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Integrating Energy Systems Language and Emergy Approach to Simulate and Analyze the Energy Flow Process of Land Transfer

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Abstract: As an effective policy to revitalize rural land assets, land transfer is important to promote reforming rural land systems in poor areas. In this study, we integrated the energy systems language and emergy approach, quantified the energy flow process under the land transfer model, simulated the resource storage and energy flow state in the land transfer process, and finally compared and discussed the economic and ecological benefits of land transfer under different scenarios. The results show the following: (1) Economic benefits were significantly improved after the land transfer, and labor storage and infrastructure value were reduced. (2) Government investment enhanced the infrastructure value, and private investment led to a rapid reduction in labor storage. (3) Expanding apple orchards positively affected labor storage and infrastructure value and negatively influenced soil organic carbon storage and rural asset storage. (4) Land transfer behavior reduced the proportion of provisioning and supporting services and increased the proportion of regulating and cultural services. Overall, the research results are helpful for clarifying the complex mechanisms of the various components in the land transfer system and provide a scientific basis for the prediction and evaluation of land transfer in similar areas.

Keywords: land transfer; energy flow; simulation; energy systems language; emergy approach

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1. Introduction

As an important natural resource, land contains both natural and human elements and is at the center of human production, life, and ecological activities [1]. Improving the utilization efficiency of land resources and implementing cultivated land protection policies are of great significance in order to highlight the importance of land resources in ensuring food security and social stability and achieving high-quality development [2,3]. "Opinions of the Central Committee of the Communist Party of China and the State Council on Doing a Good Job in Comprehensively Promoting the Key Work of Rural Revitalization in 2022", released on 4 January 2022, emphasized the implementation of hard measures for cultivated land protection, the responsibility of the Party and the government to preserve cultivated land, and the need to strictly observe the 1.8 billion mu red line of cultivated land, so that national food security and social stability can be ensured [4]. To guarantee food security, efforts must be made to improve the technical content and unit yield of grain production, encourage large-scale operations, and improve the level of agricultural modernization. Land transfer can solve the problem of land fragmentation, make effective use of rural land resources, improve agricultural production efficiency, and realize agricultural scale and mechanization [5,6].

Rural land transfer refers to the transfer of the right to operate the land by farmers with the contractual right to operate the land by keeping their contractual rights intact [6]. In 2014, the Central Government and the General Office of the State Council issued "Opinions on Guiding the Orderly Transfer of Rural Land Management Rights to Develop Moderate Scale Operations in Agriculture", which required vigorous development of land transfer and moderate scale operations [7,8]. In recent years, with the adjustment of the rural industrial structure and the promotion of agricultural technology in China, the speed of farmland transfer in various regions of the country has been accelerating, and the quantity of farmland transfer has been expanding year after year [9,10]. Data from the 2019 Statistical Annual Report on China's Rural Policy and Reform show that by the end of 2019, the household contracted farmland transfer area was 36.9987 million ha, an increase of 2.96% over 2018, accounting for 35.9% of the total. In total, 56.18, 22.69, and 10.38% of the farmland contracted by households were transferred to farmers, professional cooperatives, and enterprises, respectively.

Land transfer is the only option to develop modern agriculture in a way that can contribute to optimizing the allocation of land resources and accelerating the process of scaling up and intensifying rural land management. It can potentially assure food security and the supply of key agricultural products, which can achieve stable production and increased agriculture, and steadily increase farmers' income and rural stability [11,12]. The current research shows that the benefits of land transfer are significant. Through land transfer, farmers are freed from the shackles of land. It also enables large farming households and rural collectives under certain economic conditions to centrally manage idle and abandoned land, realizing the scale effect of land management. The vast majority of studies have confirmed that land transfer has a positive effect on improving farmers' income [13]. At the same time, studies have also shown that increasing the intensity of land transfer can reduce multidimensional poverty. Through land transfer, the rural population in poverty dropped from 770 million in 1978 to 5.51 million by the end of 2019, and the incidence of rural poverty dropped from 97.5% in 1978 to 0.6% at the end of 2019 [14]. The income level of land transfer households was 12.07% higher, and the poverty vulnerability was 5.13% lower than non-transfer households [15]. By realizing the scale economy, the agricultural income of lessee households exceeded rent expenditure, and the total income increased positively, with the lowest-income groups growing most significantly [16]. Studies have also shown that the income promotion effect of land transfer for high-income farmers was greater than that for low-income farmers, who faced a higher entry barrier to participation in land transfer [17]. Actively carrying out the transfer of land contract management rights is of great significance in promoting the positive role of land resources in food security, ecological protection, and social stability, driving balanced regional urban and rural development, benefiting most people's well-being, and achieving high-quality development of land resources [18–21].

The Tai-hang Mountains in Hebei Province, located between 38–40° N and 112–116° E, play a key role in Beijing and Tianjin's production and ecological functions. In 2015, the Hebei provincial government formulated the "Implementation Opinions on Guiding the Orderly Transfer of Rural Land Management Rights to Develop Agricultural Moderate Scale Management", which outlined a policy for land transfer in the Tai-hang Mountains. On the whole, at present, land transfer in this mountain region is conducive to maximizing the actual benefits of the land. However, as one of the main areas of concern for poverty alleviation, the Tai-hang Mountains have relatively poor conditions, and the overall agricultural development is slow. With the intensification of urbanization, more rural residents are gradually going to cities to work, resulting in serious land abandonment, which is not compatible with the long-term utilization of land. Land transfer research in this region will provide important case studies for reforming the rural land system in impoverished areas.

2. Literature Review

With the increasing attention being paid to land transfer, rural land transfer has become a subject of substantial research. The main research is focused on land transfer factors, land transfer effect, land transfer behavior, and so on. Regarding the elements that influence land transfer, scholars have found that the economic development level, rural surplus labor transfer, rural household economic status, non-agricultural employment stability, family livelihood capital, rural financial market, government assistance, rural debt, and individual livelihood capital have varying amounts of influence on land transfer [22–27].

Based on the threshold model and CHARLS 2015 data, Gao et al. found that the scale of labor migration had a periodic impact on rural land transfer [28]. Wang et al. used structural equation modeling to find that household livelihood capital substantially impacted agricultural land transfer [29]. Regarding the effect of land transfer, scholars have researched the effect of land transfer on land use efficiency, technological efficiency, total factor productivity, urban development, farmers' income, non-agricultural employment, agricultural pollution, and grain planting structure [21,30–34]. Liu et al. used the two-part control function method and found that for households with more agricultural labor, the impact of the land transfer on non-agricultural employment was positive and strong [11]. Based on the PSM method, Fei et al. analyzed the impact of land transfer on agricultural land use efficiency and found that the land use efficiency of transferred-in provinces was higher than that of transferred-out provinces, and land outflow could reduce the income of agricultural workers [9].

In recent years, research on rural land transfer behavior has tended to be diversified. Studies have used logistic regression models [35], probit and tobit regression test models [36], multi-group structural equation model, spatial econometric model [37,38], multiple difference method, propensity score matching (PSM) model [31], generalized propensity score matching (GPSM) model, DEA model [30], and quantile regression method, among others. Yang and Liu investigated the spatiotemporal changes and regional disparities in carbon conduction effects caused by land use change using a carbon conduction model of land transfer [39]. Li and Sun used a coupling coordination model to investigate the relationship between land transfer and urban social and economic benefits. The findings revealed that both government-led and market-led land transfers can enhance urban development, with the latter being more sustainable [33]. Fan et al. studied land transfer data in China based on a spatial lag model and found that land financial dependence promoted land marketization [40].

Lu et al. applied emergy theory to evaluate the social, economic, and ecological benefits before and after land transfer and carried out emergy performance and sustainability evaluations [41]. Yin et al. evaluated the intensity of cultivated land use in Shandong Province and the Dongting Lake area using emergy analysis [42]. Edrisi et al. used emergy analysis to quantify the ecological impact, bioenergy potential, socioeconomic efficiency, and sustainability of bioenergy production systems [43]. Hu et al. used emergy analysis to estimate agricultural sustainability in China [44]. Tilley and Brown used energy systems language to conduct a dynamic assessment of wetland stormwater management systems [45]. Rivera et al. described the Broa Reservoir as a dynamic system using energy systems language and evaluated its eutrophication [46]. Li et al. simulated the biomass and soil organic matter of three typical subtropical plantations in southern China based on the energy systems language model [47]. Xu et al. used the energy systems language model to quantitatively analyze the differences in functional orientation among components of the circular agricultural system [48].

In the current research on land transfer, most scholars use quantitative analysis and empirical research methods to investigate the elements that influence land transfer and its performance. There is a lack of research simulating the process of land transfer. When analyzing the elements that influence land transfer, a simple regression model cannot assess the internal logical relationship among factors. Spatial econometric models and threshold regression have estimation errors when quantifying land transfer performance and may have endogeneity problems. The multiple difference methods can solve the endogeneity problem but are unsuitable for estimating continuous explanatory variables. The propensity score matching method is mainly based on observable variables and does not control the influence of unobservable factors. When farmers' land transfer choices are affected by both observable and unobservable factors, the results obtained by propensity score matching will be biased. However, using energy systems language to construct a model can effectively simplify the complex land transfer system and can efficiently depict the energy flow between system components and interactions among subsystems. While it reflects the ecological process in the land transfer process, it can also quantify the energy flow and economic changes in the system and can simulate the ecological and economic benefits of the land transfer system continuously on a long-term scale.

Therefore, in this study, we used Odum's energy systems language to construct an energy flow model of land transfer based on the land transfer process to simulate the energy change trend of each component in the system and the trends of economic and ecological benefits under scenarios of investment behavior and land use change. This study aims to quantify the economic and ecological benefits of Lvzenong Planting Company before and after land transfer and reveal the flow pattern of material and energy in the land transfer process, demonstrate the future development direction of land transfer in multiple scenarios, and put forward new ideas of future development of agricultural land circulation in Tai-hang Mountains of Hebei and provide scientific guidance and decision basis for land resources assessment and management in related regions.

3. Materials and Methods

3.1. Research Area

The research area of this study is the Lvzenong Planting Company, located in the transitional slope from the Tai-hang Mountains to the North China Plain, in Lianggezhuang Town, Yi County, Baoding City, Hebei Province (Figure 1). The planned construction area of the project is 1000 ha, including 467 ha of high-quality apples, 467 ha of thin-skinned walnuts, and 67 ha of high-quality cherries. Lvzenong Planting Company is a key agricultural project and a demonstration area for poverty alleviation in Yi County. The project involves the five poor villages of Xiahuanghao, Zhonghuanghao, Shimendian, Beishimen, and Tawa, with a total population of 4986. The climate is temperate monsoon, the annual average rainfall is 572.4 mm, and the annual average temperature is 12 °C [41]. Before 2012, the crops in the project area were mainly food crops (corn, sweet potatoes). In 2015, the project transferred 840 ha of mountain and hilly land with an investment of RMB 80 million. After 3 years of land consolidation and transfer, the economic crops in the project area are mainly apples, with a total of 533 ha of fruit trees, including 400 ha of high-quality apples.

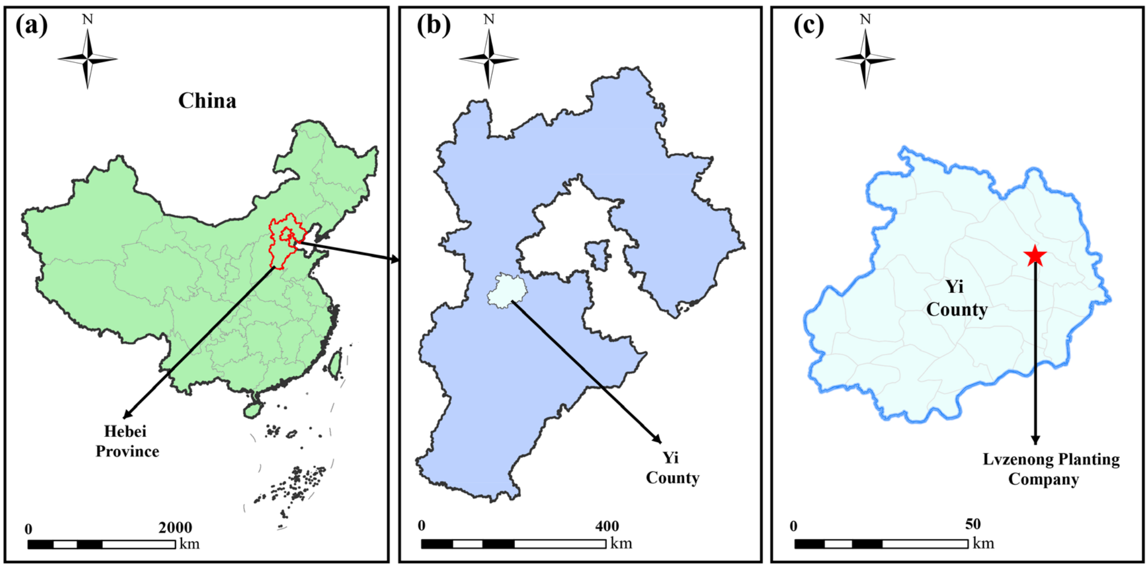

Figure 1. Map of the study region.

After 3 years of development and construction, Lvzenong Planting Company formed five functional areas: the high-quality fruit planting area, the fruit storage area, the agricultural science and technology research area, the fruit processing area, and the tourism and sightseeing area. After completion, the project will produce 17,000 tons of apples and 10,000 tons of other fruits annually, with an annual output value of nearly RMB 500 million. A total of 1300 jobs can be arranged, and nearly 5000 poor people can be lifted out of poverty. Through the influence of the demonstration area, 6667 ha of forest and fruit plantations in the western mountainous area has been utilized to form an industrial chain to drive regional economic development.

3.2. Research Methods

3.2.1. Energy Flow Model of Land Transfer System

To explore the land transfer system in the Tai-hang Mountains, we established the Lvzenong land transfer system by using energy systems language. Energy systems language is a method based on flow, stock, and their interaction. It converts a static network diagram representing the flow and stock interaction process into a dynamic model through scientific model construction. Emergy analysis uses emergy to measure the noncomparable energy in natural resources and the socioeconomic system so that the real value of natural resources, commodities, and labor services can be measured comparably. Integrating energy systems language and the emergy approach can reveal the energy flow pattern of components in the land transfer system from the perspective of the energy flow process. Combined with the equivalent value factor per unit area, continuous long-term simulation and prediction of ecosystem service value can be carried out. The model is suitable for revealing and simulating the land transfer process.

In order to clearly demonstrate the energy flow between the internal and external environment of the Lvzenong land transfer system, we used Odum's energy systems language to construct an energy flow model at the micro level [49,50], revealing the internal material energy flow pattern of each component in the system. Meanwhile, typical indicators were selected to reflect the resource storage of each component and the energy flow state between components before and after land transfer. Equilibrium equations were constructed to quantify the energy flow process under land transfer mode.

3.2.2. Model Construction and Main Steps

In this study, the primary energy flows, energy exchanges between storages, and external driving forces of the entire system are represented by energy flow diagrams. The energy stored in each part of the system moves in the form of energy flow. The meaning of each symbol in the energy flow diagram is given in Table 1, and the meaning of each parameter is presented in Table 2 (K_0–K_{13} before land transfer, K_0–K_{26} after land transfer). The process of drawing the energy flow diagram is shown in Figure 2. The relationships among components are mainly divided into three categories: (1) Energy input: Plant photosynthesis provides natural energy to producers within the system, resulting in the production of organic matter. The artificial energy input process is more complicated. Fertilizers and pesticides directly promote crop growth, and diesel, electric, and mechanical energy drive the system and indirectly promote crop growth. (2) Energy flows within the system: Crops (sweet potato, apple) and woodland absorb and utilize soil nutrients, and litter degradation returns them to the soil. Local labor and infrastructure serve as input to grow the crops. The output of agricultural products is exchanged in the market to convert funds into rural assets. (3) System energy outflows: Soil erosion results in energy loss from the system, and human activities have a considerable impact on energy flow within it. The constructed model is shown in Figure 3.

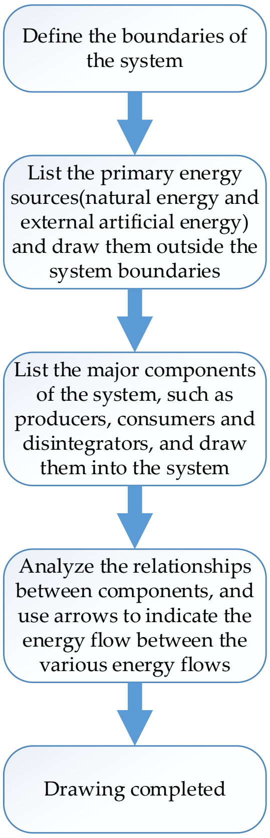

Figure 2. Steps in drawing energy flow diagram.

Table 1. Meanings of symbols in the energy flow diagram.

Symbol	Meaning	Symbol	Meaning	Symbol	Meaning	Symbol	Meaning
S	Solar energy	F	Fertilizer	M	Machinery	A	Rural assets
R	Rainwater chemical potential energy	P	Pesticide	L	Labor storage	I	Infrastructure value
W	Wind energy	D	Diesel fuel	SE	Service	GT	Government
G	Geothermal energy	E	Electricity	MT	Market	NL	Foreign labor
SP	Sweet potato planting system	O	Soil organic carbon storage	AE	Apple planting system	FT	Woodland vegetation biomass

Table 2. Parameter meanings in energy flow diagram.

Before land transfer					
K_0	Solar energy absorbed by sweet potato	K_7	Sweet potato supplied to market	K_{14}	Labor input for sweet potato planting
K_1	Fertilizer supplied for sweet potato growth	K_8	Sweet potato litter degradation process	K_{15}	Machinery supplied for sweet potato growth
K_2	Pesticide supplied for sweet potato growth	K_9	Changes in sweet potato planting area caused by human activities	K_{16}	Taxes
K_3	Diesel fuel supplied for sweet potato growth	K_{10}	Geothermal energy absorbed by soil	K_{17}	New infrastructure construction
K_4	Electricity supplied for sweet potato growth	K_{11}	Soil nutrients absorbed by sweet potato	K_{18}	Infrastructure input for sweet potato planting
K_5	Sweet potato biomass formation process	K_{12}	Soil erosion	K_{19}	Rural purchasing services
K_6	Sweet potatoes supplied to local labor	K_{13}	Labor utilizing sweet potato		

Table 2. *Cont.*

After land transfer					
K_0	Solar energy absorbed by apple	K_9	Apples supplied to market	K_{18}	Soil nutrients absorbed by woodland
K_1	Solar energy absorbed by woodland	K_{10}	Degradation of apple litter	K_{19}	Soil erosion
K_2	Fertilizer supplied for apple growth	K_{11}	Changes in apple planting area caused by human activities	K_{20}	Labor utilizing apple
K_3	Pesticide supplied for apple growth	K_{12}	Woodland biomass formation	K_{21}	Labor input for apple planting
K_4	Diesel fuel supplied for apple growth	K_{13}	Woodland output	K_{22}	Machinery supplied for apple growth
K_5	Electricity supplied for apple growth	K_{14}	Degradation of woodland litter	K_{23}	Government investment in infrastructure
K_6	Apple biomass formation process	K_{15}	Changes in woodland area caused by human activities	K_{24}	New infrastructure construction
K_7	Apples supplied to local labor	K_{16}	Geothermal energy absorbed by soil	K_{25}	Infrastructure input for apple planting
K_8	Apples supplied to tourists	K_{17}	Soil nutrients absorbed by apples	K_{26}	Rural purchasing services

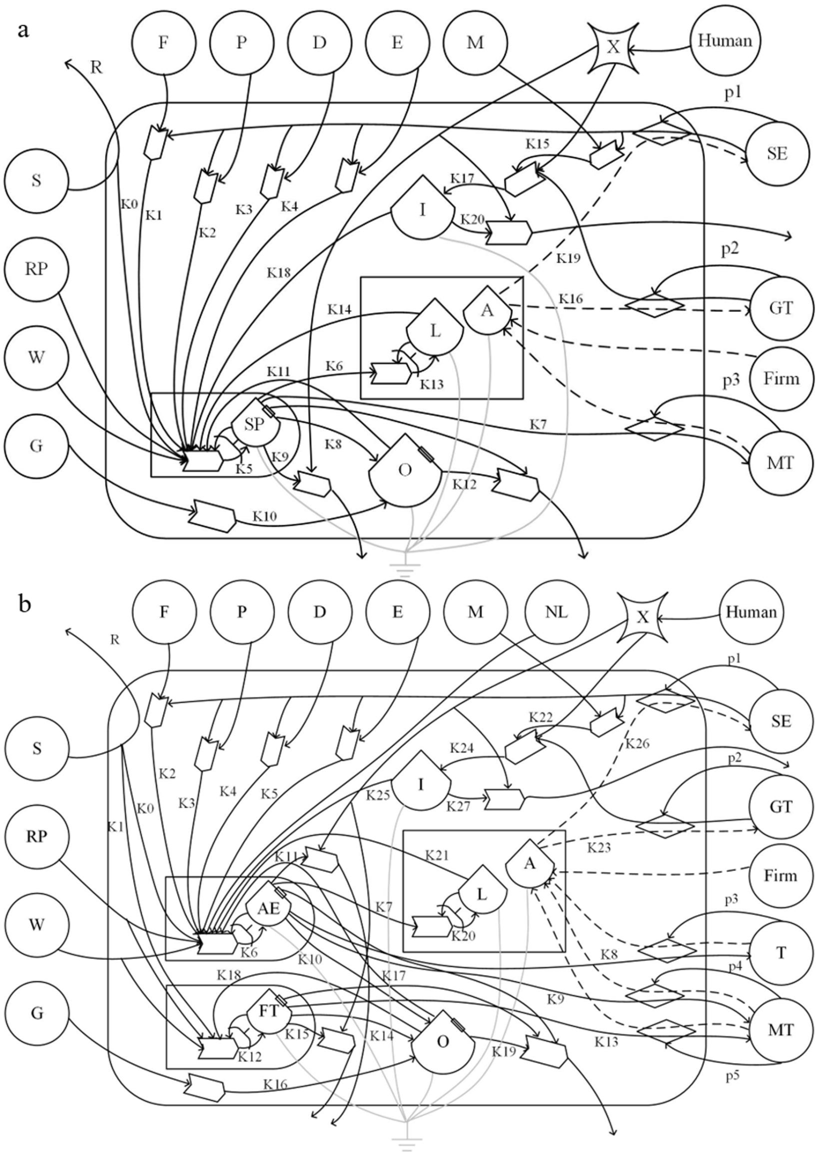

Figure 3. Energy flow model (**a**) before and (**b**) after land transfer.

3.3. Data Sources and Scenario Setting

3.3.1. Data Sources

The data used in this study were obtained from research in Lianggezhuang Town, Yi County, Baoding City, Hebei Province in August 2017, mainly through farmer surveys, expert consultations, and by querying the 2012–2016 Hebei Province Statistical Yearbook, 2016–2021 Baoding City Statistical Yearbook, statistical information of Lvzenong Planting Company and literature analysis [41,51]. In the investigation process, we first presented the list of data acquisition and confirmed the relevant data in further communication with the technical personnel of the enterprise and the local farmers. On this basis, by referring to the historical data of Lvzenong Planting Company, the Hebei Province Statistical Yearbook and the Baoding City Statistical Yearbook and calibrated with existing literatures, the research data were further supplemented and improved. The model parameters, components, functional equations, and coefficients before and after land transfer in the energy flow model are shown in Tables 3 and 4.

Table 3. Components in energy flow model before land transfer.

Parameter	Component	Functional Equation	Emergy	Unit	Coefficient	Parameter	Component	Function	Emergy	Unit	Coefficient
External	Energy input										
S	Solar energy		4.25×10^{15}	Sej/y		J_6	Sweet potatoes supplied to local labor	$K_6 \times SP \times L$	1.30×10^{13}	Sej/y	1.25×10^{-3}
RP	Rainwater chemical potential energy		2.94×10^{14}	Sej/y		J_7	Sweet potatoes supplied to the market	$K_7 \times SP$	8.64×10^{12}	Sej/y	6.00×10^{-2}
W	Wind energy		2.21×10^{14}	Sej/y		J_8	Degradation of sweet potato litter	$K_8 \times SP$	4.32×10^{12}	Sej/y	3.00×10^{-2}
G	Geothermal energy		9.31×10^{12}	Sej/y		**O**	**Soil organic carbon storage**		2.73×10^{15}	Sej/y	
F	Fertilizer		3.28×10^{15}	Sej/y		J_{10}	Geothermal energy absorbed by soil	$K_{10} \times G$	6.52×10^{12}	Sej/y	7.00×10^{-1}
P	Pesticide		1.56×10^{14}	Sej/y		J_{11}	Soil nutrients absorbed by sweet potato	$K_{11} \times RP \times W \times R \times (K_1 \times F \times SE) \times (K_2 \times P \times SE) \times (K_3 \times D \times SE) \times (K_4 \times E \times SE) \times I \times L \times O \times SP$	1.37×10^{14}	Sej/y	4.60×10^{-8}
D	Diesel fuel		3.45×10^{14}	Sej/y		J_{12}	Soil erosion	$K_{12} \times O \times SP$	2.91×10^{14}	Sej/y	7.40×10^{-2}
E	Electricity		6.77×10^{14}	Sej/y		**L**	**Labor storage**		7.20×10^{15}	Sej/y	
M	Machinery		3.09×10^{15}	Sej/y		J_{13}	Labor utilized for sweet potato	$K_{13} \times L \times SP$	3.60×10^{13}	Sej/y	3.47×10^{-3}
J_0	Energy utilized by sweet potato		2.55×10^{13}	Sej/y	8.59×10^{-9}	J_{14}	Labor input for sweet potato planting	$K_{14} \times RP \times W \times R \times (K_1 \times F \times SE) \times (K_2 \times P \times SE) \times (K_3 \times D \times SE) \times (K_4 \times E \times SE) \times I \times L \times O \times SP$	2.88×10^{13}	Sej/y	9.69×10^{-9}
R	Unused energy	S-J_0	4.22×10^{15}	Sej/y		J_{15}	Machinery supplied for sweet potato growth	$K_{15} \times M \times SE$	1.55×10^{12}	Sej/y	2.38×10^{-3}
SP	**Sweet potato biomass**		1.44×10^{14}	Sej/y		**I**	**Infrastructure value**		9.59×10^{15}	Sej/y	

Table 3. *Cont.*

Parameter	Component	Functional Equation	Emergy	Unit	Coefficient	Parameter	Component	Function	Emergy	Unit	Coefficient
J_1	Fertilizer supplied for sweet potato growth	$K_1 \times F \times SE$	4.37×10^{14}	Sej/y	6.35×10^{-1}	J_{16}	Taxes	$K_{16} \times A/p2$	7.00×10^{11}	Sej/y	1.19×10^{-3}
J_2	Pesticide supplied for sweet potato growth	$K_2 \times P \times SE$	2.15×10^{13}	Sej/y	6.57×10^{-1}	J_{17}	New infrastructure construction	$K_{17} \times (K_{15} \times M \times SE) \times (K_{16} \times A/p2)$	7.40×10^{9}	Sej/y	6.84×10^{-1}
J_3	Diesel fuel supplied for sweet potato growth	$K_3 \times D \times SE$	4.60×10^{13}	Sej/y	6.35×10^{-1}	J_{18}	Infrastructure input for sweet potato planting	$K_{18} \times RP \times W \times R \times (K_1 \times F \times SE) \times (K_2 \times P \times SE) \times (K_3 \times D \times SE) \times (K_4 \times E \times SE) \times I \times L \times O \times SP$	5.50×10^{12}	Sej/y	1.85×10^{-9}
J_4	Electricity supplied for sweet potato growth	$K_4 \times E \times SE$	9.23×10^{13}	Sej/y	6.49×10^{-1}	**A**	**Rural assets**		7.06×10^{15}	Sej/y	
J_5	Sweet potato growth	$K_5 \times RP \times W \times R \times (K_1 \times F \times SE) \times (K_2 \times P \times SE) \times (K_3 \times D \times SE) \times (K_4 \times E \times SE) \times I \times L \times O \times SP$	2.88×10^{13}	Sej/y	9.70×10^{-9}	J_{19}	Rural purchasing services	$K_{19} \times A$	2.10×10^{12}	Sej/y	2.97×10^{-4}

Table 4. Components in energy flow model after land transfer.

Parameter	Component	Functional Equation	Emergy	Unit	Coefficient	Parameter	Component	Function	Emergy	Unit	Coefficient
External	Energy input										
S	Solar energy		4.25×10^{15}	Sej/y		J_9	Apples supplied to the market	$K_9 \times AE$	8.16×10^{12}	Sej/y	8.00×10^{-2}
RP	Rainwater chemical potential energy		2.94×10^{14}	Sej/y		J_{10}	Degradation of apple litter	$K_{10} \times AE$	5.00×10^{12}	Sej/y	4.90×10^{-2}

Table 4. *Cont.*

Parameter	Component	Functional Equation	Emergy	Unit	Coefficient	Parameter	Component	Function	Emergy	Unit	Coefficient
W	Wind energy		2.21×10^{14}	Sej/y		**FT**	**Woodland vegetation biomass**		3.40×10^{15}	Sej/y	
G	Geothermal energy		9.31×10^{12}	Sej/y		J_{12}	Growth of woodland	$K_{12} \times RP \times W \times R \times O \times FT$	1.90×10^{14}	Sej/y	7.81×10^{-6}
F	Fertilizer		2.53×10^{15}	Sej/y		J_{13}	Output of woodland	$K_{13} \times FT$	2.00×10^{14}	Sej/y	5.88×10^{-2}
P	Pesticide		6.87×10^{13}	Sej/y		J_{14}	Degradation of woodland litter	$K_{14} \times FT$	1.78×10^{14}	Sej/y	5.25×10^{-2}
D	Diesel fuel		6.17×10^{13}	Sej/y		**O**	**Soil organic carbon storage**		2.73×10^{15}	Sej/y	
E	Electricity		7.56×10^{14}	Sej/y		J_{16}	Geothermal energy absorbed by soil	$K_{16} \times G$	6.52×10^{12}	Sej/y	7.00×10^{-1}
M	Machinery		2.71×10^{15}	Sej/y		J_{17}	Soil nutrients absorbed by apple	$K_{17} \times RP \times W \times R \times (K_2 \times F \times SE) \times (K_3 \times P \times SE) \times (K_4 \times D \times SE) \times (K_5 \times E \times SE) \times NL \times I \times L \times O \times AE$	1.44×10^{14}	Sej/y	1.77×10^{-9}
NL	Foreign labor		6.72×10^{15}	Sej/y		J_{18}	Soil nutrients absorbed by woodland	$K_{18} \times RP \times W \times R \times O \times FT$	1.73×10^{14}	Sej/y	7.10×10^{-6}
J_0	Energy utilized by apples	$K_0 \times RP \times W \times R \times (K_2 \times F \times SE) \times (K_3 \times P \times SE) \times (K_4 \times D \times SE) \times (K_5 \times E \times SE) \times NL \times I \times L \times O \times AE$	1.06×10^{13}	Sej/y	1.31×10^{-10}	J_{19}	Soil erosion	$K_{19} \times O \times AE \times FT$	1.00×10^{14}	Sej/y	5.52×10^{-1}
J_1	Energy utilized by woodland	$K_1 \times RP \times W \times R \times O \times FT$	5.06×10^{14}	Sej/y	7.90×10^{-1}	**L**	**Labor storage**		1.39×10^{16}	Sej/y	
R	Unused energy	$S\text{-}J_0\text{-}J_1$	4.04×10^{15}	Sej/y		J_{20}	Labor utilizing apple	$K_{20} \times L \times AE$	4.00×10^{13}	Sej/y	2.82×10^{-3}

Table 4. *Cont.*

Parameter	Component	Functional Equation	Emergy	Unit	Coefficient	Parameter	Component	Function	Emergy	Unit	Coefficient
AE	**Apple biomass**		1.02×10^{14}	Sej/y		J_{21}	Labor input for apple planting	$K_{21} \times RP \times W \times R \times (K_2 \times F \times SE) \times (K_3 \times P \times SE) \times (K_4 \times D \times SE) \times (K_5 \times E \times SE) \times NL \times I \times L \times O \times AE$	1.21×10^{14}	Sej/y	1.49×10^{-9}
J_2	Fertilizer supplies for apple growth	$K_2 \times F \times SE$	5.06×10^{14}	Sej/y	7.90×10^{-1}	**I**	**Infrastructure value**		1.24×10^{16}	Sej/y	
J_3	Pesticide supplies for apple growth	$K_3 \times P \times SE$	1.26×10^{13}	Sej/y	7.26×10^{-1}	J_{22}	Machinery supplies for apple growth	$K_{22} \times M \times SE$	1.35×10^{12}	Sej/y	1.97×10^{-3}
J_4	Diesel fuel supplies for apple growth	$K_4 \times D \times SE$	1.10×10^{13}	Sej/y	7.02×10^{-1}	J_{23}	Government investment in infrastructure	$K_{23} \times A/p2$	7.52×10^{11}	Sej/y	6.29×10^{-4}
J_5	Electricity supplies for apple growth	$K_5 \times E \times SE$	1.37×10^{14}	Sej/y	7.18×10^{-1}	J_{24}	New infrastructure construction	$K_{24} \times (K_{22} \times M \times SE) \times (K_{23} \times A/p2)$	6.40×10^{9}	Sej/y	6.28×10^{-1}
J_6	Apple growth	$K_6 \times RP \times W \times R \times (K_2 \times F \times SE) \times (K_3 \times P \times SE) \times (K_4 \times D \times SE) \times (K_5 \times E \times SE) \times NL \times I \times L \times O \times AE$	2.15×10^{13}	Sej/y	2.65×10^{-10}	J_{25}	Infrastructure input for apple planting	$K_{25} \times RP \times W \times R \times (K_2 \times F \times SE) \times (K_3 \times P \times SE) \times (K_4 \times D \times SE) \times (K_5 \times E \times SE) \times NL \times I \times L \times O \times AE$	6.71×10^{12}	Sej/y	8.26×10^{-11}
J_7	Apples supplied to local labor	$K_7 \times AE \times L$	4.08×10^{12}	Sej/y	2.88×10^{-4}	**A**	**Rural assets**		1.43×10^{16}	Sej/y	
J_8	Apples supplied to tourists	$K_8 \times AE$	4.08×10^{12}	Sej/y	4.00×10^{-2}	J_{26}	Rural purchasing services	$K_{26} \times A$	2.54×10^{12}	Sej/y	1.77×10^{-4}

3.3.2. Scenario Setting

Scenario analysis refers to exploring and constructing possible future trends and conducting an in-depth analysis to judge their future development. Scenario simulation can reflect future prospects under different plans and provide a practical reference for decision-makers. In order to quantitatively evaluate the interactions among components in the land transfer system and reveal the changes of components in the Lvzenong Planting Company under different scenarios, according to the historical development background of the Tai-hang Mountains in Hebei Province, we set up scenarios from the perspective of investment behavior and land use change in which the scale of internal components of the system was changed, so as to explore comprehensive land management and sustainable development. First, in order to improve agricultural productivity, the government issued a number of policies to significantly stimulate the growth of agricultural mechanization. Through infrastructure investment, the specific role of agricultural mechanization in the land transfer system can be explored. From the standpoint of financial gain, the output value of the Lvzenong Planting Company after land transfer mainly depends on apple cultivation, which occupies an important position in the land transfer system. Consequently, we selected the infrastructure value system, apple planting system, and woodland system as the objects to set the scenarios. Based on the above premise, we set up five scenarios, as described in Table 5.

Table 5. Scenario setting.

Scenario	After Land Transfer
Investment behavior perspective	Government investment (increased by 10%, while private investment remained unchanged)
	Private investment (increased by 10%, while government investment remained unchanged)
	Mixed investment (both government and private investment increased by 5%)
Land use change perspective	Apple planting area and woodland area decreased by 5%
	Apple planting area and woodland area increased by 5%

4. Results

4.1. Simulation of Energy Flow before and after Land Transfer

In the simulation, Lvzenong Planting Company mainly planted sweet potatoes before land transfer. After three years of construction, the sweet potato planting areas are transferred to apple planting areas and woodland. Before and after land transfer, the biomass of the sweet potato, apple, and woodland systems all show a general downward trend. Before land transfer, the biomass of the sweet potato system increased slowly in the first two years, then gradually decreased. After 38 years, with an average annual decrease of 2.76%, the biomass decreases to the minimum value. After land transfer, the biomass of the apple system does not fluctuate considerably during the first 10 years, remaining at 1×10^{14} sej, and then demonstrates a decreasing trend. After 44 years, the biomass reaches the minimum value, with an average annual decline of 2.91% (Figure 4a). The biomass of the woodland system shows a constant downward trend, with a gradually slowing rate of decline. After 58 years, with an average annual decrease of 1.72%, the biomass decreases to the minimum value (Figure 4b). Soil organic carbon storage declines sharply in the 22 years before land transfer, with an average annual decrease of 3.67%, and then recovers slowly. After land transfer, soil organic carbon storage decreases rapidly in the first 20 years, at an average annual rate of 4.06%, followed by a steady decline, reaching a steady state after about 70 years (Figure 4c).

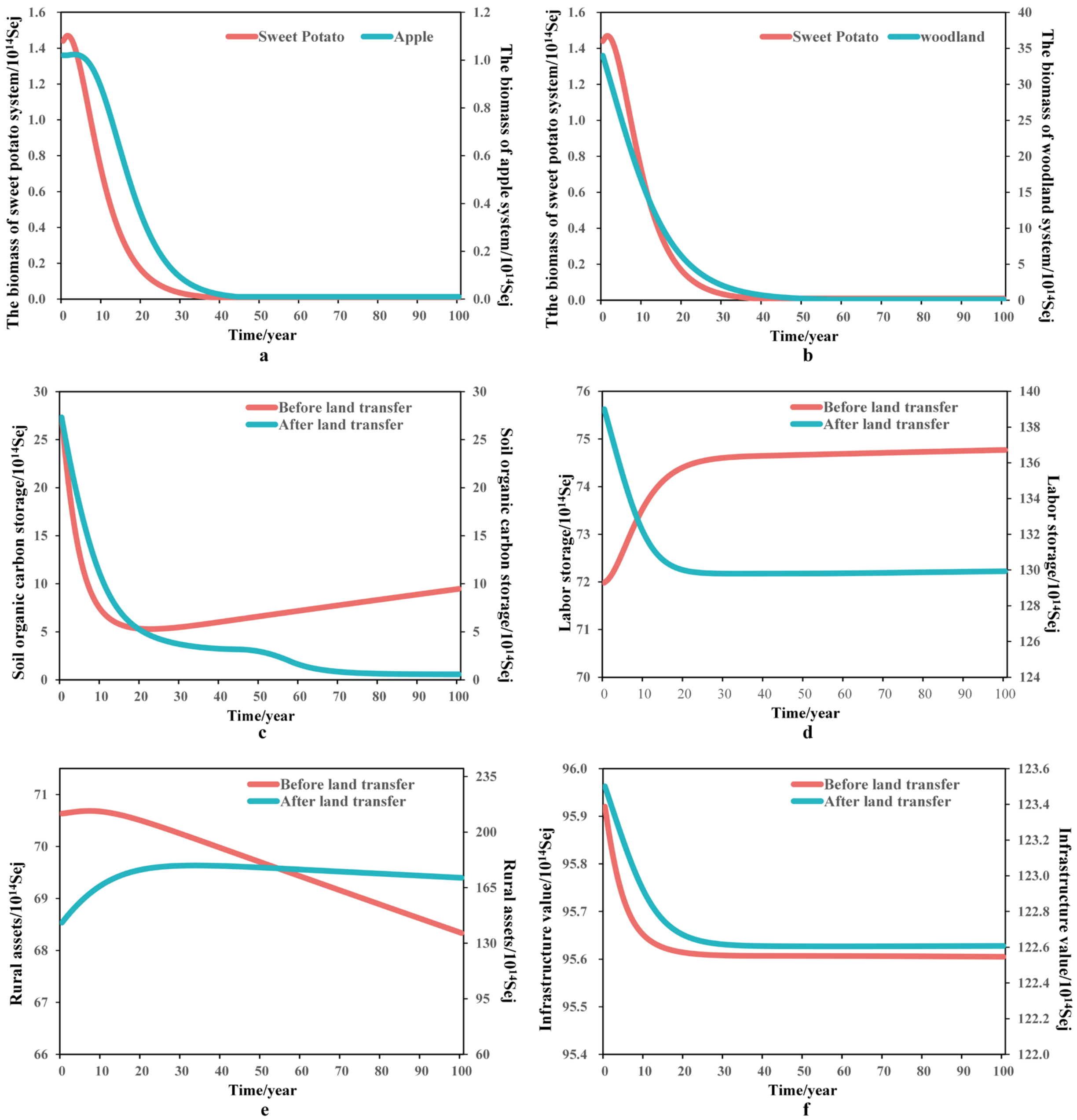

Figure 4. Energy changes of system components before and after land transfer. (**a**) the biomass of sweet potato system and apple system, (**b**) the biomass of sweet potato system and woodland system, (**c**) soil organic carbon storage, (**d**) labor storage, (**e**) rural assets, (**f**) infrastructure value.

Before land transfer, labor storage gradually increased, reaching a steady state of 74.61×10^{14} sej after about 30 years, with an average annual increase of 0.12%. After land transfer, a large amount of foreign labor is attracted to the area to obtain employment. The initial value of labor storage is much higher than that of the original labor storage before land transfer. Labor storage shows a gradual downward trend, reaching a steady state of 129.98×10^{14} sej after about 20 years, with an average annual decrease of 0.32% (Figure 4d). Before land transfer, rural assets do not fluctuate considerably during the first 10 years, remaining at 70.6×10^{14} sej, and then slowly declining, with an average annual decrease of 0.04%. Rural assets are much higher after land transfer than before. Rural assets show a steady upward trend, reaching a stable state of 170×10^{14} sej after about 30 years (Figure 4e). Before and after land transfer, infrastructure value decreases steadily to a stable state, but infrastructure value is much higher after land transfer than before. The decline rate is higher before than after land transfer. Infrastructure value reaches a stable state of 95.6×10^{14} sej in the 25th year before land transfer and 122.6×10^{14} sej in the 30th year after land transfer (Figure 4f).

Before land transfer, farmers' income decreased gradually, and many farmers went to work in cities, leaving sweet potato planting areas abandoned. Due to the gradual abandonment of the planting areas, the biomass of the sweet potato system shows a continuous downward trend. A large part of the nutrients required for sweet potato growth come from the soil. At the initial stage, the rate of soil organic carbon obtaining energy from litter degradation is lower than the rate required for sweet potato growth, which leads to the continuous reduction of soil organic carbon storage. With the further abandonment of sweet potato planting areas, the ecological environment is restored, soil organic matter increases slowly, and soil organic carbon storage increases. Due to the desertion of these areas, there is a surplus supply of labor, and the input rate is much greater than the consumption rate, resulting in an increase in labor storage. Due to the decreased crop income, rural collective assets continue to decrease. Although the consumption of infrastructure slows down due to the reduction of sweet potato system energy, the supply of infrastructure also decreases due to the reduced rural collective assets. The supply reduction rate is higher than the consumption reduction rate, which leads to decreased infrastructure value.

After land transfer, farmers' income increases significantly, attracting a large amount of labor for employment and significantly increasing rural collective assets. Due to the continuous construction of apple planting areas, the amount of apple planting continues to increase. However, the land productivity is limited, and the system has difficulty continuously providing sufficient growth conditions, thus apple system energy shows a downward trend after the 10th year. The continuous increase in apple planting damages the ecological environment deteriorates soil erosion, and reduces nutrients obtained by woodland growth, leading to a continuous decline in woodland system energy. Since a large part of the nutrients required for apple growth come from the soil, soil organic carbon storage decreases rapidly at the initial stage. With decreased apple system biomass, the decline of soil organic carbon storage gradually slows down. As apple planting areas are under construction, labor and infrastructure construction demand increase. The input rate is less than the consumption rate, resulting in reduced labor storage and infrastructure value.

Overall, after land transfer, Lvzenong Planting Company provides many jobs through the introduction of projects and industrial upgrading. It attracts a large amount of foreign labor, and local labor is only a part of the total labor. With the new apple planting technology, the crop income is much higher than before land transfer, which increases farmers' income and expands rural collective assets. The economic benefits of land transfer are obvious.

4.2. Scenario Analysis after Land Transfer

4.2.1. Simulation Based on Perspective of Investment Behavior

In the simulation, Lvzenong Planting Company transfers sweet potato planting areas to apple planting areas and woodland. We analyzed the degree of interaction among components in the system after land transfer from the perspective of four investment behaviors: no investment, government investment, private investment, and mixed investment. The biomass of the apple system increases significantly in the first 10 years under the private investment and mixed investment scenarios, with peak values of 1.36×10^{14} and 1.18×10^{14} sej, respectively. Under the no investment and government investment scenarios, the biomass of the apple system does not change significantly in the first 10 years, and then decreases steadily, reaching a minimum value after 45 years (Figure 5a). The biomass of the woodland system always shows a downward trend, and does not change significantly with the change of investment scenario (Figure 5b). Under the four scenarios, soil organic carbon storage decreases rapidly in the first 20 years, showing the fastest decline in the private investment scenario, with an average annual decline of 4.47%. It fluctuates smoothly in the following 30 years, and then declines slowly again after 50 years, and reaches a steady state after 60 years (Figure 5c). The changing direction of labor storage is basically the same, showing a gradual downward trend, reaching a stable state after about 20 years. Among the four steady-state values, the lowest is 126.6 × 10^{14} sej for the private investment scenario, followed by 127.8 × 10^{14} sej for the mixed investment scenario (Figure 5d). The changes in rural assets in the four scenarios are basically consistent, showing a steady increase trend and reaching a steady state of 170 × 10^{14} sej after about 30 years (Figure 5e). Infrastructure value under the government investment and mixed investment scenarios shows a rapid growth trend, with an average annual growth of 1.69 and 0.63%. The growth rate is higher in the government investment scenario than in the mixed investment scenario. Under the no investment and private investment scenarios, infrastructure value steadily declines to a steady state of 122.63 × 10^{14} and 122.39 × 10^{14} sej, respectively, with a small change (Figure 5f).

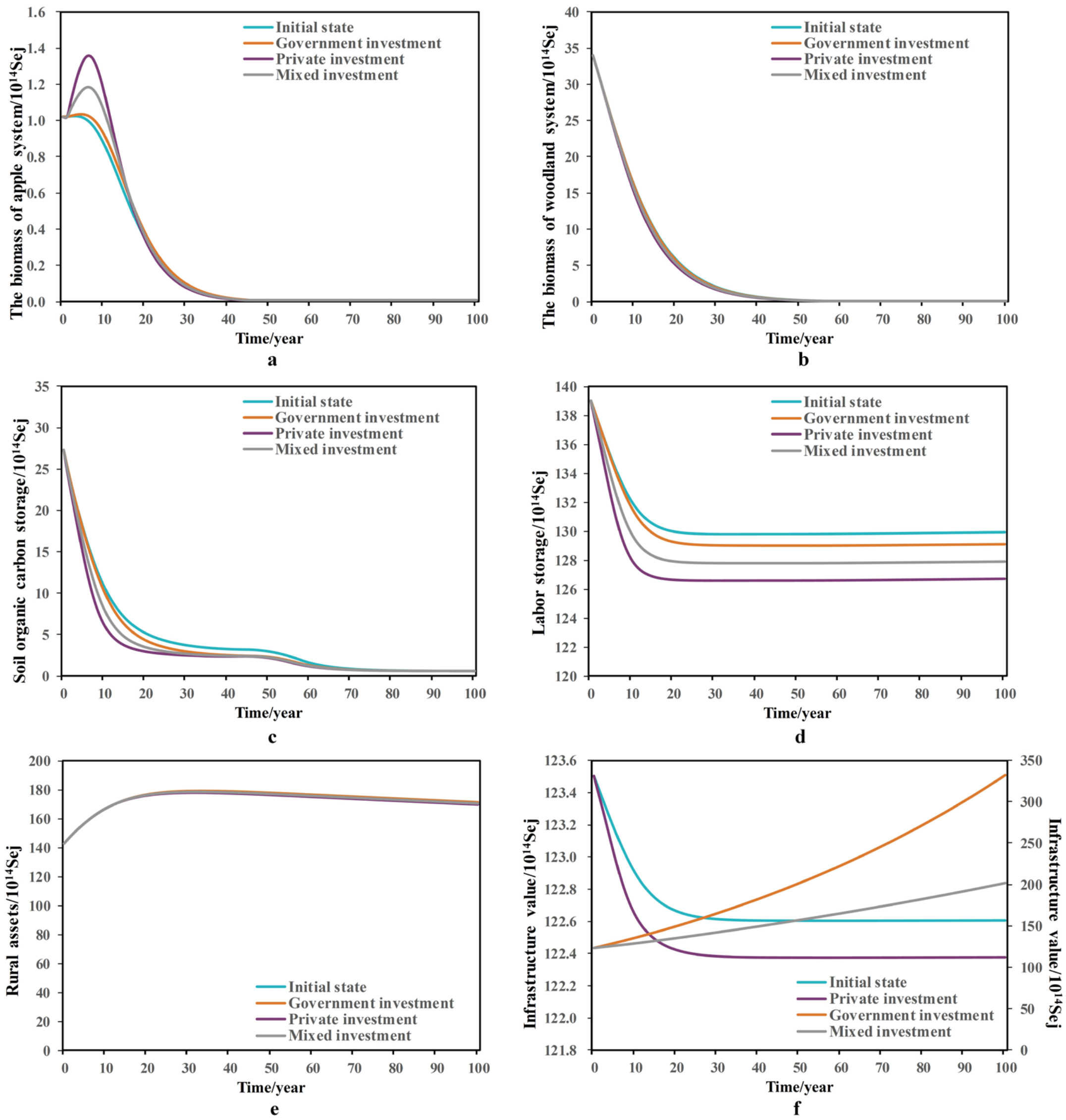

Figure 5. Energy changes of system components based on the perspective of investment behavior. (**a**) the biomass of apple system, (**b**) the biomass of woodland system, (**c**) soil organic carbon storage, (**d**) labor storage, (**e**) rural assets, (**f**) infrastructure value.

Government investment behavior directly affects infrastructure development, and increased government investment will drive the rate of infrastructure addition well beyond the rate of infrastructure consumption in apple planting areas, resulting in a significant increase in infrastructure value. Increased private investment will directly increase the value of purchased services and indirectly affect the value of infrastructure after interacting with machinery, causing the highest significant initial increase in the biomass of the apple system, and a significant increase in the demand for labor, and further accelerating the rate of labor consumption, leading to a rapid and large decrease in labor storage. The mixed investment scenario has increased government and private investment in equal proportions. However, government investment will act directly on infrastructure, while the impact of private investment on infrastructure is indirect. Even though the same proportion of new investment is added in both types of investment, it still causes the infrastructure value change trend to be biased toward the trend under government investment behavior, so the infrastructure value increases less. Private investment will positively affect the biomass of the apple system and negatively affect infrastructure value. Government and mixed investment behavior will positively affect infrastructure value. Any type of investment behavior has a negative impact on soil organic carbon storage and labor storage, with private investment behavior having the most significant negative impact. Woodland system biomass and rural assets do not change significantly with changes in investment behavior.

4.2.2. Simulation Based on the Perspective of Land Use Change

In the simulation, Lvzenong Planting Company transfers sweet potato planting areas to apple planting areas and woodland. We analyzed the interactive relationship between components in the system after land transfer from the perspective of land use change.

When the apple planting areas are increased, the apple system biomass rapidly increases to the maximum value of 0.91×10^{14} sej in the ninth year, and then decreases to a steady state. When the apple planting areas are reduced, the biomass sharply declines in the first 10 years and then decreases at a slower rate (Figure 6a). With an increase in apple planting areas, the biomass of the woodland system decreases sharply. When the apple planting areas are decreased, the woodland system biomass decreases slowly (Figure 6b). With all three land use types, soil organic carbon storage first decreases rapidly and then slowly reaches a steady state. Under the scenario of reducing apple planting areas and increasing woodland areas, the steady-state value is the highest of 4.8×10^{14} sej (Figure 6c). When the apple planting areas are increased, labor storage rapidly declines, then slowly rises to a steady state of 132×10^{14} sej after 15 years. With reduced apple planting areas, labor storage continues to decline, reaching a steady state of 118.6×10^{14} sej after 60 years (Figure 6d). With all three types of land use, rural assets rise slowly, and increase faster after apple planting areas are reduced. The highest steady state of rural assets is 220×10^{14} sej (Figure 6e). Infrastructure value shows a downward trend, and declines faster after apple planting areas are reduced, reaching a steady state of 121.9×10^{14} sej after 60 years (Figure 6f).

From the perspective of land use change, the change trends of components in the system after land transfer are generally consistent, except for the biomass of the apple system and labor storage. However, the change in direction and amplitude are completely different from the initial state. Increasing apple planting requires more labor, which increases the labor consumption rate, so the initial labor storage declines rapidly. After 9 years, the apple system biomass begins to decline, and the labor demand decreases. Labor storage slowly recovers after the 14th year and reaches a stable state after 30 years. The increased apple cultivation brings economic benefits to the rural collective and increases the income level of farmers while increasing the village's collective assets, but the increase in rural assets is less than that in the scenario with reduced apple planting areas. This indicates that increasing the apple planting areas by 5% and reducing the woodland areas by 5% may not be the best way to increase the economic benefits for Lvzenong Planting Company. The current amount of apple planting is no longer the best choice for maximizing benefits. Therefore, expanding the apple orchards while reducing woodland areas would positively affect the biomass of the apple system, labor storage, and infrastructure value and negatively affect the biomass of the woodland system, soil organic carbon storage, and rural assets.

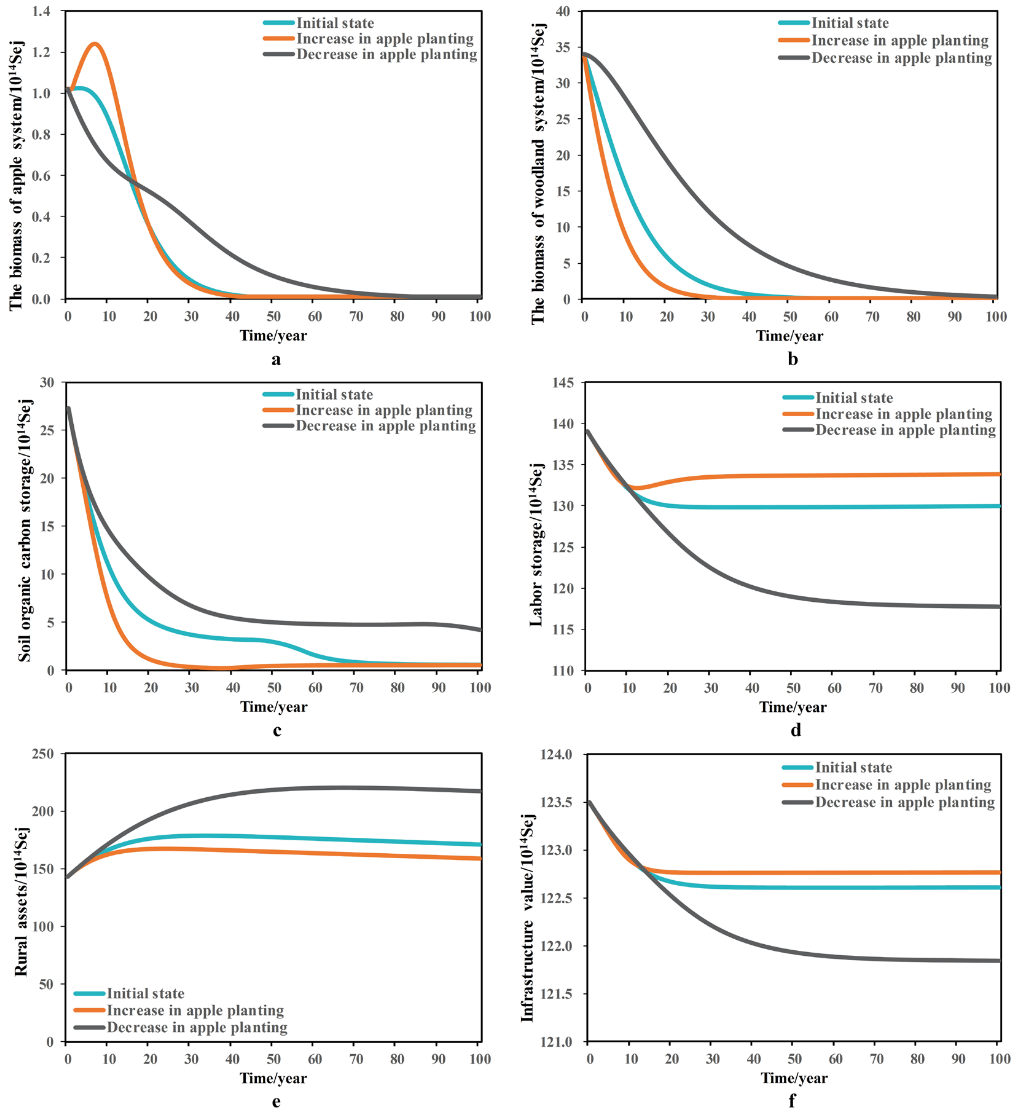

Figure 6. Energy changes of system components based on the perspective of land use change. (**a**) the biomass of apple system, (**b**) the biomass of woodland system, (**c**) soil organic carbon storage, (**d**) labor storage, (**e**) rural assets, (**f**) infrastructure value.

4.3. Simulation of Ecosystem Service Change in Land Transfer

A dynamic evaluation of ecosystem services can accurately represent changes in ecological benefits. Land transfer will lead to changes in land use type and intensity, impacting the value of ecosystem services by affecting ecosystem patterns, processes, and functions. The analysis of changes in ecosystem services induced by the land transfer of Lvzenong Planting Company has crucial implications for formulating land transfer management policies in Tai-hang Mountains, Hebei Province.

Using the value equivalent factor in unit area method, Xie et al. developed a method for dynamic evaluation of Chinese terrestrial ecosystem service value. They produced a table of ecosystem service value equivalent per unit area [52]. Four types of ecosystem services are included in the table: (1) provisioning services, (2) regulating services, (3) supporting services, and (4) cultural services. In this study, we simulated the value of ecosystem services of Lvzenong Planting Company in the next 100 years based on an energy flow model of the land transfer system combined with the equivalence table constructed by Xie et al.

According to the analysis of Table 6, the total value of ecosystem services of Lvzenong Planting Company before land transfer is RMB 324,950.55 $\times$ 10^4, 154,815.03 $\times$ 10^4, 35,338.31 $\times$ 10^4, and 2256.60 $\times$ 10^4 in years 0, 10, 20, and 100, respectively. The total value decreases by RMB

170,135.52 × 10^4 (−52.36%) in years 0–10, RMB 289,612.24 × 10^4 (−89.13%) in years 0–20, and RMB 322,693.95 × 10^4 (−52.36%) in years 0–100. In terms of the four ecosystem service types, the value of provisioning, regulating, supporting, and cultural services decreases by RMB 56,777.80 × 10^4, 157,262.24 × 10^4, 101,709.87 × 10^4, and 6944.05 × 10^4, respectively, in years 0–100. After land transfer, the total value of ecosystem services is RMB 2,507,815.88 × 10^4, 1,271,629.65 × 10^4, 473,149.72 × 10^4, and 8955.55 × 10^4 in year 0, 10, 20, and 100, respectively. The total value decreases by RMB 1,236,186.22 × 10^4 (−49.29%) in years 0–10, 2,034,666.16 × 10^4 (−81.13%) in years 0–20, and 2,498,860.33 × 10^4 (−99.64%) in years 0–100. The value of provisioning, regulating, supporting, and cultural services decreases from 0 to 100 years by RMB 307,414.15 × 10^4, 1,257,851.40 × 10^4, 760,711.47 × 10^4, and 172,883.30 × 10^4, respectively.

The total ecosystem services value and the value of the four services of Lvzenong Planting Company are much higher after than before land transfer. The total value of ecosystem services in the region before land transfer decreases by 97.68% after 30 years, and the ecological service capacity provided by the sweet potato system is almost lost after 40 years. The total value of ecosystem services in the region after land transfer decreases by about 93.83% after 30 years, and the capacity of ecological services provided by apple and woodland ecosystems is almost lost after 40 years. The greatest decrease in total value is observed in the first 10 years for the increased apple planting scenario (−66.09%) and the smallest decrease in total value is observed in the decreased apple planting scenario (−19.55%). The least decrease in total value is observed in the decreased apple planting scenario from 0 to 100 years (−99.03%). In terms of the four ecosystem service types, the value of each service shows a trend of slight increase and then decrease in the first few years before land transfer, and the value of each service keeps decreasing after land transfer.

As shown in Figure 7, the proportions of the four types of ecosystem services in the seven states were analyzed, and it can be found that the changing trend of the proportion of provisioning and supporting services is the same (except in the mixed investment state), with the proportion increasing after land transfer in the government investment state, increasing then decreasing then increasing again in the private investment state, increasing then decreasing in the increased apple planting state, and decreasing then increasing in the decreased apple planting state. In the mixed investment state, the proportion of provisioning service increases then decreases, then increases again, and the proportion of supporting service increases. The change trend of the proportion of regulating and cultural service is exactly the same, but the change direction is exactly opposite to that of provisioning service. Land transfer behavior decreases the proportion of provisioning and supporting services, with a greater decrease in the former, and increases the proportion of regulating and cultural services, with a greater increase in the latter. Private investment behavior leads to a faster increase in the proportion of provisioning and supporting services and a faster decrease in the proportion of regulating and cultural services.

Table 6. Changes in ecosystem services value of Lvzenong Planting Company.

Ecosystem Services Value (RMB 10,000)	Year	Before Land Transfer	After Land Transfer	Government Investment	Private Investment	Mixed Investment	Increased Apple Planting	Decreased Apple Planting
Provisioning value	Year 0	57,174.84	308,599.73	308,599.73	308,599.73	308,599.73	308,599.73	308,599.73
	Year 10	27,239.61	161,073.63	162,644.23	164,863.59	164,302.32	114,696.83	246,151.49
	Year 20	6217.75	60,188.81	60,413.47	53,774.03	56,889.57	26,704.56	173,246.90
	Year 100	397.05	1185.58	1185.58	1185.58	1185.58	1185.58	2991.54
Regulating value	Year 0	158,361.98	1,262,333.97	1,262,333.97	1,262,333.97	1,262,333.97	1,262,333.97	1,262,333.97
	Year 10	75,447.83	638,696.47	642,243.87	637,596.83	641,495.61	425,058.61	1,016,125.08
	Year 20	17,221.83	237,569.44	236,584.64	210,257.46	222,472.86	94,104.45	711,929.47
	Year 100	1099.74	4482.56	4482.56	4482.56	4482.56	4482.56	12,230.18
Supporting value	Year 0	102,421.12	763,454.81	763,454.81	763,454.81	763,454.81	763,454.81	763,454.81
	Year 10	48,796.13	388,056.74	390,455.35	388,852.54	390,665.44	260,955.20	613,735.84
	Year 20	11,138.28	144,440.83	144,012.73	128,016.98	135,451.34	58,245.41	430,285.47
	Year 100	711.26	2743.34	2743.34	2743.34	2743.34	2743.34	7397.36
Cultural value	Year 0	6992.61	173,427.37	173,427.37	173,427.37	173,427.37	173,427.37	173,427.37
	Year 10	3331.46	83,802.82	83,727.65	80,405.65	82,152.46	49,772.67	141,407.65
	Year 20	760.44	30,950.64	30,443.12	26,988.71	28,563.56	9970.25	98,446.59
	Year 100	48.56	544.07	544.07	544.07	544.07	544.07	1678.93
Total value	Year 0	324,950.55	2,507,815.88	2,507,815.88	2,507,815.88	2,507,815.88	2,507,815.88	2,507,815.88
	Year 10	154,815.03	1,271,629.65	1,279,071.10	1,271,718.61	1,278,615.82	850,483.31	2,017,420.06
	Year 20	35,338.31	473,149.72	471,453.96	419,037.18	443,377.34	189,024.67	1,413,908.43
	Year 100	2256.60	8955.55	8955.55	8955.55	8955.55	8955.55	24,298.01
Change rate of total value	Year 0–10	−52.36%	−49.29%	−49.00%	−49.29%	−49.01%	−66.09%	−19.55%
	Year 0–20	−89.13%	−81.13%	−81.20%	−83.29%	−82.32%	−92.46%	−43.62%
	Year 0–100	−99.31%	−99.64%	−99.64%	−99.64%	−99.64%	−99.64%	−99.03%

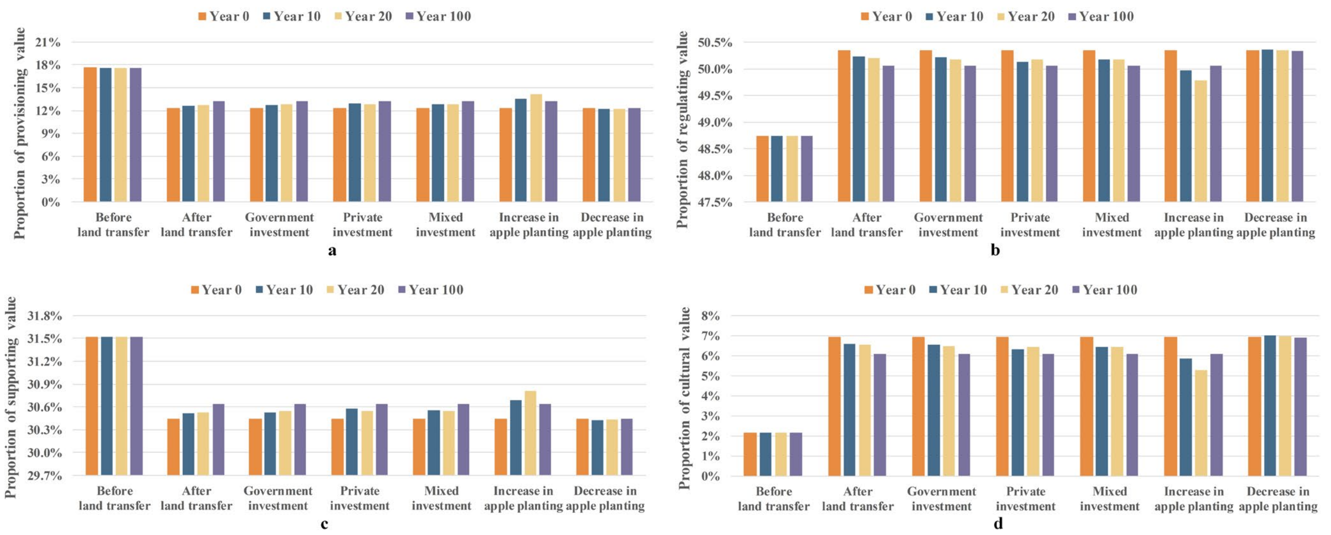

Figure 7. Proportions of four types of ecosystem services. (**a**) provisioning value, (**b**) regulating value, (**c**) supporting value, (**d**) cultural value.

5. Discussion

Land transfer can improve farmers' income while helping the development of the agricultural scale, which is consistent with the research results of Peng et al. [53]. Moreover, this paper also concludes that land transfer can effectively integrate labor resources. This is because, by transferring the right to operate the land to other farmers and economic organizations, land transfer avoids problems such as wasted labor and idle land while allowing farmers to completely remove themselves from the farm and devote themselves to other work. Fan and Wang believe that infrastructure construction is of great significance to standardize the government's investment and improve the utilization efficiency of financial capital in rural infrastructure construction [54], which is similar to the conclusion of this study. The effect of agricultural mechanization on labor storage after land transfer is also significant. This is due to the new infrastructure formed by the government's investment in the land transfer process, as manifested by new agricultural machinery and equipment. The input of new infrastructure will increase the demand for labor in apple cultivation and further decrease labor storage. The results obtained by Zhou and Ma confirm this finding [55].

In the context of comprehensively promoting rural revitalization, this study combines energy systems language and the emergy approach to build an energy flow model of land transfer, which reveals the energy flow relationship among the components of the system in the land transfer process and reflects the complex ecological processes within the system and the interactions among the components and helps to quantify the complex ecological and socioeconomic benefits brought by land transfer. In a broad sense, it provides suggestions for land transfer in the Tai-hang Mountain area of Hebei Province, as well as a reference for other regions with similar characteristics throughout the country, contributing to the realization of high-quality development in China.

6. Conclusions

In this work, we simulated the state of resource storage and energy flow in the land transfer process based on the energy systems language model, and the main conclusions are as follows:

1. The impact of the land transfer on the rural economy is first manifested in increased farmers' income; second, land transfer is conducive to the development of the agricultural scale, through which the rural economy can be mobilized to achieve a greater scope of resource integration, which again can be an effective integration of rural labor

resources. Ultimately, the value of rural assets and infrastructure after land transfer is much higher than before the transfer.

2. Government investment behavior directly affects infrastructure construction. Private investment behavior indirectly affects infrastructure value by increasing the amount of purchased services and reacting with machinery, leading to the trend of changing infrastructure value in favor of the trend under government investment behavior. When the level of agricultural mechanization of Lvzenong Planting Company is increased by 20%, the value of infrastructure still shows a decreasing trend. It slows down by 0.0457 and 0.0211% before and after land transfer, respectively.
3. Expanding apple orchards while reducing woodland areas will positively affect the biomass of the apple system and the value of labor storage and infrastructure and negatively affect the biomass of the woodland system, soil organic carbon storage, and rural assets.
4. Land transfer behavior will reduce the share of provisioning and supporting services and increase the share of regulating and cultural services.

Based on the above discussion and conclusions, this paper has some policy implications: (1) Land transfer should be actively publicized to further deepen farmers' understanding of rural land ownership and transfer procedures, promote land transfer, and realize efficient use of rural land. (2) The government should promulgate corresponding policies and regulations to regulate land transfer and protect farmers' rights and interests. (3) Financial support for land transfer should be increased, with a focus on cultivating and supporting leading agricultural enterprises, and support should be given to project construction in terms of financial support, marketing platform construction, etc., for various business entities with a strong drive, market competitiveness, and demonstration ability.

The land transfer model based on Odum's energy systems language and the emer-gy approach integrates multiple ecosystems and socioeconomic systems and breaks through the limitations of current studies that focus on a single ecosystem or socioeco-nomic system, and the assessment results are more scientific. However, this study still has shortcomings, which will need to be addressed in the future. From the perspective of system components, for the convenience of model construction, this study did not consider other land use types and only considered the land types mainly involved in the land transfer process in the study area. The land transfer process of Lvzenong Planting Company mainly involved the sweet potato plantation area, apple plantation area, and woodland. In contrast, the main land use types in the Tai-hang Mountains are cropland and grassland, followed by woodland and construction land. The model does not consider the influence of grassland and construction land on the energy flow in the study area. Moreover, to simplify the socioeconomic system involved in the process of land transfer, only the economic market was taken as a place for commodity and capital exchange, and the influence of the financial market on land transfer was not considered. The components of the system could be further enriched in the future by introducing more kinds of ecosystems and socioeconomic systems to explore the energy flow process of land transfer in the Tai-hang Mountains.

Exploring the complex energy flow within the land transfer system will help to provide a reference for the direction of land system reform in poverty-stricken areas and lay a solid foundation for sustainable agricultural development and rural revitalization. Future research needs to further improve the composition of the land transfer system, introduce more components, explore better development modes of land transfer, and further improve the performance of land transfer and the efficiency of the sustainable use of land resources.

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