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A Scenario-Based Simulation of Land System Changes on Dietary Changes: A Case Study in China

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Abstract: The dietary change of Chinese residents is driven by increasing incomes and urbanization, which will bring about non-negligible changes in the food production of the land system. To explore how dietary changes might influence future land systems and the environment, this research hypothesizes two potential dietary change scenarios in the period 2010–2030, based on the current trends and Dietary Guidelines for Chinese Residents (DGCR), and applies the CLUMondo model to simulate the spatiotemporal patterns of land systems and estimates a lifecycle's environmental impacts on dietary change. As shown in the results, dietary changes would obviously alter the land cover, agricultural intensity, and livestock density of land systems, and the changes in land use intensity are noteworthy. If the current trend of dietary change is unchecked, the intensification and expansion of agriculture and animal husbandry would be widely distributed in North China and Northwest China, where the intensity of cropland was low in the past and the ecosystem was relatively fragile. Moreover, the increasing demands for food lead to sharp increases in the carbon footprint, water footprint, and ecological footprint from food production. In contrast, the balanced diet recommended by DGCR could offer considerable environmental benefits. This diet is conducive to cutting down land use intensity, helping natural systems avoid intensification, and the expansion of agriculture and animal husbandry, which lower footprints from food production and have helped to implement the policy of returning croplands to grassland and forests in China. Therefore, popularizing balanced diets could be a win–win for human health and environmental sustainability.

Keywords: land system; land use intensity; dietary change; scenario simulation; CLUMondo

1. Introduction

Diets tightly link human health to environmental sustainability [1]. With economic development and urbanization, the traditional diets of Chinese residents have been replaced by diets higher in animal products [2]. In China, meat intake per capita has increased five-fold in the past 50 years and would soon exceed the upper limit of the recommended meat intake in the Dietary Guidelines for Chinese Residents (DGCR) if the trend continues [3]. The demand for foods is such a fundamental demand for human-beings that diet is one of the most influential driving factors for land use change. Diet in China has been the principal cause for agricultural land use change over the past 50 years [4]. Inappropriate diets can not only lead to chronic non-communicable diseases [5–10] but can increase environmental burdens by emitting more greenhouse gases, consuming more water, and occupying more natural capital [11–14].

Human demands for resources and services supplied by the land are the main causes for land system changes. Land systems not only include the common connotations of land cover and land use but also include all the functions and effects provided by the land [15]. This progress, in recognition of the land, which helps to reveal the interrelationship between land system changes and the operation of the social-ecosystem, has prompted researchers to transfer their research objects from land-use or land-cover during the land-use and land-cover change (LUCC) project to land systems [16–22]. Specifically, land systems cannot be defined as mutually exclusive classes according to their land-use or land-cover but can be regarded as a series of entities with the same land cover but different land use intensity in application. In addition, land systems can represent multifunctional land, such as rural villages combining residential utilization with crop production and livestock production [23,24].

Simulating the trajectories and patterns of land change by a series of scenarios is an accepted way to anticipate land change [25–29]. Comparing different outcomes under different scenarios is conducive to illustrating the adaptation of land systems to macroscopic environments and assisting in the decision-making of sustainable socioeconomic development and ecosystem conservation. Scenario analysis of dietary changes is usually a comparison of the current diet or the diet of developed countries with the recommended diets [30,31]. Modeling is the core of simulation, and land system modeling has been improved to adapt to new research tendencies [32,33]. For example, the CLUMondo model has been further developed based on the modelling framework in the series of CLUE models [34–38]. It is specifically designed to simulate changes in land cover and land use, as well as land use intensity and representing multifunctional land [34]. Compared with earlier versions, this model can more intuitively and effectively reflect the interaction between supplies of the land system and the demands of the social-ecosystem.

In this article, we define and classify the land system by land cover, agriculture intensity, and livestock density and apply the CLUMondo model to simulate future land systems in China under different dietary change scenarios based on the current trends and DGCR. Then, we assess the influence of dietary change on land system, which might give insight into formulating policies about sustainable agricultural development, health education, and environmental management.

2. Materials and Methods

2.1. Data Sources

The land system map with spatial resolutions of 5 km was drawn on the basis of provincial statistical data on the yield per unit of crops, livestock density maps, and the land cover map. Statistical data on the yield per unit of crops were obtained from the National Bureau of Statistics of the People's Republic of China [39]. Livestock density maps of the pigs, poultry, bovines, goats, and sheep in 2000 and 2010 were obtained from the FAO Geographic Information Network [40], and their spatial resolutions are 5 km. Land cover maps with the six first-level land cover classes in 2000 and 2010 were obtained Resources and Environmental Data Cloud Platform (REDCP) [41], and their spatial resolutions are 1 km. In addition to the accessibility factors, the biophysical and socioeconomic location factors were calculated from land cover maps or traffic maps. Other data were obtained from the REDCP [41]. To compute the demands for food in these scenarios, we downloaded the proportions of the losses and feed for each kind of food, as well as the per capita supply of each food from FAOSTAT [42], and adopted the annual population in the period from 2010 to 2030 from the medium-fertility variant of the China in World Population Prospects: The 2015 Revision [43]. The land demands for the built-up area and the forest area refer to the binding targets in the National Land Planning Outline (2016–2030) [44]. In this article, the values of CF, WF, and EF associated with each food were referenced by a life cycle assessment (LCA) database [45].

In each map, the boundary data for China were provided by the National Administration of Surveying, Mapping, and Geoinformation of China [46], and the boundary data for the 8 human geography regions (Figure 1) were obtained from Fang et al. [47].

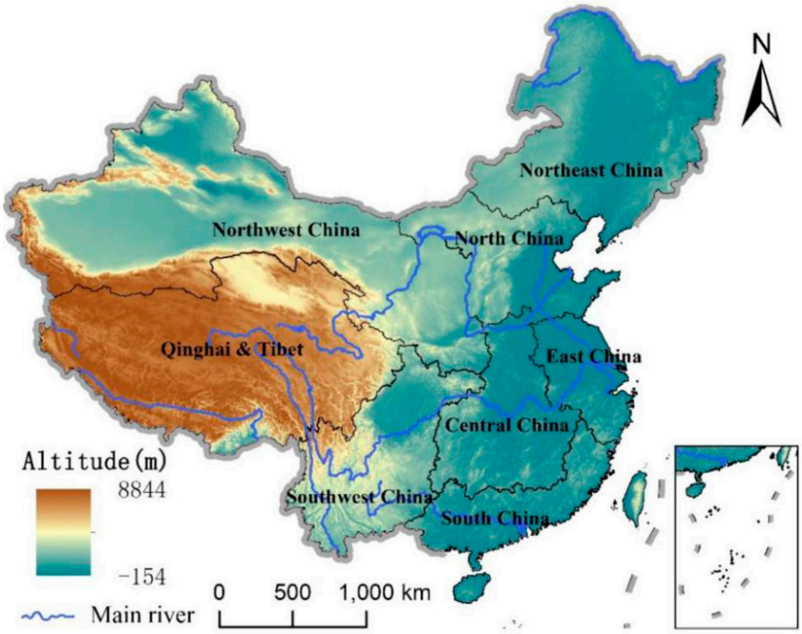

Figure 1. A topographic map and spatial distribution of eight human geography regions in China.

2.2. *Overall Approach*

We researched the response of the land system to dietary change in four major steps. First, we classified the combination of land cover, livestock system, and agricultural intensity into a series of land systems that can be used as entities for modeling. Second, we hypothesized two potential dietary change scenarios based on the current trend and DGCR and estimated the land use demands in China under these scenarios. Third, we parameterized the CLUMondo model to output the spatiotemporal patterns of the land system changes from 2010 to 2030 under two scenarios. Fourth, we analyzed the spatial changes in land use and land use intensity and further assessed the changes in the lifecycle environmental impacts from food production in all land systems on the basis of carbon footprint (CF), water footprint (WF), and ecological footprint (EF). The overall framework of the study is illustrated in Figure 2.

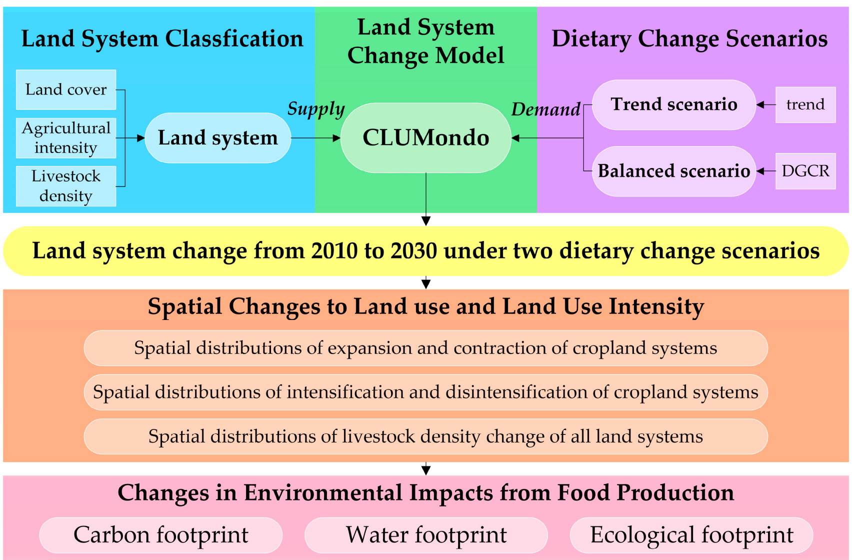

Figure 2. The overall framework of the study.

2.3. Land Systems Classification

The series of land systems was categorized based on land system classification designed by three main classification factors: (1) land cover, (2) livestock density, and (3) agricultural intensity [23,24]. Land cover is represented by a series of variables, such as forest cover (%), grassland cover (%), bare cover (%), cropland cover (%), and built-up area cover (%). Agricultural intensity is represented by the yield per unit of crops based on provincial statistical data. Because bovines, goats, and sheep are more directly dependent on local land resources than monogastric species, such as pigs and poultry, and their spatial distributions also have different characteristics [48], livestock were divided into pigs and poultry (pp), and bovines, goats, and sheep (bgs).

Land systems are divided step by step with the produce (Figure 3) after calculating the percentage of land cover, grains production, and the density of monogastric livestock (pp) and ruminant livestock (bgs) in each land system. First, the three distinctive land systems, settlement systems, bare systems, and water systems, were extracted. These three kinds of land systems are easy to extract owing to their relatively obvious boundaries and high aggregation. The rest of the land is divided into cropland, mosaic cropland, grassland, forest, and mosaic natural systems according to their percentages of cropland, forest, and grassland cover and subdivided into various land systems via the type and number of the livestock. In addition, the cropland system should be further subdivided by the intensity of agriculture. To avoid dividing too many land system categories, only the land system types with a total area of more than 1% were further subdivided. Finally, a land system classification system, including 20 different types of land systems, was constructed to depict China's land system maps in 2000 and 2010.

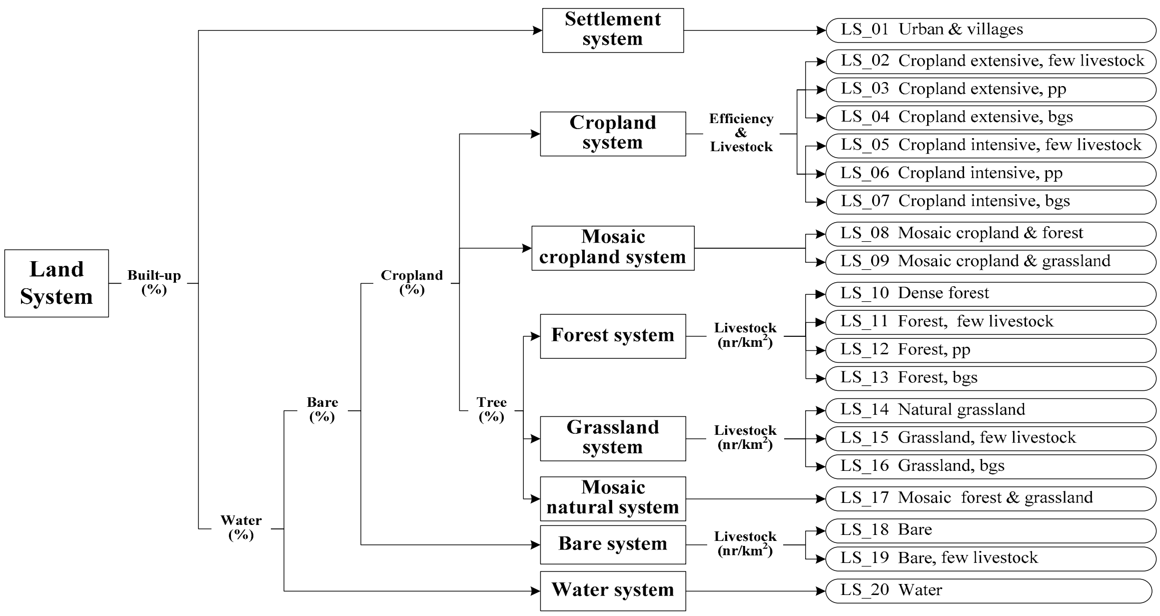

Figure 3. Land system classification procedure. All land systems are listed in the dextral circles.

2.4. CLUMondo Model

In the CLUMondo modeling framework, the simulation of land system changes are based on empirically quantified relations between land systems and their driving factors, in combination with the dynamic modeling of competition between different land use types [34]. The CLUMondo model includes two modules: One is a non-spatial demand module, and the other is a spatial allocation module. Land use demands (the core of scenario setting) are input into the non-spatial demand module, and the spatial allocation module translates these demands into spatial changes in the land system.

Each grid cell in CLUMondo represents a land system supplying a certain amount of social-ecosystem goods and services to meet the regional demands for these goods and services, such as crops, meat, and built-up land. In order to fulfill these land use demands for a hypothesized scenario in the entire model region. The model calculates the area of various land system types and allocates every land system at specific locations, determined by local suitability, competitive strength, and some conversion rules. The modeling procedure is shown in Figure 4.

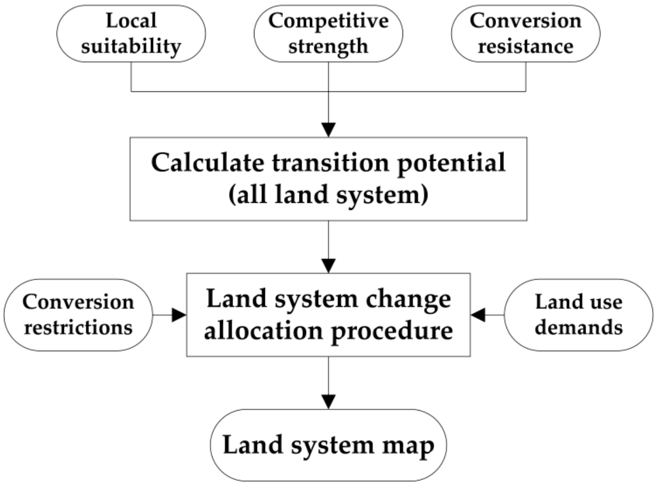

Figure 4. The allocation module of the CLUMondo model.

Calculating transition potential is the basis of the allocation module. The transition potential (Ptran) of the grid cell (i) for each land system (LS) in time (t) is calculated according to the sum of local suitability (Ploc), the competitive strength (Pcomp), and conversion resistance (Pres) of a land system:

$$Ptran_{t,i,LS} = Ploc_{t,i,LS} + Pcomp_{t,i,LS} + Pres_{LS.} \quad (1)$$

To determine the local suitability, this model uses logistic regression based on the following equation:

$$\text{Log}\ [P_i/(1 - P_i)] = \beta_0 + \beta_1 X_{1,i} + \beta_2 X_{2,i} + \ldots \ldots + \beta_n X_{n,I} \quad (2)$$

where Pi is the probability of a grid cell (i) for the occurrence of the considered land system type, and the coefficients (β) of factor (Xn) is estimated through logistic regression using the initial pattern of the land systems.

For a proper analysis, a maximum of the 7 most appropriate factors were selected to calculate the coefficients for all land system types, and the least significant factors had to be eliminated, as long as they were more than 0.05.

Considering previous studies [27,49], we selected 13 biophysical and socioeconomic location factors for the 6 categories (Table 1), including climatic factors, soil characteristic, topographic, vegetation, accessibility, and socioeconomic factors.

Table 1. Spatial determinants used for the regression analyses.

Category	Factors	Unit
Climate	Mean annual temperature	°C
	Annual precipitation	mm
Soil characteristics	Sand content	mass%
	Silt content	mass%
	Clay content	mass%
	Soil average erosion modulus	t/km^2×a
Topographics	Elevation	m
	Slope	degree
Vegetation	Normalized difference vegetation index	g/m^2
Location	Distance to city	km
	Distance to water	km
	Distance to road	km
	Distance to railway	km
Socio-economics	Population density	people/km^2
	Economic density	RMB/km^2

2.5. Land Use Demand under Dietary Change Scenarios

To explore the mechanism for the response of the land system to dietary change, we hypothesize two potential scenarios of dietary change in China from 2010 to 2030. The balanced scenario assumes that residents in China will accept a balanced diet, which means that each food intakes per capita in 2030 will uniformly decrease to the median of the recommended standards in the DGCR. On the contrary, the trend scenario follows the trend of the growth of each food's intake per capita in the previous decade. Different demands for meat production in the future are the main difference between a balanced scenario and a trend scenario. Under a trend scenario, not only will the demand for meat increase, but the demand for total crops will also increase to feed livestock, though the cereal and vegetable intake per capita has decreased since 2008 [42].

Both scenarios have four land use demands, including meat, crops, built-up areas, and forest areas. Meat consists of beef, mutton, pork, poultry and egg, and the crops include rice, wheat, other cereals, beans, potatoes, and vegetables. In both scenarios, the annual total demands for meat are equal to the products of the annual population and per capita demands plus losses. Unlike meat, the demands for crops should also be added to the supply for feeding livestock. In this article, the emphasized scenarios feature different demands for meat and crops. Hence, the settings for the specific conversion of spatial policies and land system types, as well as other demands, are equal under the two scenarios to ensure the reliability of the outputs from the model. Furthermore, the land area and the amount of livestock based on the raster data may have a slight deviation from the statistics. Accordingly, the products of the initial total production and annual change rates of the demands were substituted for the actual annual quantities of demands. Land use demands in 2030 under the two scenarios are shown in Table 2.

Table 2. Land use demands in 2030 under two dietary change scenarios.

Scenarios	Meat	Crops	Built-up Area	Forest Area
TREND	+50.51%	+23.70%	+14.93%	+10.80%
BALANCED	−46.85%	−26.97%	+14.93%	+10.80%

3. Results

3.1. Land System Changes under Different Dietary Scenarios

Figure 5 and Table S1 show a comparison of the spatial distributions of land systems in 2010 with the simulation patterns in 2030 under the trend scenario and balanced scenario, indicating that changes in land use demand will directly lead to the conversion of the land system, and different land use demands under different scenarios will lead to completely different spatial distribution patterns of the land systems. Additionally, Figure 6 provides a close-up view to show the results for the two representative regions in more detail.

The sankey diagrams shown in Figure 7 are based on the land system conversion matrix of two periods (2010–2020 and 2020–2030) under the two scenarios. These diagrams are able to visually represent the dynamic characteristics and differences of the shifts among the various land systems over multiple time intervals [50], which include the three dimensions of time, land system type, and area.

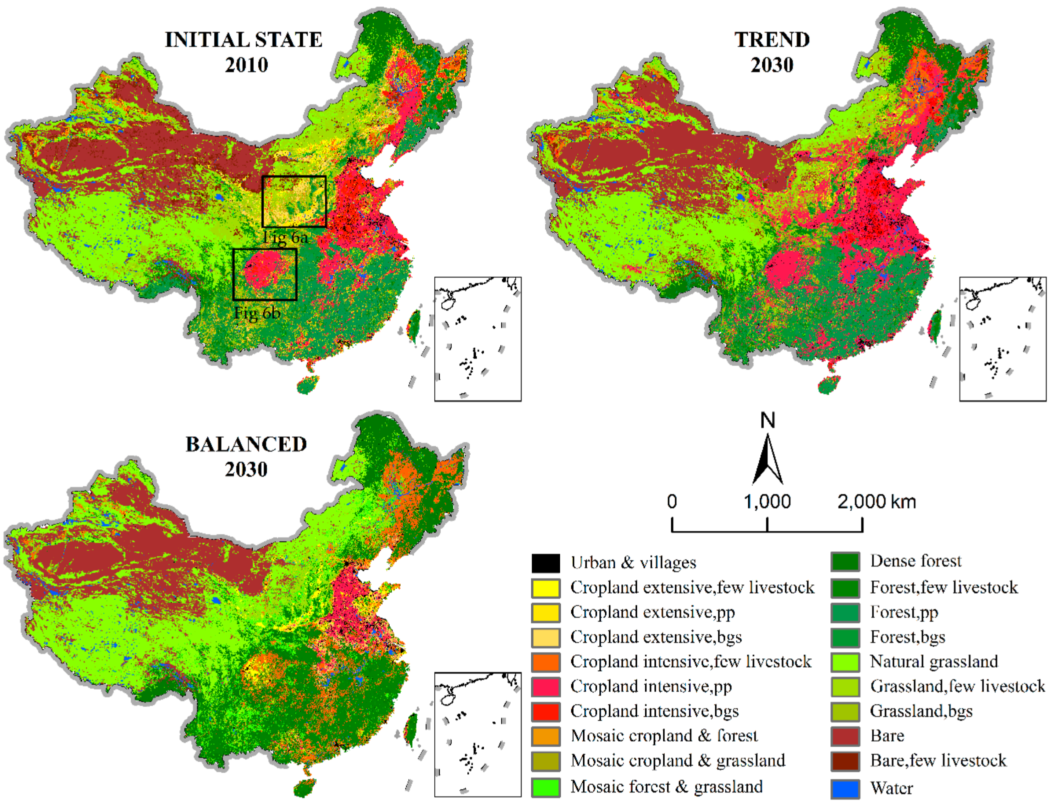

Figure 5. Spatial distributions of the land systems for the initial year (2010) and the simulation results under the two scenarios for 2030.

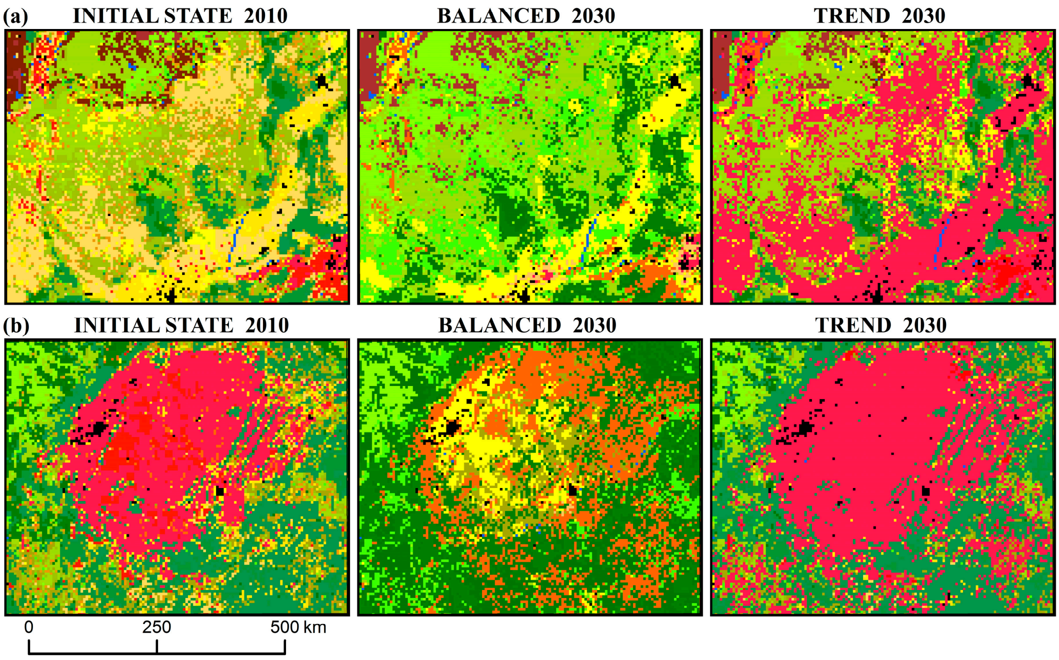

Figure 6. Detailed simulated land system maps for the year 2000 and 2030 under two scenarios. The close-up regions and the legend are indicated in Figure 5.

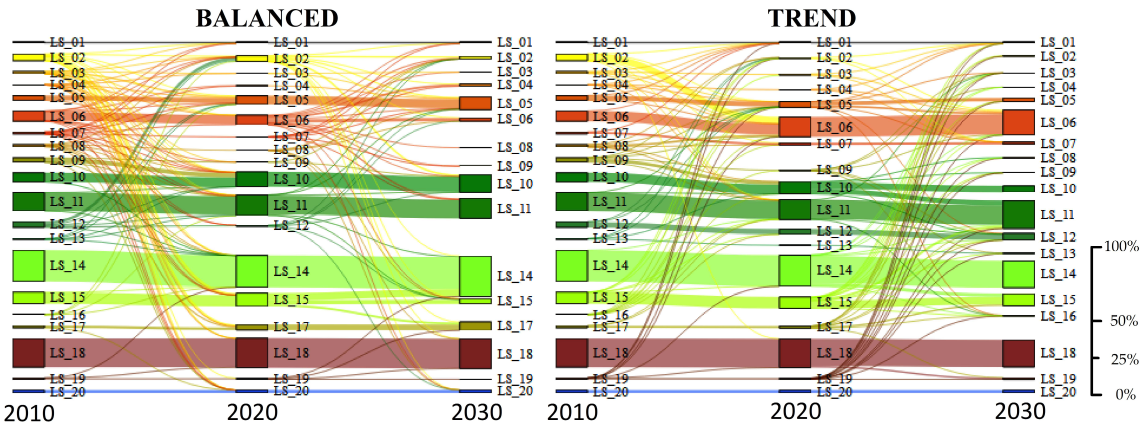

Figure 7. Sankey diagrams of the land system conversion under two scenarios. The area of each land system conversion is presented by the thickness of the line.

Under the trend scenario, the total amount of the cropland system increases 20.21% from 2010 to 2030. Extensive cropland systems transfer into intensive cropland systems, as well as forest systems and grassland system with livestock. Meanwhile, the livestock density of the cropland systems with livestock increases significantly. This shows that the utilization of cropland is more concentrated and its intensity is higher in China under a trend scenario. The gross of the (mosaic) forest systems, as well as the number of forest systems and grassland systems with livestock, also increase. However, the areas with dense forest systems and natural grassland systems decrease 30.52% and 14.01%, respectively, which reveals that the range of farming livestock would non-negligibly expand for the incremental meats demand. The shifts are gradual for bare systems. In the first decade, bare systems mainly transform into open forest systems and grassland systems with livestock, but some bare systems are reclaimed as cropland systems in the last decade because of the increasing crop demand.

The pattern of the land system change is different under the balanced scenario. The total amount of cropland system reduces 13.59% from 2010 to 2030, and a great number of extensive cropland systems are converted into non-cultivated land systems. Further, cropland systems with few livestock account for more than half of the total cropland systems. Additionally, forest systems with livestock almost transfer into dense forest systems or forest systems with few livestock, and grassland systems with bovines, goats, and sheep transfer into natural grassland systems and grassland systems with few livestock. On the whole, the land use intensity of natural systems reduces noticeably under the balanced scenario. For instance, the areas of the dense forest systems and natural grassland systems are 180.10% and 50.71% more than those of the trend scenario. The change of the bare systems is smaller under the balanced scenario, and almost all the bare systems with few livestock will be converted into grassland systems or bare systems by 2030.

The dramatic divergence of the two scenarios shown in Figure 6 is the exemplification of the land system change caused by dietary changes in China. Figure 6a zooms into the Loess Plateau (LP) and its vicinity. The increase in land use intensity is so dramatic that intensive cropland systems with pigs and poultry would supplant the domination of extensive cropland systems in LP under the trend scenarios. Under the balanced scenarios, the intensity of cropland systems would not increase, and both the deintensification of animal husbandry and the return of farmland to grassland would be apparent, which might be conducive to environmental conservation in an area with fragile ecosystems. Figure 6b provides a view of the Sichuan Basin (SB) and the adjacent area. A balanced diet would also lead to a conversion from intensive cropland systems to extensive cropland systems and a drastic reduction in livestock density in the current grain major producing areas. On the contrary, the intensification and expansion of agriculture and animal husbandry will become evident if the current trend of dietary change is unchecked.

3.2. Spatial Changes to Land Use and Land Use Intensity

Based on the land system classification adopted in this article, it is possible to further analyze the land cover, land use, and land use intensity of the land system. Land use and land use intensity would inevitably undergo different changes for different judgments based on the trend of Chinese dietary changes under the trend scenario and balanced scenario. To analyze the response of Land use and land use intensity to different demands for food, the spatial distributions of expansion and contraction, as well as the changes of the intensity of agricultural utilization, were mapped (Figures 8 and 9). Then, we calculated the changes in livestock density under the two scenarios (Figure 10). Meanwhile, the spatial heterogeneity of the adaptation of land use and land use intensity is determined by comparing these changes in each human geography regions.

Cropland expansion mainly occupies forest, grassland, and bare land. Cropland contraction is often associated with forest, grassland, bare land, and water. Under both scenarios, the expansion of the cropland system is mainly concentrated in North China and Northwest China, and most contractions are located in Southwest China and Central China. However, there are three principal different features. First, the new cropland area increases 24.09% under the trend scenario, which is one fourth of that under the balanced scenario, whereas the returning cropland area under the balanced scenario is half as high as that under the trend scenario. Second, more cropland systems convert to a grassland system under the balanced scenario, which is 9.3 times larger than that of the trend scenario. Third, the area of shift from a (mosaic) cropland system to a forest system under the balanced scenario is 26.57% more than that of the trend scenario.

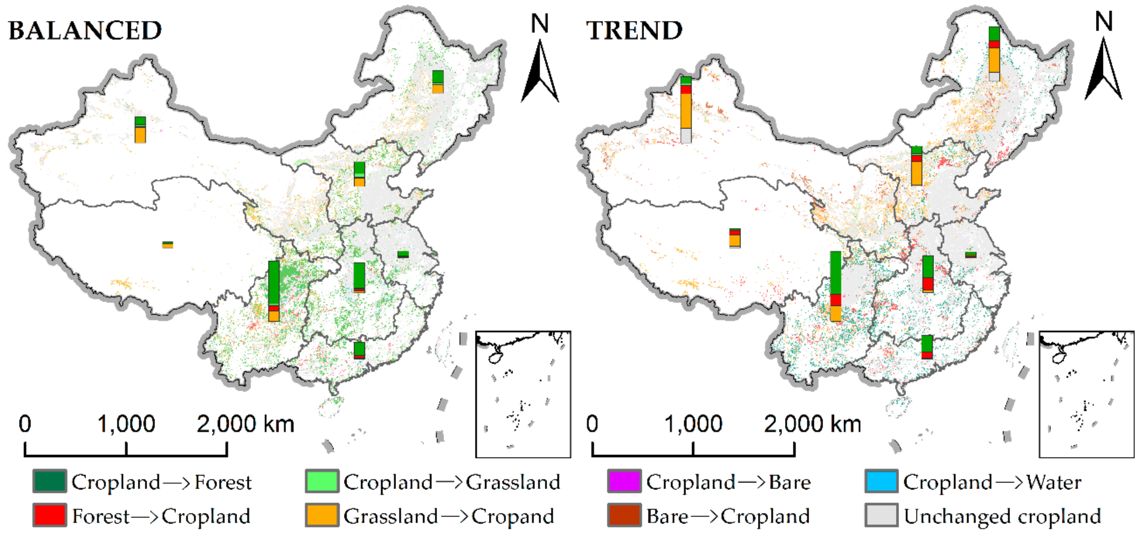

Figure 8. The spatial distributions of the expansion and contraction of cropland systems under two scenarios. The areas of expansion and contraction in each human geography region are presented by the columns.

The cropland system with weakened intensity accounts for 47.43% under the balanced scenarios, and the deintensification concentrates in SB and the Huang-Huai-Hai Plain (HHHP). Although only 38.92% of the cropland systems intensify under the trend scenario, the cropland systems in LP, the Inner Mongolia Plateau (IMP), and Northern Xinjiang (NX) intensify remarkably. All these results seem to indicate that dietary changes following current trends will lead to the expansion and intensification of cropland systems, as well as the contraction of the natural system. However, the dietary changes to a balanced diet would not only contract croplands and reduce the intensity of cropland systems but also effectively promote the implementation of a policy for returning croplands to grasslands and forests.

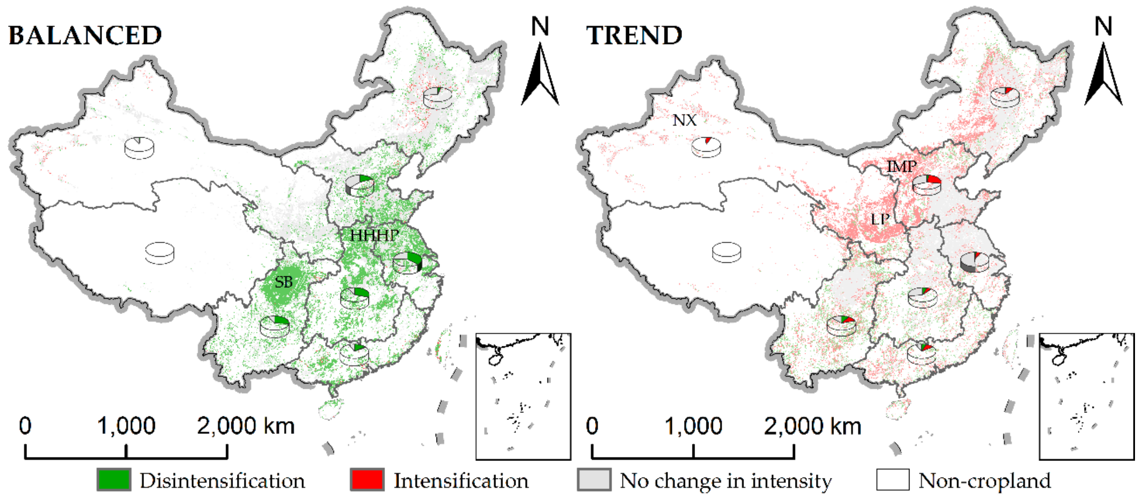

Figure 9. The spatial distributions of the intensification and deintensification of cropland systems under the two scenarios. The proportions of the intensification and deintensification in each human geographical region are represented by the pie chart.

Under the trend scenario, the total area of land system with increased livestock density is 2.14 × 106 km^2 from 2010 to 2030, which accounts for 22.75% of the whole territory. As shown in Figure 8, the meat production in all human geography regions increases. More than half of the land systems with increased livestock density are distributed in Northwest China, North China, and Northeast China, which contribute 25.97%, 18.65%, and 17.45% of the national meat production increments, respectively. In contrast, only 0.33% of the land systems increase under the balanced scenario. Decreases in livestock density occur in 25.84% of the whole territory, and sharp reductions are found in Southwest China and Central China. Briefly speaking, a balanced diet would lessen or maintain the livestock density in nearly all land systems, but increasing the demand for animal food would lead to the expansion and intensification of animal husbandry under the trend scenario.

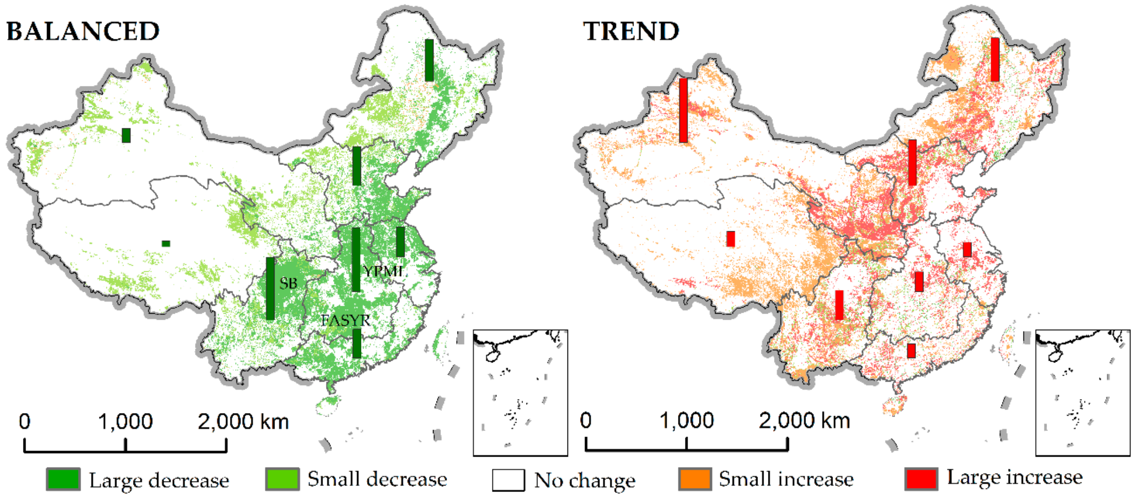

Figure 10. The spatial distributions of the livestock density changes in all land systems under the two scenarios. The total number of changes in the livestock number in each human geography region is represented by the columns.

3.3. Changes in Lifecycle Environmental Impacts from Food Production

CF, WF, and EF are, respectively, used to quantify the extent of the generation of greenhouse gas, the consumption of water resources, and the utilization of natural capital from food production in each land system [51]. Based on land use intensity, we measured these footprints from food production of each land system type (Table S2). Additionally, the changes in the gross of these footprints from food production under two scenarios in the period from 2010 to 2030 are summarized in Table S3, and Figure 11 shows the spatial distribution of these changes as well as the gross of the changes in each human geographical region.

Changes towards a balanced diet can have significant benefits on all three footprints. The CF, WF, and EF from food production in China, respectively, decrease by 692 Mt CO_2 eq, 491 Bm^3, and 360 Mg ha from 2010 to 2030 under the balanced scenario, and increased by 698 Mt CO_2 eq, 500 Bm^3, and 373 Mg ha under the trend scenario.

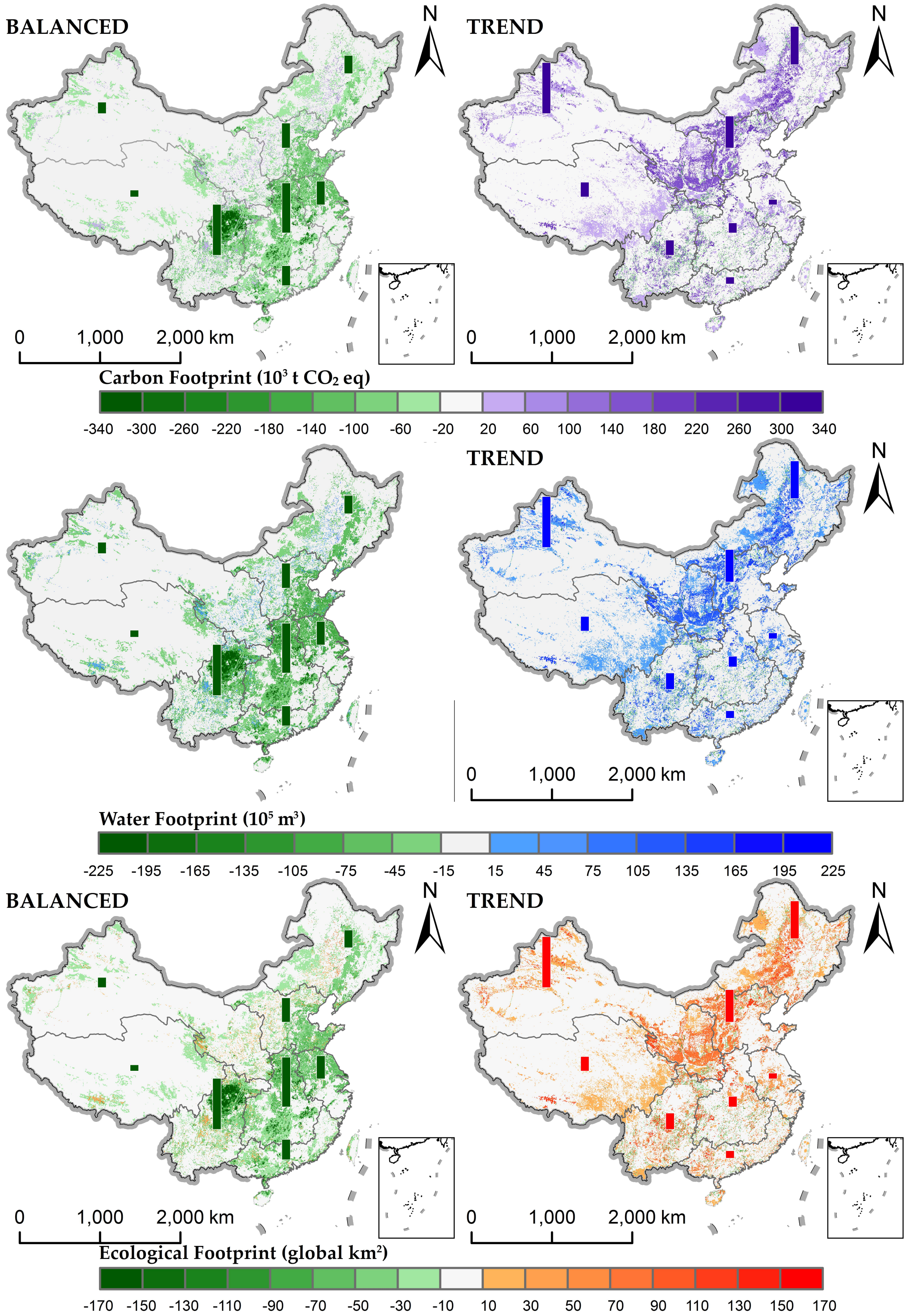

Figure 11. The spatial distributions of the changes in the CF, WF, and EF under the two scenarios. The total changes in CF, WF, and EF in each human geography region are represented by the columns.

As shown in Figure 11, the characteristics of the spatial distribution and variation patterns of the three environmental indicators are similar. Under the balanced scenario, the three environmental indicators of the vast majority land systems lessen. The regions with the largest decrements are Southwest China and Central China, which take up nearly half of the total decrements of each environmental indicator. The trend scenario is the opposite. The vast majority land systems raise the CF, WF, and EF, and the sum of the increment of Northwest China, Northeast China, and North China account for 69.74%, 68.63%, and 68.90% of the total increment of CF, WF, and EF, respectively. Therefore, diet developing along the current trend would have more negative environmental impacts on land systems by emitting greenhouse gases, consuming water resources, and occupying more natural capital. In contrast, a balanced diet would not only reduce the risk of environmental degradation in Northwest China, Northeast China, and North China whose ecosystems are relatively fragile, but also mitigate current environmental impacts, especially in Southwest China and Central China.

4. Discussion

4.1. Comparison with Previous Studies

The results indicate that the response of the land system to dietary changes in China would be noticeable, especially in terms of land use intensity. A greater demand for food would enhance land use intensity and increase the CF, WF, and EF. A balanced diet tends to decrease land use intensity and alleviate pressure on the sustainability of the environment. These tendencies are consistent with those of some previous studies [12,52], even if our methods and materials are different (Table 3).

Table 3. Overview of the comparison between various studies on the environmental impacts of dietary changes and our study.

Researches	Study Area	Dietary Change Scenarios	Spatial Resolution	Environmental Impacts
Our study	China	Two scenarios based on current trends and DGCR.	5 km	Changes in land cover and land use intensity; CF, WF, and EF
Song et al., 2019	China	Two scenarios based on the 2000 and 2013 versions of the dietary reference intake guidelines.	County-level	CF, WF, and EF
Vanham et al., 2018	UK, France, Germany	Three scenarios based on healthy diet with meat, healthy pescetarian diet and healthy vegetarian diet.	Sub-national geographical entities	WF
Alexander et al., 2016	Global	Two scenarios based on the global adoption of the current diets of India and the USA.	Country-level	Changes in agricultural land area

However, studies analyzing the spatiotemporal heterogeneity of the effects of land use on dietary change are rare, while some previous studies are only based on the panel data of agricultural land and does not take other land-use types into account [4,53], which ignores future changes in agricultural utilization intensity and neglects to magnify the changes in agricultural land area. Reclaiming massive new croplands to meet food demands may not be as effective as enhancing agricultural intensity, especially in China where there is a rare reserve of cultivated land and a growing awareness of ecological protection. In our study, an integrated land system change model, such as CLUMondo, was used to simulate competition among different land types to accurately and visually reveal the spatiotemporal patterns of change in agricultural land.

Currently, footprint methods are often adopted to evaluate the impact of dietary changes on the ecosystem [11,54,55]. The common methods based on survey data from customers or government statistics can calculate the environmental impacts of consuming various foods in detail, but are difficult to use for further spatial analyses. Even though some studies have adopted small-area statistics [54], these studies can only analyze where the residents have produced more footprints and cannot reflect what places are more seriously affected by dietary changes.

4.2. Validation of the Method and Uncertainty

Using a more complicated land system classification rather than land use/cover classification as the entities for land change modeling is a key factor in simulating changes in land use intensity. To ensure the land system classification is desirable, we use the receiver operating characteristic (ROC) to describe the goodness of fit of the logistic regressions [56]. Table 4 shows that all values of the ROC in the regressions are above 0.7, and the weighted average value of the ROC, taking the area of each land systems as the weight, reached 0.8891. The goodness of fit of the logistic regressions not only showed the great explanatory power of the driving factors for every land system in this article, but also indicates that the regression results is trustworthy.

Subsequently, we simulated the land system changes in China from 2000 to 2010 via the statistical data and land system map in 2000 to validate the whole model. The output of the simulation was overlaid onto the land system map in 2010 to create the confusion matrix, and the Kappa indicator was calculated on the confusion matrix to measure the performance of the evaluation model. In this way, the accuracy of the simulation is relatively high with a Kappa of 0.81, which means that the simulation of the land system changes to dietary changes from 2010 to 2030 may have high credibility.

Table 4. The ROC value of the logistic regression of different land systems.

Land System Type	**LS_01**	**LS_02**	**LS_03**	**LS_04**	**LS_05**	**LS_06**	**LS_07**	**LS_08**	**LS_09**	**LS_10**
ROC	0.96	0.88	0.89	0.87	0.94	0.86	0.92	0.79	0.78	0.86
Land System Type	**LS_11**	**LS_12**	**LS_13**	**LS_14**	**LS_15**	**LS_16**	**LS_17**	**LS_18**	**LS_19**	**LS_20**
ROC	0.83	0.94	0.86	0.89	0.85	0.79	0.74	0.95	0.86	0.93
Weighted Mean of ROC	0.8891									

In addition to the accuracy of the simulation, this some unavoidable uncertainty still exists in this article. Although the LCA database adopted in this article pertains to the world, some calculations of the environmental indicators of food production are mostly based on the European and American food production chains, which probably are different from actual Chinese situations. Therefore, a local LCA database should be established to solve the problems in China. Meanwhile, this research assumed the change rate of the domestic food volume of imports and exports to be consistent with those of aggregate food demand. However, changes in food trade may not be as smooth as changes in aggregate demand [57,58], and we will explore this issue in future work.

4.3. Effects of Dietary Change

Dietary change is one of the great challenges facing humanity because of the tight link between diets, the environment, and human health. In recent years, economic development and urbanization have led to an increasing trend in the consumption of animal food in China [30]. However, producing animal food emits more greenhouse gases, consumes more water, and occupies more natural capital [11,55]. For example, the CF, WF, and EF from producing one kilogram of beef is about 43.49, 146.23, and 11.67 times that of one kilogram of tomato, respectively [51]. Additionally, an expansion of livestock would bring about climate change, species extinctions, and even some new diseases [59–64]. Moreover, more grassland and forest systems will avoid being reclaimed or grazed if the Chinese widely adopt the diet recommended by the DGCR. Therefore, it is necessary to enhance residents' awareness of the environmental benefits of a balanced diet, especially urban residents who consume 50% more meat than rural residents in China [39].

This situation is now capable of being improved because more people are in pursuit of a balanced diet. Ignoring the effects of dietary change on the land system may misjudge future patterns in land management and environment conditions [12]. Hence, the government should take more measures on the demand side of the diet to achieve sustainability for agriculture, animal husbandry, and environment [65,66].

5. Conclusions

In this article, we assessed how dietary changes might influence future land systems in China. Patterns of land system changes from 2010 to 2030 under two dietary change scenarios were simulated, and the spatiotemporal distributions of the landscape, land use intensity, and livestock density were analyzed quantitatively. Subsequently, CF, WF, and EF were used to evaluate the lifecycle environmental impacts of land system change produced by dietary change in China. The major findings are summarized as follows.

1. The demand for food dominated by dietary change determines the land use intensity of the land system. If dietary change maintains the current trend, land use intensity of the cropland system would also increase, and many forest systems and grassland systems would be reclaimed as cropland systems. Moreover, the development intensity and scope of animal husbandry would increase significantly. In contrast, both land use intensity and livestock density decrease under a balanced scenario.
2. The results also show that land system change has a strong spatial heterogeneity. Under the trend scenario, the intensification and expansion of agriculture and animal husbandry are mainly distributed in Northwest China, North China, and Northeast China, where the intensity of cropland was low in the past and the ecosystem was relatively fragile. Moreover, the carbon footprint, water footprint, and ecological footprint from food production would have sharp increases. In contrast, land systems in these places are more stable under the balanced scenario. Additionally, the intensity of the cropland system in Southwest China and Central China would reduce, and livestock density would also decrease in East China and South China.
3. The dramatic divergence of the two dietary change scenarios reveals that adopting a balanced diet could offer considerable environmental benefits. Owing to the lower demand for food, popularizing more balanced diets contributes to cutting down land use intensity, thereby moving natural systems away from the intensification and expansion of agriculture and animal husbandry, lowering lifecycle environmental impacts, and implementing a policy of returning croplands to grasslands and forests in China. Therefore, popularizing balanced diets could be a win–win for human health and environmental sustainability.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/11/19/5196/s1, Table S1: The areas of each land system type under the two scenarios in the period from 2010 to 2030. Table S2: The CF, WF, and EF from food production of each land system type. Table S3: The changes in the gross of CF, WF, and EF from food production under two scenarios in the period from 2010 to 2030.

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