Study on micro-mechanism of the affordable housing community in urban renewal the case of Zunyi city, Guizhou province

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Introduction: Affordable housing in China refers to housing with social security for low and middle income people under the unified planning and coordination of the government. In the process of urbanization, the construction of affordable housing and commercial housing should be developed in parallel, but under the role of the real estate market economy, the development of the two is unbalanced, resulting in a disparity in quantity, a large gap in quality, unreasonable management, and even residential segregation. The construction and development of China's affordable housing community is a huge and complex systemic project. This study focuses on a series of problems in the relationship between supply and demand of affordable housing based only on the development context of urban renewal at this stage.

Methods: Based on existing literature and official data, combined with field visits and research, this study uses Vensim PLE software to build a system model for converting various types of stock into affordable housing, and to investigate the effect of various policies on solving the problem of supply and demand of affordable housing.

Results: The research results show that 1) the policies stimulate the increase of urban population and help promote the supply cycle of affordable housing; 2) under the stimulation of the supply policy of converting stock housing into affordable housing, social investment will improve by 33%–64% and the gap of affordable housing will decrease by 29%–58%; 3) under the stimulation of the policy of optimizing the management of affordable housing, the coverage rate of affordable population will improve by 3%–5% and the middle and low income households' *per capita* housing floor area will increase by 9%–18% l; 4) under the comprehensive influence of the combined policies, the urban population will grow healthily, the *per capita* income and *per capita* housing floor area of low- and middle- income people will be improved, the stock of housing will be reduced, the number of affordable housing will increase, the affordable housing gap will be reduced, and the affordable housing community will be developed sustainably and healthily.

Meaning: The research results and recommendations will provide references for the government and competent authorities to enact or update the policies on affordable housing.

KEYWORDS

urban renewal, affordable housing community, micro-mechanism, system dynamics, sustainable development

1 Introduction

Cities in the 21st century are facing many problems, such as uneven urbanization, incomplete urban renewal, inadequate housing security and policy formulation and implementation out of practice. Sustainable urban development has become a core element of relevant policy formulation. Urban renewal was first proposed by the Central Committee of the Communist Party of China in 2019 and will be included in the 14th Five-Year Plan in 2021. As early as 2013, some scholars found that China's residential production was excessive, and due to the combined effect of home purchase conditions and the market, China's residential housing has continued to develop in an environment where supply exceeds demand. In this process, the following problems have been accumulated and fermented: 1. There is a contradiction between improving the quality of living and improving the efficiency of use in urban regeneration: At this stage, China has mainly carried out urban regeneration in old neighborhoods by "reserved, retrofitting and demolishing", but has neglected the renewal of urban housing stock, which is an important part of high-quality development construction. 2, The contradiction between supply and demand of affordable housing: on the supply side, the authorities ignore the affordable nature of housing, resulting in the number of affordable housing construction and investment scale are far less than the market commercial housing; on the demand side, due to the imperfect secondary distribution system and the limited disposable income of the middle and low income groups, but their huge number, which leads to the problem that they have housing guarantee needs but cannot be met is increasingly prominent. 3. The contradiction between "large housing inventory" and "small housing area *per capita*": China's housing inventory is increasing, and the phenomenon of empty cities and the phenomenon of small housing area *per capita* for low- and middle-income people exist simultaneously.

Researchers have analyzed the reasons for the above problems from different perspectives. Firstly, from the point of view of economic impact: a decline in demand in the market for commercial housing will not push down the price of housing, but will reduce the number of transactions and therefore increase the stock of housing (Cermakova et al., 2023). Some countries may be experiencing an imperceptible and transient state of poverty, leading to social exclusion and an imbalance between housing supply and demand (Luczak and Kalinowski, 2022). Given the increased costs of construction by enterprises and the difficulty of mortgage financing, it can lead to the difficulty of social investment forces to enter into the construction of affordable housing and the problem of its undersupply (Venhoda, 2022). At the global level, the widening gap between housing prices and residents' incomes due to the impact of COVID-19 leads to a large number of young people being forced to leave the cities where they live, with population loss and a reduction in the real housing space *per capita* (Hromada and Cermakova, 2021). Then, from the point of view of policy implications: between the dual development of affordable and commercial housing, a third housing sector of a non-profit nature is missing as a complementary structure, ignoring people who are not covered by the guarantee

policy and lack the purchasing power of commercial housing (Borgersen, 2022).

Researchers have used different analytical methods from different perspectives and proposed solutions to the above problems. From the perspective of physical field theory, it is proposed to construct a residential field force model to analyze the possibility of residential regeneration (Li, Y. 2012). From the perspective of architectural planning, the problem of new construction, preservation and renewal of projects in the historical environment is studied (Qu, Z. 2015). From the perspective of housing reform, a "gray Markov model" is constructed to predict the development trend of housing and commercial housing (Jin, 2012). From the perspective of housing stock market price, the Hedonic model is used to analyze and categorize the housing stock market and propose policies for sustainable development of housing stock (Huang, G. 2016). From the spatial relationship between housing and employment, the theoretical analysis framework of spatial dislocation for the implementation of housing policies is framed, its mechanism of action is analyzed, and policy recommendations are made (Wang, 2018). From the perspective of social equity, under the framework of the relationship between housing policy and housing equity, evaluation indicators are constructed, a simulation model of housing resource allocation is built, and suggestions are made to prevent welfare traps and deepen system reform (Yuejin, 2017). From the perspective of urbanization process, the concept of shared ownership is introduced in the affordable housing policy to expand the coverage of affordable housing for the middle and low-income groups and analyze the future development trend of affordable housing (Tang, 2019). From the perspective of urban renewal, the process of transforming stock housing into affordable housing is the same as the urban village micro-renovation model, and the comprehensive benefits of the renovation project are evaluated using the epi-material element model, and its good economic, cultural and social benefits help guide the participation of all social parties (Liu and Li, 2019). From the perspective of construction cost control, the use of a system with intelligent sensors to monitor all the renovation procedures in the process of converting stock housing into affordable housing can optimize the comprehensive benefits for all stakeholders (Wang et al., 2017).

In this paper, we focus on the relationship between supply and demand of affordable housing, find the appropriate influencing factors in the complex giant system of the city, apply the principle of system dynamics, take Zunyi city as the research object, and use Vensim PLE software to build a system model of urban affordable housing communities in the context of urban renewal (referred to as "Affordable Housing System" in the following), explore the micro mechanism of affordable housing communities, and provide reference basis and policy recommendations for the renewal of stock into affordable housing. The study uses Vensim PLE software to build a system model of urban housing settlements in the context of urban renewal (hereafter referred to as the "housing system"), to explore the micro mechanisms of housing settlements, and to provide reference and policy recommendations for the renewal of housing stock into housing. Cities are complex giant systems that contain many subsystems that interact with each other to form a complex

FIGURE 1
Technology roadmap for this study.
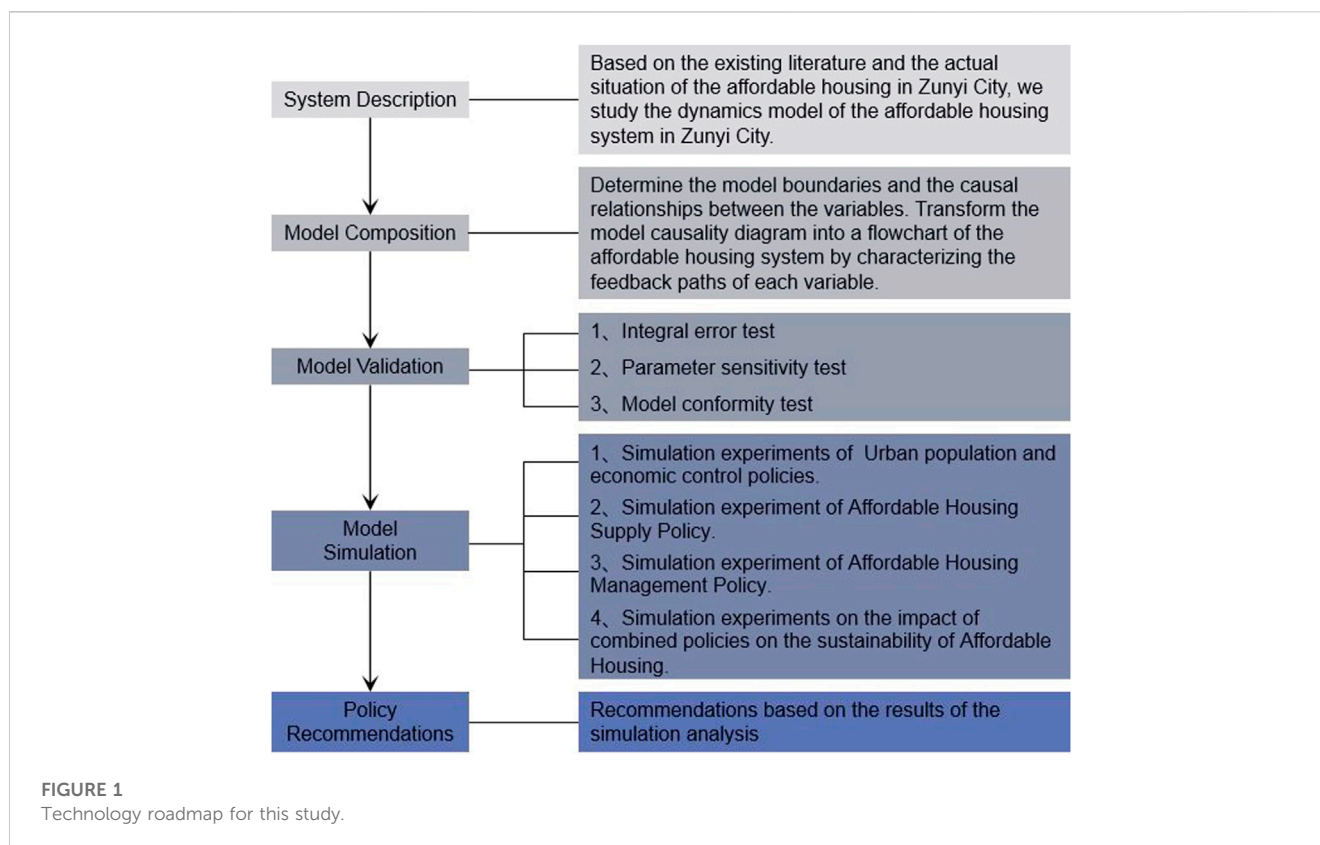
network structure (Wu, 2015). Studying the role of affordable housing communities in urban systems requires analyzing the results of multiple subsystems produced by the combined effects of different policies (Wang, 2019). Based on the research and literature analysis, a total of 29 variables, including the number of urban population, the number of enterprises, the number of market stock housing and the number of guaranteed housing units, were selected to construct a system dynamics model of guaranteed housing. Feedback loops are formed between the variables in the system, and many problems arising from the variables over time changes are analyzed and solved by constructing quantitative models (Wang, Q. 1994).

2 Research methodology

At present, there are five main sources of affordable housing: affordable housing built with government investment, affordable housing recovered by the government according to law, public housing left unsold by various enterprises and institutions, affordable housing allocated in commercial housing projects and housing raised by other means. Combining the current situation of China's housing security system and commercial housing market, we analyze the impact of various policy regulation on the relationship between the supply of affordable housing from the perspective of urban renewal, and establish a system dynamics model for affordable housing communities; and on the basis of existing literature and field research on affordable housing communities in Zunyi City, we conduct model verification and

policy simulation experiments, and finally give policy recommendations for the sustainable development of the social security career. The technical roadmap of this study is shown in Figure 1.

3 Conceptual model of affordable housing community system

3.1 Modeling purpose

In the context of urban renewal, the purpose of constructing a model of the security system is to: clarify the relationship between supply and demand of affordable housing, observe the impact of population and economic policies, affordable housing supply policies and affordable housing management policies on the security system, explore the development direction of the affordable housing in the urban megasystem, reveal the relationship between residents and housing in the affordable housing communities and the relationship between residents and the settlement environment, and seek solutions to the imbalance between supply and demand of affordable housing, the solution to the problems of unbalanced supply and demand, single mode of supply and financial pressure is sought. In the light of the evaluation index system of various housing security access conditions (He, 2020), and based on the "smart growth" theory (Li, 2013) and the development plan of "reducing incremental quantity and removing stock" (Zou, B. 2013), and based on the analysis of the actual situation, we build a conceptual model of the affordable housing
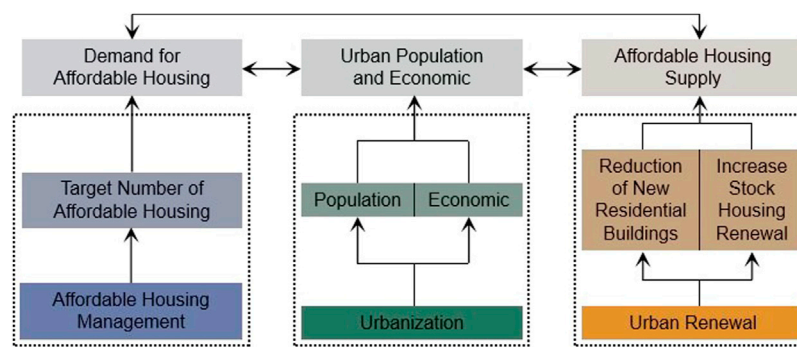
FIGURE 2
Conceptual model of the affordable housing community system, containing three subsystems: population and economy, affordable housing supply and affordable housing demand.

system (Figure 2), which includes three subsystems: population and economy, affordable housing supply and affordable housing demand. In this paper, urban renewal and urbanization development policies are formulated as constraints, and urban population and economic control policies, affordable housing supply policies and affordable housing management policies are used as regulatory elements to simulate the micro mechanisms of affordable housing communities under the influence of different policies.

3.2 Model boundary

In this paper, the affordable housing System is constructed, and the influencing factors other than the system model are considered as steady states. In the context of urban renewal, China has moved from the high-speed development stage of large-scale demolition and construction to the development stage of de-stocking, and there will be few new residential buildings in the future (Zhou, B. and Yu, M. 2022), and instead, the stock of residential buildings will be updated and transformed into affordable housing. In this paper, the stock of housing mainly includes unsold commercial houses, second-hand houses, and bad houses. The Ministry of Housing and Urban-Rural Development (MOHURD) delineates five categories of affordable housing, mainly including low-cost housing, affordable housing, public rental housing, shantytown renovation, and price-restricted commercial housing (Jin, 2012).

3.3 Cause-and-effect diagram of the whole system

In the giant system of the city, focusing on the affordable settlement, a system dynamics research method is used to sort out its subsystems and the mechanisms of mutual influence. The system consists of three subsystems: demographic and economic subsystem, housing supply subsystem and housing demand subsystem. The population and economic subsystem is characterized by the variable "Urban Population", and the larger the population, the better the economic development, and the more

favorable to the supply and capital investment of housing. The housing supply subsystem is characterized by the "Stock Housing Coversion Quantity". Assuming that the quantity of housing stock is relatively stable, the higher the renewal rate of housing stock in the market, the more housing stock is converted into housing, and the lower the quantity of housing stock in the market, the stronger the demand for upgrading the quality of housing. The housing demand subsystem is characterized by the "Affordable Housing Quantity". The larger the number of low- and middle-income households and the smaller the housing area *per capita*, the higher the demand for subsidized housing and the larger the shortage of subsidized housing. Some scholars suggest that diversified funds for housing construction should be explored (Chen and He, 2011; Wang and Zhao, 2014). Therefore, the variables of "fiscal expenditure" and "social investment" are set in the affordable housing system of this paper to reduce the financial pressure of the government and introduce social forces to promote the linkage between the affordable housing system and the market economy.

In this study, three subsystems constitute the overall model of the affordable housing communities (Figure 3). If the current urban state is considered stable, the problems in the affordable housing communities system need to be solved by corresponding policy stimulation or mechanism adjustment. If the population control policy stimulates the increase of urban population, which leads to the increase of the affordable housing gap and reflects the increase of the demand for affordable housing. If the policy of affordable housing supply stimulates the renewal of market stock into affordable housing, the increase in demand for affordable housing can be met.

3.4 System variables and main feedback paths

There are many factors that affect the sustainability of the affordable housing communities. Based on the relationship between the demographic and economic subsystem, the affordable housing supply subsystem and the affordable housing demand subsystem, the statistics of the variables in the affordable housing system are shown in Appendix 1.
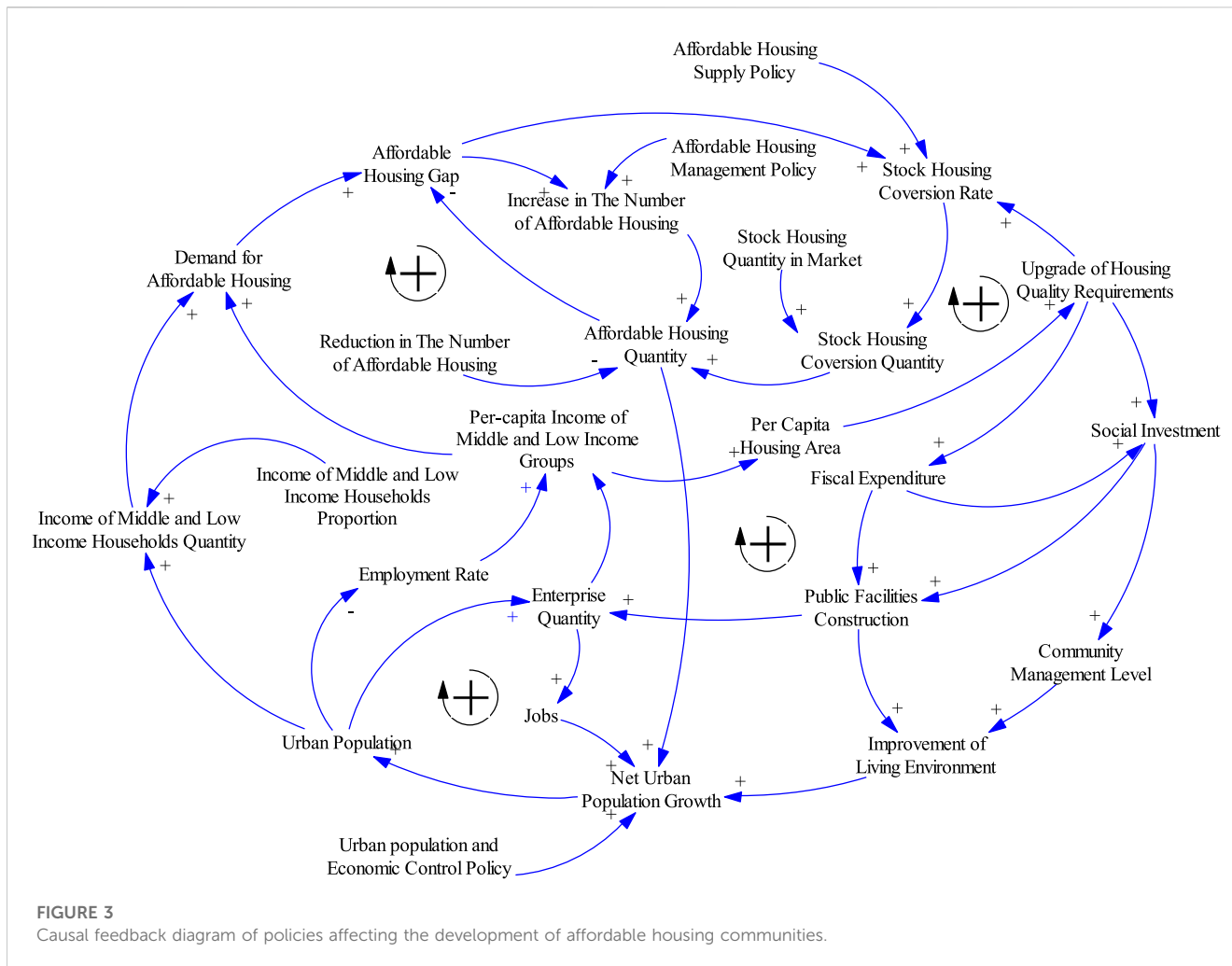
FIGURE 3
Causal feedback diagram of policies affecting the development of affordable housing communities.

The main feedback paths of the demographic and economic subsystems are as follows:

R1: Net Urban Population Growth → Urban Population → Employment Rate → Enterprise Quantity → Jobs → Net Urban Population Growth.

R2: Jobs → Urban Population → Income of Middle and Low Income Households Quantity → Demand for Affordable Housing → Affordable Housing Gap → Stock Housing Coversion Rate → Stock Housing Coversion Quantity → Affordable Housing Quantity → Net Urban Population Growth.

R3: Net Urban Population Growth ← Improvement of Living Environment ← Public Facilities Construction → Enterprise Quantity → Jobs → Net Urban Population Growth.

The three feedback routes, R1, R2 and R3, express the relationship between urban population size and the demand and supply of affordable housing. In the process of urban population growth, the employment rate and the demand for affordable housing will increase accordingly, as a way to improve the conversion rate of the market stock of housing. These positive feedback paths need to be generated through the influence of urban population and economic control policies, such as: relevant government departments actively optimize the investment attraction system, optimize the layout of the local industrial chain, and create more

jobs; introduce a system to promote local employment and settlement protection for college students to attract outstanding talents; relax the local employment and settlement system for foreign workers to retain the urban labor force; accelerate the reform of the household registration system to promote the mobility of people, etc.

The main feedback paths of the affordable housing supply subsystem are as follows:

R4: Public Facilities Construction → Enterprise Quantity → Per-capita Income of Middle and Low Income Groups → Per Capita Housing Area → Upgrade of Housing Quality Requirements → Fiscal Expenditure → Public Facilities Construction.

R5: Public Facilities Construction → Enterprise Quantity → Per-capita Income of Middle and Low Income Groups → Per Capita Housing Area → Upgrade of Housing Quality Requirements → Social Investment → Public Facilities Construction.

R6: Improvement of Living Environment ← Public Facilities Construction ← Fiscal Expenditure ← Upgrade of Housing Quality Requirements → Social Investment → Community Management Level → Improvement of Living Environment.

The three feedback lines, R4, R5 and R6, express the relationship between housing floor area *per capita* and the

construction of affordable housing. As the actual housing floor area *per capita* of the low- and middle-income groups decreases, people's demand for housing quality upgrades will continue to increase, thus further promoting social investment in the field of affordable housing construction and alleviating the pressure on fiscal expenditures. These positive feedback paths need to be generated through the influence of policies on the supply of affordable housing, for example,: relevant government departments introduce special funds and liberal financing policies on supporting enterprises to convert market stock housing into affordable housing to enhance the conversion rate of market stock housing and promote urban renewal while meeting market demand; introduce policies to optimize the construction of urban public facilities to enhance the living environment and eliminate the supply of affordable housing. The government has also introduced policies to optimize the construction of public facilities in cities to enhance the living environment, eliminate regional disparities in the supply of affordable housing, and attract more social investment to the construction of affordable housing.

The main feedback paths of the affordable housing demand subsystem are as follows:

R7: Affordable Housing Quantity → Affordable Housing Gap → Increase in The Number of Affordable Housing.

R8: Affordable Housing Quantity → Affordable Housing Gap → Stock Housing Coversion Rate → Stock Housing Coversion Quantity.

R9: Stock Housing Coversion Rate ← Affordable Housing Gap ← Demand for Affordable Housing ← Per-capita Income of Middle and Low Income Groups ← Per Capita Housing Area ← Upgrade of Housing Quality Requirements ← Stock Housing Coversion Rate.

The three feedback lines, R7, R8 and R9, express the relationship between the number of affordable housing and the affordable housing gap and commercial housing market. As the number of affordable housing tends to a state of dynamic equilibrium, the affordable housing gap will gradually decrease and the *per capita* housing floor area of the middle and low-income groups will gradually expand. While solving the housing problems of low- and middle-income groups, the social security career will also integrate smoothly with the housing market. These positive feedback paths need to be generated through the influence of the affordable housing management policies, such as: relevant government departments update and adjust the affordable housing application, admission, waiting list, and withdrawal mechanisms in a timely manner according to the comprehensive factors such as local demographic changes, employment rate, and basic *per capita* wage, in order to effectively expand the coverage of the social security career; formulate regional and phased rental and housing loans for those with immediate housing needs among the middle and low-income groups. The policy of loans for renting or purchasing affordable housing for those with immediate housing needs in the middle and lower income groups is to protect the housing problems of the middle and lower income groups from fluctuations in housing market prices from the perspective of social welfare undertakings, and to distinguish housing policy from real estate policy.

4 Inflow-and-outflow diagram of system dynamics model for affordable housing communities

4.1 System inflow-and-outflow diagram design

Based on the cause-effect diagram (Figure 3) and the system variable settings (Table 1) of the affordable housing communities, the system dynamics model was developed in Vensim PLE to obtain the system flow diagram (Figure 4). There are 4 state variables, 4 rate variables, and 21 auxiliary variables.

4.2 Description of key variables and calculation equations

First, since China has not yet established a comprehensive housing census system, it is difficult to obtain comprehensive data on housing stock, and the academic community often uses the calculation formula to estimate the housing stock, i.e., "housing stock = housing use area *per capita* * population" (Zhang and Zhou, 2017). Secondly, the demand for affordable housing is mainly affected by market house prices and *per capita* disposable income (Lu and Liu, 2013a), so the logarithm of the variable P7 *per capita* disposable income (low and middle income people) is used as the demand for affordable housing in this system. The calculation formula in the affordable housing system is shown in Appendix 1, and the statistics of data source information of the calculation formula is shown in Appendix 2.

The spatial boundary of the scenario simulation is the four main urban areas of Zunyi City, and the time boundary is from 2011 to 2035. The minimum time unit in the system is 1 year. Among them, the historical data from 2011 to 2020 are used for parameter design and model testing, and the data are mainly derived from the statistical yearbook of Zunyi City and the statistical yearbook of urban construction in each year; the logical values are combined and calculated by the model to simulate the system change scenarios from 2021 to 2035.

4.3 Model validation

In this study, the model will be tested for consistency of magnitudes, integration error test, parameter sensitivity test, and model fit test, respectively. The Units Check function that comes with Vensim is used to check the magnitudes of the variables in the system, and after passing the magnitude consistency test, the following model tests are carried out step by step.

4.3.1 Integral error test

According to the experience of previous studies, the absolute value of the system operation step in the integration error test formula is best controlled between 0.125-0.5 times the smallest time unit within the system (Wang, Q. 1994), so the integration error test multiplier in this study is ±25%, and the results of the operation with the four variables P1, S1, S4, and N1 are tested.

As shown in Figure 5, none of the four variables showed significant changes under the change of step size, i.e., the
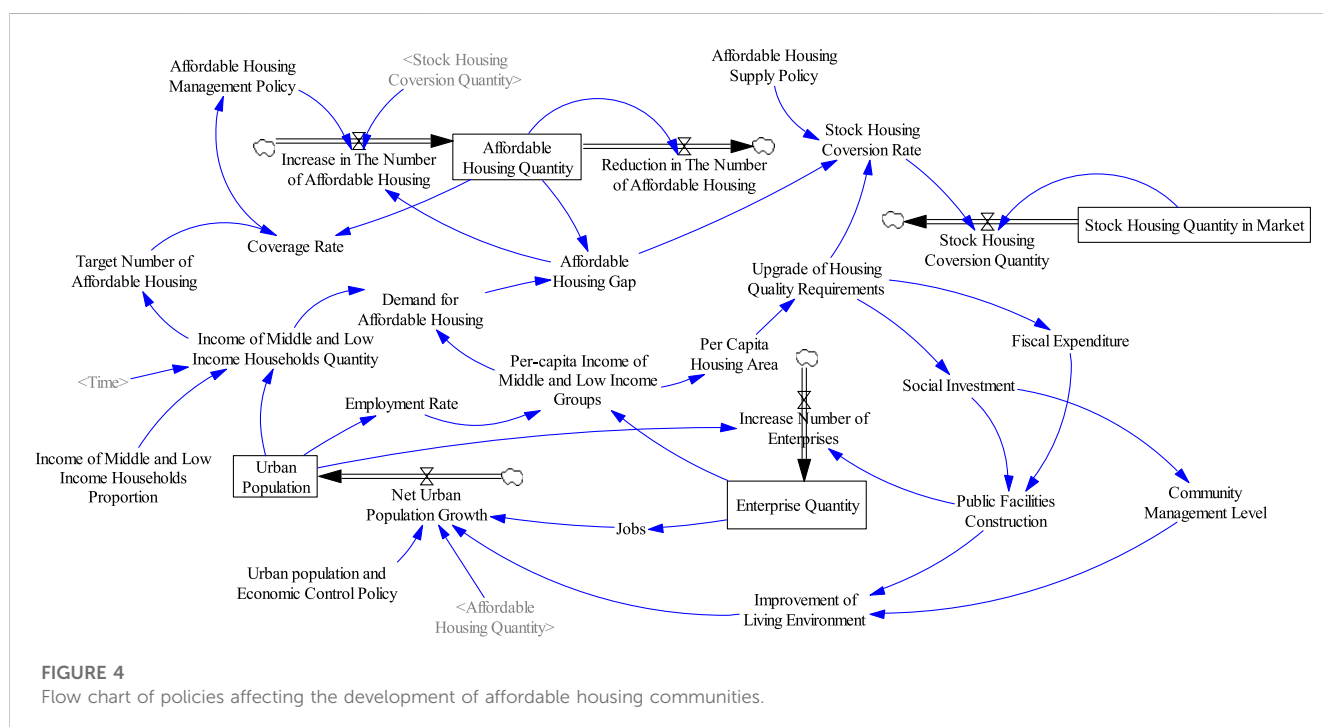
TABLE 1 Error check.

Time	Urban population (Person)			Per-capita income of middle and low income groups (RMB/person)			Per capita housing area (㎡/PERSON)		
	Simulation value	True value	Data error (%)	Simulation value	True value	Data error (%)	Simulation value	True value	Data error (%)
2011	2,266,500	2,266,500	0.00	17,426	17,426	0.00	34.00	34.00	0.00
2012	2,281,220	2,438,300	6.44	19,546	19,748	1.02	35.48	34.20	3.75
2013	2,519,770	2,636,900	4.44	21,337	20,504	4.06	36.57	36.00	1.59
2014	2,684,340	2,756,850	2.63	23,247	22,728	2.28	37.73	36.50	3.38
2015	2,777,280	2,876,800	3.46	25,289	24,997	1.17	38.97	39.20	0.57
2016	2,901,110	3,100,500	6.43	27,478	27,097	1.41	40.31	42.20	4.49
2017	3,158,570	3,264,700	3.25	29,828	29,617	0.71	41.73	43.60	4.28
2018	3,352,670	3,425,700	2.13	32,357	32,312	0.14	43.27	43.80	1.21
2019	3,386,680	3,586,750	5.58	35,081	35,352	0.77	44.93	44.30	1.41
2020	3,464,190	3,747,800	7.57	38,021	37,190	2.23	46.71	44.50	4.97
Average Error			4.19			1.38			2.57

sensitivity of the system to the step size was low, and therefore passed the integration error test, indicating that the model was stable.

4.3.2 Parameter sensitivity test

In this paper, two typical variables in the population and economic subsystem and the affordable house system are selected for testing (Figure 6), and the parameters are adjusted to increase the number of urban population (P1) by 10% and the number of enterprises (P5) by 10%, respectively. The change in their values has a significant effect on the demand for affordable housing (N5) and *per capita* disposable income (low and middle income people) (P7), thus passing the parameter sensitivity test and indicating that the model is sensitive.

FIGURE 4
Flow chart of policies affecting the development of affordable housing communities.

FIGURE 5
Results of integration error test for state variables.

FIGURE 6
Parameter sensitivity tests for typical variables.
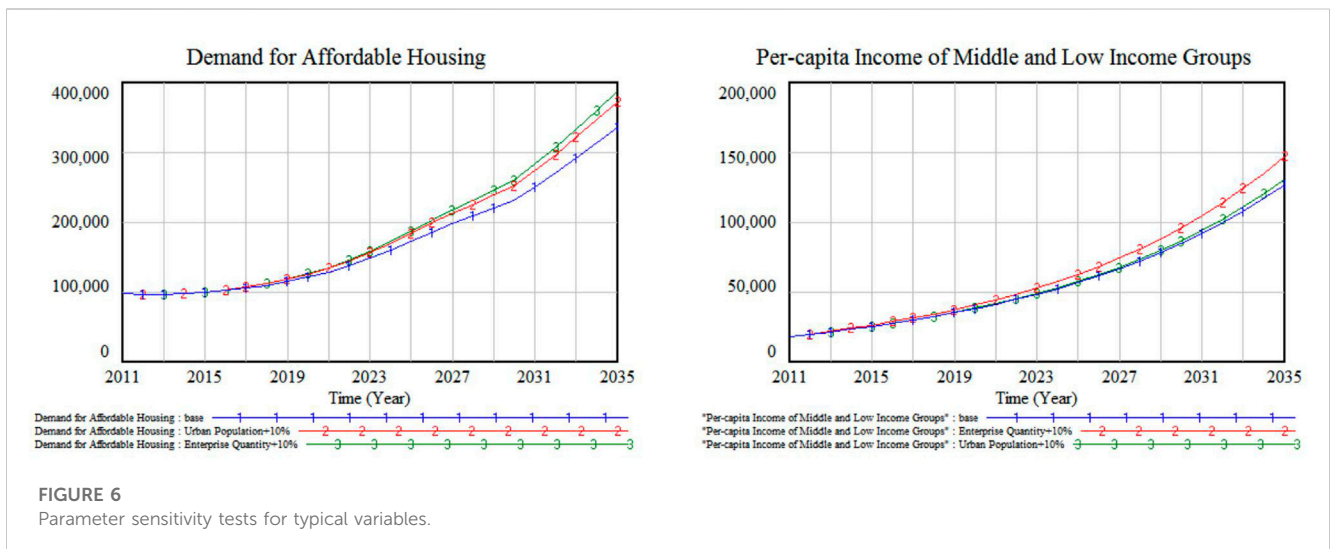
4.3.3 Model conformity test

To ensure the consistency between the simulated behavior of the system model and the historical data, the simulated values of

three important variables were subjected to error analysis with their real historical values during the test period 2011–2020: the number of urban population in P1, the disposable income *per*

capita (low and middle income people) in P7, and the housing floor area *per capita* in S4. The results of the model fit test are shown in Table 1, 7.57%, 4.06%, and 4.97% are the maximum absolute value of error in the three data sets, respectively, which are less than 10% (Liu, C. and Tu, G. 2015), and the absolute value of the average error in each group is less than 5% (Wang, 2019), thus passing the model fit test and indicating that the model is reliable.

Through the above multiple tests, it is shown that the affordable housing System model constructed in this study can effectively reveal the microscopic mechanisms of the affordable housing communities in the context of urban renewal, and thus policy simulation experiments can be conducted.

5 Policy simulation experiment for protected housing settlements in urban renewal

This study focuses on three policy dimensions, namely, urban population and economic control policy, affordable housing supply policy and affordable housing management policy, to simulate the affordable system. First, the effect of the variable PLC1 urban population and economic control policy on the system in the population and economy subsystem is mainly reflected by the *per capita* disposable income of the low- and middle-income population in variable P7. Secondly, the effect of variable PL2 affordable housing supply policy on the system in the affordable housing supply subsystem is mainly reflected by variables S4 *per capita* housing floor area, S5 social investment, and S8 market stock housing conversion rate. Then, the effect of variable PLC3 affordable housing management policy in the affordable housing demand subsystem on the system is mainly reflected by variables N2 affordable housing gap and N6 coverage rate.

Some scholars argue that as the annual *per capita* income of society rises year by year, more and more middle and low income people's income also rises, but the access conditions for purchasing affordable housing have not been updated, resulting in the number of people eligible to apply for affordable housing decreasing year by year, leading to a decrease in the coverage of affordable housing, thus the contradiction of high access conditions and a large shortage of affordable housing arises (Lu and Liu, 2013b). Therefore, there is a need to adjust the entry conditions for applying for affordable housing by adjusting the policy of affordable housing management, so as to ensure that the affordable housing application system can cover the middle and low income people to the maximum extent.

5.1 Simulation experiment of urban population and economic control policy

In terms of urban population and economic control policies. As of 2020, the urbanization rate of Zunyi City is 56.7%, which does not achieve the target of 60% urbanization rate of resident population in the National New Urbanization Plan (2014–2020) (Li, J. and Li, N. 2021; Wang et al., 2023), and approximately 220,000 people are not

yet to achieve urbanization development. In China's 2035 Medium and Long Range Development Plan, more population will enter the urban development. Therefore, the variable PLC1 urban population and economic control policy is used as a moderating factor in this paper. The initial value of variable PLC1 is 1, as a control group, and the changes of other variables in the system are observed by gradually increasing the value of variable PLC1. The results of the simulation experiment are shown in Figure 7.

The results illustrate that in the population and economic subsystem, as the urban population and economic control policy intensifies, the number of urban population and the number of jobs will increase directly, the number of low- and middle-income households will increase by 12%–25%, and their *per capita* disposable income will also increase by 1%–3%, indicating that the policy is conducive to promoting the cycle of supply and demand for affordable housing. In the whole protection system, with the increase of urban population and economic control policy, the shortage of affordable housing will increase, and the demand for upgrading the quality of affordable housing will become more and more obvious and urgent. Under this condition, the innovative idea of renewing the market stock into affordable housing will be driven and realized.

As shown in Table 2, the variable PLC1 urban population and economic control policy intensity from 1 to 1.50, the city's net population growth increased by 12%–25%, and the market stock housing conversion rate subsequently doubled the average annual growth rate, these policies have a significant contribution to promote the development of municipal de-stocking, that is, the stock renewal helps to solve the problem of large shortage of affordable housing.

Suggestions for these policies are as follows. Introduce policies to support the development of enterprises: change the traditional thinking of real estate development, attract enterprises to settle in the city through land finance, build a complete industrial chain, and create quality jobs to achieve the purpose of steadily expanding the number of urban population. Introduce policies to protect low- and middle-income families from settling in cities: Let more low- and middle-income people settle in cities by introducing and implementing policies to improve the living environment, increase the conversion rate of stock housing, and fill the gap of affordable housing.

5.2 Simulation experiment of affordable housing supply policy

In terms of the affordable housing supply policy. In this paper, the variable PLC2 affordable housing supply policy is used as a regulation factor. The initial value of variable PLC2 is 1 as the control group, and by gradually increasing the value of variable PLC2, it indicates the gradual reduction of the number of newly built affordable housing, while innovatively proposing the policy of converting the renewal of market stock into affordable housing and guiding social investment into the future cause of affordable housing development. The results of the simulation experiment are shown in Figure 8.

The results illustrate that with the increase in the intensity of the variable PLC2 affordable housing supply policy, in the affordable housing supply subsystem, social investment will be elevated by
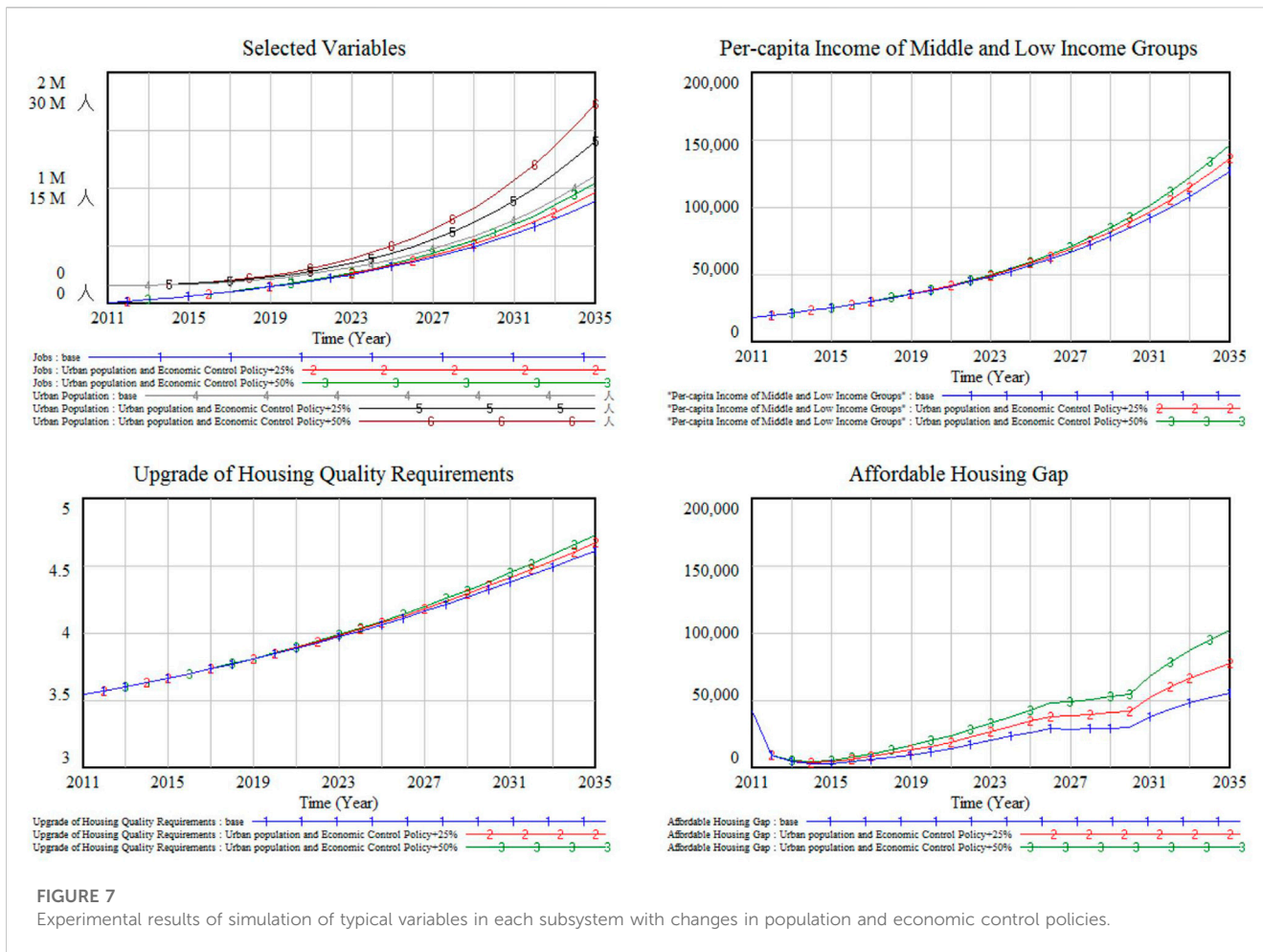
FIGURE 7
Experimental results of simulation of typical variables in each subsystem with changes in population and economic control policies.

TABLE 2 Comparison of data on the conversion rate of market stock housing in proportion to the intensity of urban population and economic control policies.

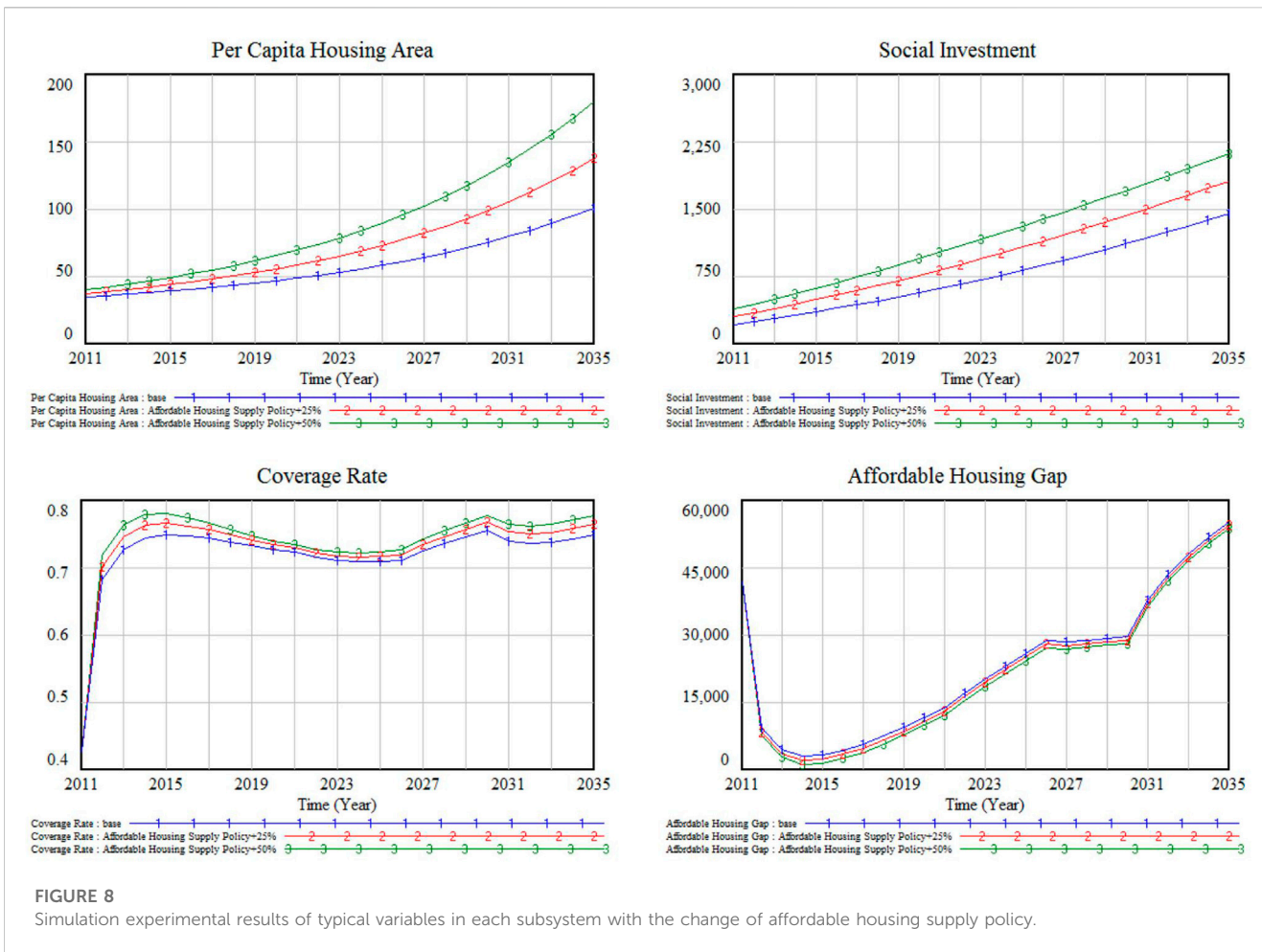| Name of policy change	Number of policy change	S9 Grouth rate (%)
base	1	0.44
Urban population and Economic Control Policy+25%	1.25	0.90
Urban population and Economic Control Policy+50%	1.50	1.84

33%–64%, the affordable housing gap will be decreased by 29%–58%, and the *per capita* housing floor area of low- and middle-income people will be increased by 23%–48%, with significant policy influence. However, the effect of the affordable housing supply policy on other variables in the overall affordable housing System is poor. Therefore, it indicates that changes in the affordable housing supply policy alone cannot solve the problems of large affordable housing gap and low affordable housing coverage, and need to be combined with other affordable housing-related policies to effectively solve the problems.

Suggestions for policies to enhance the supply of affordable housing are as follows. Introduce financial policies to support the transformation of stock housing and conversion into affordable housing: through graded tax and fee reductions, setting up special subsidy funds, and lowering the threshold for corporate investment

and financing, etc., to open up channels for attracting social investment into the housing guarantee business. Introduce policies for moderate value-added management of housing: through the construction of various public service facilities for housing, diversified property rights allocation and property services, improve the quality of housing and reasonably narrow the gap between housing areas and commercial housing areas.

5.3 Simulation experiment of affordable housing management policy

In terms of the safeguard housing management policy. In this paper, the variable PLC3 affordable housing management policy is used as a moderating factor. The initial value of variable PLC3 is 1 as a

FIGURE 8
Simulation experimental results of typical variables in each subsystem with the change of affordable housing supply policy.

control group, and by gradually increasing the value of variable PLC3, it indicates that the affordable housing management policies will be adjusted in a timely manner according to the market law, combined with the increase rate of the average annual disposable income of the middle and low income people, and they mainly include: the entry conditions of affordable housing application, waiting mode, withdrawal mechanism, market price, etc., and also will involve the cost of living expenses of the affordable housing communities, public facilities management, health management, parking space management, etc. The results of the simulation experiment are shown in Figure 9.

The results show that with the increase in the intensity of the reform of the safeguard housing management policy of variable PLC3, the safeguard housing gap will be reduced by 5%–9% in the safeguard housing demand subsystem, the coverage rate of the safeguard population will be increased by 3%–5%, the *per capita* housing floor area of low- and middle-income households will be increased by 9%–18% l, and the safeguard and fairness of the secondary social distribution can be better reflected. It can also positively influence other variables in the whole affordable housing System.

Suggestions for these policies are as follows. Introduce policies on access, waiting list, and launch supervision of affordable housing: change the previous mode of emphasizing construction and not management, and promote the flow of applications or purchases of affordable housing by combining intelligent system management,

manual emergency processing, and occasional random checks to verify the situation of those who apply for or purchase affordable housing and achieve dynamic balance. Introduce a policy to promote large mixed living and small clustering in urban living areas: Promote the integration of people of different income levels in urban living spaces through the conversion of stock commercial housing and the renovation of unused public housing in order to avoid social instability such as residential segregation, spatial alienation and class hierarchy.

As shown in Table 3, the intensity of variable PLC3 affordable housing management policy reform was increased from 1 to 1.50, and both variable S3 living environment and variable S6 community management level were improved. The data of the above two sets of variables were obtained by establishing an evaluation mechanism to research, collect, and analyze the scores of the residents in the affordable housing communities.

5.4 Policy combination simulation experiment

The above policies are combined together to conduct simulation experiments on the whole affordable housing System, and the simulation experiment results are shown in Figure 10. Under the combined policies, the urban population and social investment grow
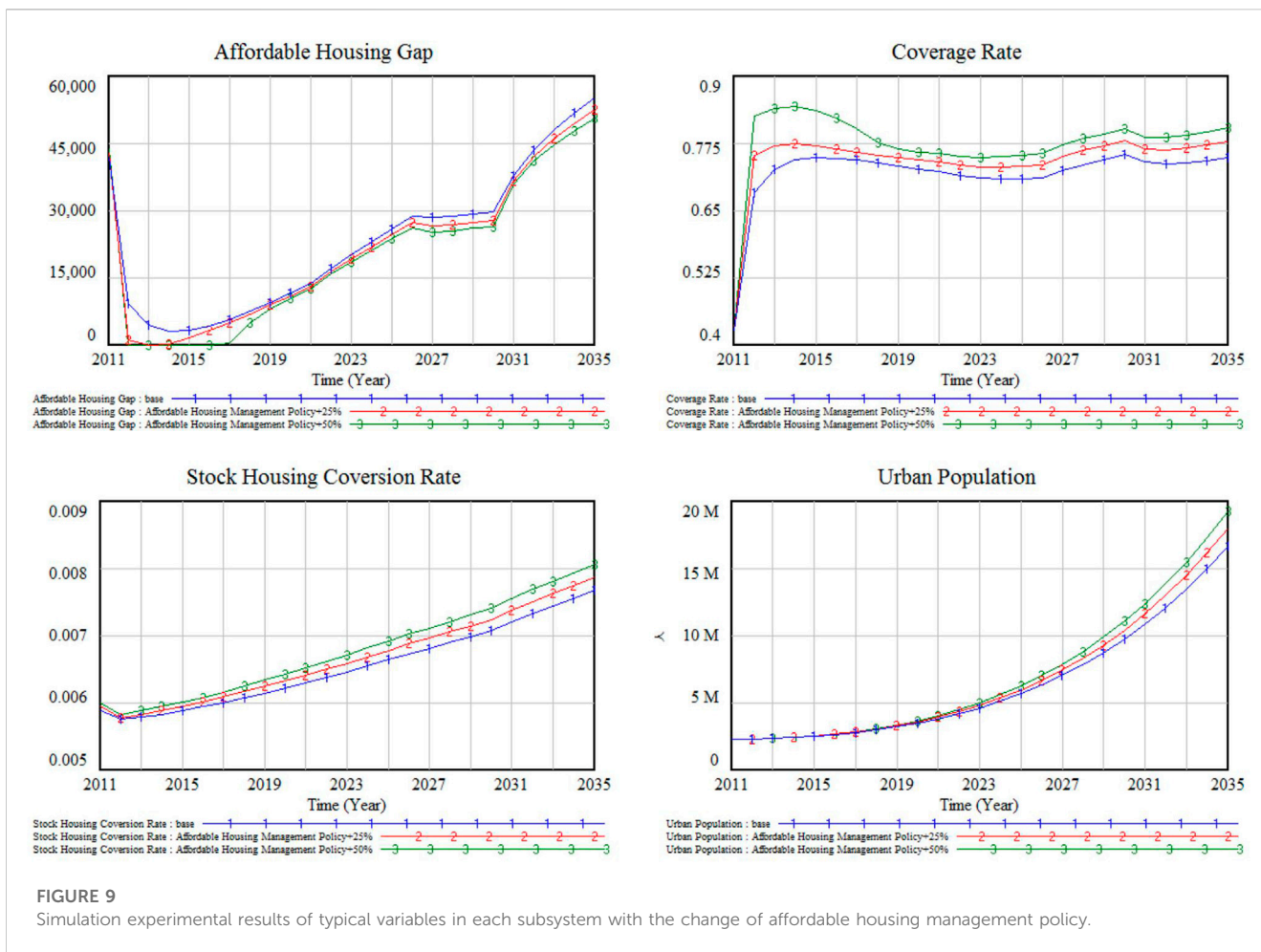
FIGURE 9
Simulation experimental results of typical variables in each subsystem with the change of affordable housing management policy.

TABLE 3 Comparison table of data on the level of living environment and community management proportional to the intensity of reform of housing management policies.

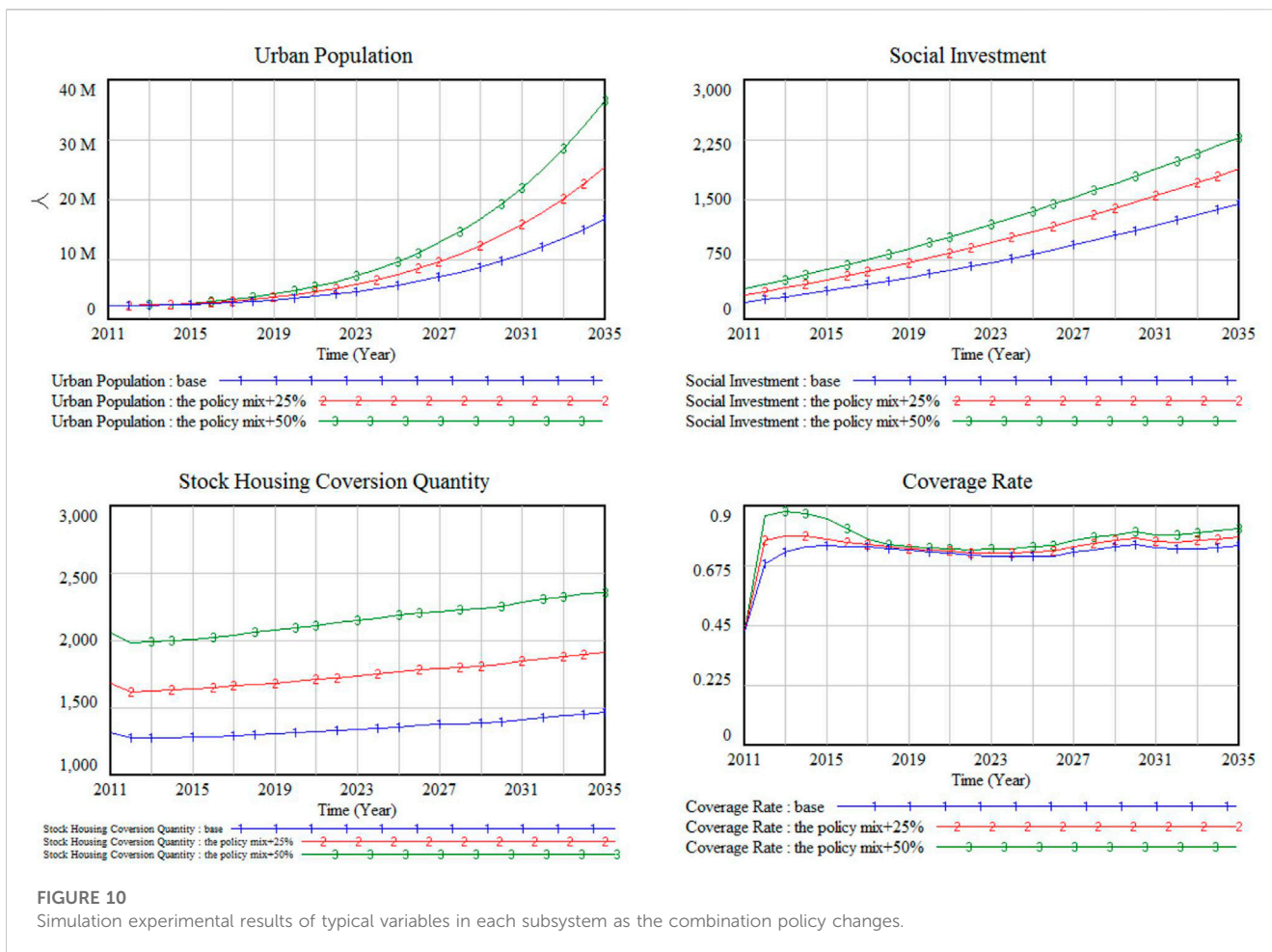| Name of policy change	Number of policy change	S3 Grouth rate (%)	S6 Grouth rate (%)
base	1	0.77	1.23
Affordable Housing Management Policy+25%	1.25	1.19	1.87
Affordable Housing Management Policy+50%	1.50	2.21	3.48

steadily, which improves the number of stock housing renewal into affordable housing, effectively protects people's housing rights and interests, and also effectively stimulates the market vitality of affordable housing. At the same time, it expands the coverage of people who apply for affordable housing, so that more people who meet the application requirements can settle in the city in time and improve the overall sense of happiness and belonging in the society.

6 Conclusion

In this paper, based on the theory of supply and demand relationship and the development plan of de-stocking, system dynamics is applied to establish the system model of Zunyi city's

affordable housing communities based on a combination of qualitative and quantitative analysis in the context of urban renewal. The variables of the subsystems of the affordable housing system are: The population and economic subsystem is characterized by the variable "Urban Population", The housing supply subsystem is characterized by the "Stock Housing Coversion Quantity", The housing demand subsystem is characterized by the "Affordable Housing Quantity". The following conclusions and recommendations are drawn by setting up different policy scenarios and observing the trends of each variable in the system through the control variables method.

1. In cities with insufficient urbanization, urban population and economic control policies need to be steadily strengthened in

FIGURE 10
Simulation experimental results of typical variables in each subsystem as the combination policy changes.

order to promote urban population increase. Urban population increase is the driving foundation for promoting economic development and reforming the cause of affordable housing development. The policy stimulus is to expand the demand for affordable housing, increase the conversion rate of market stock housing, and solve the problem of single mode of supply and shortage of supply of affordable housing.

2. According to the development idea of de-stocking housing, the innovative policy of supplying affordable housing can effectively stimulate market vitality and increase the supply of affordable housing. New housing construction will gradually decrease in the future, or even a precipitous decrease will occur. In terms of solving the problem of resolving people's livelihood, such a policy can meet the demand of low- and middle-income people for affordable housing and fill the gap of affordable housing. In terms of promoting urban development, the way local governments used to rely on land policies to increase revenue will change, and new urban GDP growth points will emerge. Converting the market stock of housing into affordable housing can solve the problem of excess stock of housing while also alleviating the pressure of financial expenditure on social security undertakings, guiding social investment forces into the cause of converting stock of housing into affordable housing, continuously stimulating the vitality of affordable housing communities, improving the construction of public facilities in affordable

housing communities, and enhancing the management level and housing quality of affordable housing communities.

3. Reforming the management policy of affordable housing is an important means to reflect housing security and social equity. The purpose of the reform is to expand the coverage of the affordable population and solve the housing needs of the middle and low income people who are outside the conditions of affordable housing application. The role of the reform is to assist in the effective implementation of the affordable housing supply policy, form a complete affordable housing supply chain, and make the whole affordable system and urban giant system sustainable.

This study uses Vensim PLE software to establish a system dynamics model of the microscopic mechanism of the affordable housing communities in Zunyi city. Based on the model simulation results, corresponding policy recommendations are proposed around the problem of how to convert the housing stock into affordable housing, which helps to solve the problem of unbalanced development of the local affordable housing supply and demand relationship. However, this study also has certain limitations, mainly in the following three aspects: the system model lacks more subdivided economic-related variables, and only selects the total financial and social investment at a more macro level, e.g., the price of different types of affordable housing, the loan situation, the difference in the price of commercial housing,

etc.; the system model does not include variables related to the differences in the location of affordable housing construction, e.g., central urban areas, suburban areas, This study also lacks the qualification and consideration of the time cycle changes of the policy, which will lead to the research findings presenting a temporary stability phenomenon and lacking dynamic and balanced development. The above deficiencies will be improved and refined in future studies.

Data availability statement

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

Author contributions

QH wrote the main manuscript text, and build model, test model, model simulation. LG directed and revised the manuscript and contributed to all aspects of this work, and conducted the experiment and analyzed the data, JY: test model, formula calibration, data sorting, manuscript revision. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

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Appendix 1

TABLE 1A Variables and equations of the system dynamics model for affordable housing communities.

Subsystem category	Code	Variable name	Equation
Population and Economic Subsystem	P1	Urban Population	P1 = INTEG (P2,P1o),Units: Person
	P2	Net Urban Population Growth	P2=((P3*S3)*PLC1*b1+N1*b2+P2o)
	P3	Jobs	P3 = r1 *P5-P3o
	P4	Employment Rate	P4 = -r2 *P1+b3
	P5	Enterprise Quantity	P5 = INTEG (P6,P5o),Units: Per
	P6	Increase Number of Enterprises	P6 = r3*P1+r4*S2+a1
	P7	Per-capita Income of Middle and Low Income Groups	P7 = -P4o *P4+b4 *P5+P7o
Affordable Housing Supply Subsystem	S1	Stock Housing Quantity in Market	S1 = INTEG (-S9,S1o)
	S2	Public Facilities Construction	S2 = r5 *S7+r6*S5+S2o
	S3	Improvement of Living Environment	S3 = S6+LN(S2)
	S4	Per Capita Housing Area	S4 = a2 *P7+S4o
	S5	Social Investment	S5 = S5o*S10-S7o
	S6	Community Management Level	S6 = LN(S5)
	S7	Fiscal Expenditure	S7=(S71 *S10-S72)
	S8	Stock Housing Coversion Rate	S8=(N2*b5+S10*r7)*PLC2
	S9	Stock Housing Coversion Quantity	S9 = S1*S8
	S10	Upgrade of Housing Quality Requirements	S10 = LN(S4)
Affordable Housing Demand Subsystem	N1	Affordable Housing Quantity	N1 = INTEG (N4-N3,N1o)
	N2	Affordable Housing Gap	N2 = IF THEN ELSE (N5≥ N1, N5-N1, 0)
	N3	Reduction in The Number of Affordable Housing	N3 = N1* a4
	N4	Increase in The Number of Affordable Housing	N4 = IF THEN ELSE (N2≤0, S9*PLC3, (N2*r8+S9)*PLC3)
	N5	Demand for Affordable Housing	N5 = N8*LN(P7)*b6
	N6	Coverage Rate	N6 = N1/N7
	N7	Target Number of Affordable Housing	N7 = N8/a3
	N8	Income of Middle and Low Income Households Quantity	N8 = N9(Time)*P1/a3
	N9	Income of Middle and Low Income Households Proportion	N9 ([(0,0)-(3000,10)], (2011,0.69) (2016,0.6), (2021,0.5), (2026,0.42) (2030,0.33), (2035,0.27))
Policy and Atrategic Variables	PLC1	Urban population and Economic Control Policy	1
	PLC2	Affordable Housing Supply Policy	1
	PLC3	Affordable Housing Management Policy	1/N6

Appendix 2

TABLE 2A Parameters setting of the system dynamics model for housing settlements.

Code	Name of parameters	Asignment	Unite	Data source
P1o	Number of urban population in Zunyi City in 2010	2.27E+06	PERSON	Zunyi City Statistical Yearbook
N1o	Number of affordabal housing in Zunyi City in 2010	55,680	PER	Urban Construction Statistical Yearbook
P2o	Net Urban Population growth in Zunyi City in 2010	12,321	PERSON	Zunyi City Statistical Yearbook
P3o	Number of jobs in Zunyi in 2010	37,034	PER	Zunyi City Statistical Yearbook
P4o	Consumption *per capita* in Zunyi in 2010	87,253.50	Yuan	Zunyi City Statistical Yearbook
P5o	Number of Enterprises in Zunyi City in 2010	16,450	PER	Zunyi City Statistical Yearbook
P7o	Average annual income of low and middle income families in 2010 in Zunyi	97,967	Yuan	Zunyi City Statistical Yearbook
S1o	Number of Market Stock Housing in Zunyi City in 2020	222,720	PER	Urban Construction Statistical Yearbook
S2o	Construction of Urban Public Facilities in Zunyi City in 2010	30,619.60	WanYuan	Urban Construction Statistical Yearbook
S4o	Per capita housing floor area of low- and middle-income people	23.60	㎡	Research Data
S5o	Renewal cost of stock housing	1,151.18	Yuan	Research Data
S71	Zunyi City 2010 Financial Allocation for Security	1.59E+07	Yuan	Zunyi City Statistical Yearbook
S72	Zunyi City 2010 Infrastructure Construction Allocation	5.33E+07	Yuan	Urban Construction Statistical Yearbook
S7o	Financial Urban Renewal Investment in 2010 in Zunyi City	3,862.47	Yuan	Urban Construction Statistical Yearbook
a1	Year-on-year increase in the number of enterprises in Zunyi City in 2010	329.30	PER	Logical Value
a2	Per capita housing purchase consumption index of low- and middle-income households	6.08E-04	%	Logical Value
a3	Proportion of low- and middle-income households with immediate housing needs	3.46	—	Logical Value
a4	The proportion of the decrease in the number of affordable housing in the total number of affordable housing	1.43E-02	—	Research Data
b1	Model index of urban population and economic control politics	9.81E-02	—	Logical Value
b2	Model index for converting the number of affordable housing units into net urban population growth	5.33E-05	—	Logical Value
b3	Stability index of employment rate	0.97	—	Logical Value
b4	Model index for converting the number of enterprises into income	0.29	—	Logical Value
b5	Model index of the conversion rate between affordable housing gap and market stock	5.28E-07	%	Logical Value
b6	Model index between the *per capita* income of low and medium households and the amount of affordable housing demand	0.02	—	Logical Value
r1	Average number of new jobs per enterprise per year	2.34	PER	Inference value
r2	Year-on-year employment growth rate	9.18E-10	%	Logical Value
r3	Amount of employment rate growth	0.13	%	Logical Value
r4	Year-on-year improvement rate of urban public facilities	1.39	%	Logical Value
r5	Year-on-year growth rate of urban public facilities improvement	1.81	%	Logical Value
r6	Growth rate of social urban renewal investment	501.70	%	Logical Value
r7	Growth rate of housing quality upgrade demand	0.16	%	Logical Value
r8	Growth rate of affordabal housing gap	0.30	—	Logical Value