-1302/c.2005.08.002.
[31] H. Lei, D. Jinghu, D. Leilei, Study on the spatial identification of housing vacancy, Remote Sens. Technol. Appl. (2020) 820–831, https://doi.org/10.1117/1.1509457.
[32] Z. Chen, B. Yu, C. Yang, Y. Zhou, S. Yao, X. Qian, C. Wang, B. Wu, J. Wu, An extended time series (2000-2018) of global NPP-VIIRS-like nighttime light data from a cross-sensor calibration, Earth Syst. Sci. Data 13 (2021) 889–906, https://doi.org/10.5194/essd-13-889-2021.
[33] Z. Chen, B. Yu, C. Yang, Y. Zhou, S. Yao, X. Qian, C. Wang, B. Wu, J. Wu, An extended time-series (2000-2018) of global NPP-VIIRS-like nighttime light data (n.d.), https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/YGIVCD, 2020.
[34] National Geomatics Center of China, National basic geographic Information database (n.d.), https://www.ngcc.cn/ngcc/html/1//391/392/16114.html. (Accessed 10 February 2022).
[35] J. Yang, X. Huang, 30 m annual land cover and its dynamics in China from 1990 to 2019, Earth Syst. Sci. Data Discuss. 4417810 (2021) 1–29, https://doi.org/10.5194/essd-2021-7.

[36] J. Yang, X. Huang, 30 M Annual Land Cover and its Dynamics in China from 1990 to 2019 (1.0.0) [Data Set], 2021, https://doi.org/10.5281/zenodo.4417810, 2021.
[37] 2005, 2010, 2015, 2020) Shandong provincial Bureau of statistics, Shandong Statistical Yearbook 2000-2020 (n.d.), http://tjj.shandong.gov.cn/col/col6279/index.html, 2000. (Accessed 15 February 2022).
[38] B.W. Ang, Decomposition analysis for policymaking in energy: which is the preferred method?, Response Strateg, Work. Gr. 32 (2004) 1131–1139, https://doi.org/10.1016/S0301-4215(03)00076-4.
[39] B. Zhang, Why is Japan's housing vacancy rate so high a history of postwar housing policy, Soc. Sci. Jpn. J. 23 (2020) 65–77, https://doi.org/10.1093/ssjj/jyz041.
[40] J.P. Lévy, O. Boisard, J. Salingue, The ASHA model: an alternative to the Markovian approach to housing vacancy chains: an application to the study of population in Lille (Nord, France), Urban Stud. 54 (2017) 2448–2471, https://doi.org/10.1177/0042098016651553.
[41] J. Pan, L. Dong, Spatial identification of housing vacancy in China, Chinese Geogr, Sci 31 (2021) 359–375, https://doi.org/10.1007/s11769-020-1171-7.
[42] C. Deilmann, K.H. Effenberger, J. Banse, Housing stock shrinkage: vacancy and demolition trends in Germany, Build. Res. Inf. 37 (2009) 660–668, https://doi.org/10.1080/09613210903166739.
[43] L. Hsueh, H. Tseng, C. Hsieh, Relationship between the housing vacancy rate, housing price, and the moving rate at the township level in taiwan, 1990 and 2000, Int. Real Estate Rev. 10 (2007) 119–150.
[44] Y. Kaya, Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios IPCC Energy and Industry Subgroup, Response Strategies Working Group, 1990.
[45] SURVEY AND RESEARCH CENTER FOR CHINA HOUSEHOLO FINANCE, (n.d.). https://chfs.swufe.edu.cn/sjzx/sjsq.htm.
[46] T.W. Tencent, Tencent real estate research Institute, China real estate news, national urban housing market Survey report (n.d.), https://gz.house.qq.com/a/20150604/039544.htm, May 2015. (Accessed 15 February 2022).
[47] W. Guan-cen, C. Huan, X. Shan-shan, Multi- scenario evolutionary Game analysis of local governments ' behavior choice in housing regulation policy, Oper. Res. Manag. Sci. 28 (2019) (In Chinese).
[48] L. Yaoyao, Q. Yuan, Z. Daolin, J. Xi, Z. Jiaqi, The impact of land supply scale on house prices based on the perspective of different housing attributes, China L. Sci. 34 (2020), https://doi.org/10.11994/zgtdkx.20201207.153906 (In Chinese).
[49] X. Huijia, The Impact of Home Equity and Home Debt on Women's Labor Force Participation - the Role of Property Attributes, South China Popul, 2009, pp. 57–64 (In Chinese).
[50] L. Wangjun, Z. Jingjing, L. Fang, Housing Property，Ｒesidential location and Migrants'Assimilation in China, Lanzhou Acad. J. 324 (2020) 69–83 (In Chinese).