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A Study on Optimal Agroforestry Planting Patterns in the Buffer Zone of World Natural Heritage Sites

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Abstract: As the protection layer of world natural heritage sites, the buffer zone should enable economic development while protecting the environment. To carry out agricultural activities in the buffer zone, it is necessary to balance agricultural development and environmental protection. In addition, the development of agroforestry has the benefits of developing the economy, maintaining biodiversity, and protecting the environment. In order to promote the coordination of environmental protection and community economic development, it is particularly important to scientifically select agroforestry planting patterns in the buffer zone of world natural heritage sites. This study utilized a mixed-methods research approach that included qualitative and quantitative research. Taking the buffer zone of Shibing Karst Heritage Site in southern China as an example, based on the seven agroforestry planting patterns surveyed in the buffer zone of the world natural heritage site, the four dimensions of net output value, carbon emission, environmental cost, and comprehensive livelihood score of different agroforestry planting patterns were calculated. The sorting scores of the values were calculated as Borda numbers. The sorting scores of the seven agroforestry planting patterns were B(A1) = 17, B(A2) = 18, B(A3) = 8, B(A4) = 8, B(A5) = 14, B(A6) = 12, and B(A7) = 7. The results showed that the priority sequence of seven agroforestry patterns was A2 > A1 > A5 > A6 > A3 = A4 > A7. A2 was the best among the seven agroforestry planting patterns, and A7 ranked last. The results can provide a quantitative evaluation basis for scientific optimization of agroforestry development planting patterns, and provide a reference for promoting the protection of world natural heritage.

Keywords: world natural heritage; protection; livelihood capital; borda count

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1. Introduction

World heritage sites constitute valuable human wealth and have outstanding universal value. Buffer zones, which serve as the protection layer of the heritage site, are closely related to the heritage site. However, the management of buffer zones often does not take into account the needs of resource exploitation by local populations [1]. The buffer zone must maintain a balance between agriculture development and protection of nature. The primary goal of the agroforestry system is to minimize resource competition and maximize ecological and economic benefits [2]. Agroforestry systems can improve environmental quality and promote biodiversity conservation [3]. Agroforestry systems are considered to be one of the most promising means to enhance land use in the buffer zone. Where there has been a history of tree crop cultivation in the vicinity of a protected area, the environment outside the boundary develops ecologically favorable characteristics for protection, and even extension, of the biological diversity of the park itself [4]. The protection of world natural heritage for agroforestry in the buffer zone can be described in terms of direct protection and indirect protection [5].

In part, the ecological integrity of a world natural heritage site depends on the connection of the wider landscape [6]. The environmental degradation around a world natural heritage site reduces its area and increases edge effects, which are an important determinant of the persistence of biodiversity [7]. Some of these edge effects can lead to habitat changes [8]. The degradation that occurs around the protected area can easily lead to similar degradation within its territory [9]. The agroforestry system is the best choice to improve biodiversity and ecosystem services in degraded areas [10]. Although agroforestry systems are unlikely to provide a habitat for specialist forest species that require large tracts of undisturbed forest or woodland, they can support biodiversity in otherwise open landscapes and allow movement of species between habitat remnants, and buffer protected areas from the impacts of more intensive systems [11]. Humans may have negative effects on the environment due to inappropriate agricultural activities. The negative effects on the environment are rarely considered in the profitability analysis of agricultural systems because of the lack of market value [12]. Tiezzi studied agricultural chemical pollution and calculated the loss of nitrogen, phosphorus, and potassium [13]. Pretty et al. studied environmental problems and measured the health costs caused by modern agriculture [14]. However, these studies are mainly at the macro level, and examine environmental externalities at a regional or country scale. There is no comparative study on the environmental costs between specific agroforestry planting patterns. The research on the environmental cost of agroforestry is helpful for producers to realize the importance of developing agroforestry and protecting the environment.

In addition, the protection of world natural heritage is closely related to the livelihood of local residents. Muhammad investigated the sustainability of livelihoods and environmental issues in marine protected areas using structural equation models. The results showed that the improvement of residents' livelihood capital has a positive and significant impact on their attitudes towards environmental protection [15]. Residents' attitudes and behaviors towards local resources and the environment are mainly affected by their livelihoods in protected areas. If the development interests of the local people are marginalized for a long period of time, they may adopt actions which are detrimental to the goal of protection [16]. The implementation of conservation without considering the economy often leads to local resistance [17]. If the local people lack livelihood capital, they may undertake behaviors that are not conducive to the ecology [18]. Conservation programs are effective and sustainable only if they have the dual objective of improving local livelihoods and ecological conditions [19]. Therefore, the protection of world natural heritage must take into account the livelihoods of local residents. Agroforestry is an important livelihood strategy for the rural population [20], which can help farmers alleviate livelihood problems and improve livelihood flexibility [21]. Farmers' livelihoods have been greatly improved through the implementation of agroforestry, which can provide many benefits such as food, fodder, and fuelwood [22,23]. Agroforestry increases species diversity, ensures economic returns, and maintains farmers' livelihoods [24]. The livelihood capital of farmers is the foundation of poverty eradication, environmental protection, and sustainable use of natural resources in the protected areas [5,25]. Most of these studies examined the differences between agroforestry and non-agroforestry systems at a large scale, and did not specifically focus on the different agroforestry planting patterns.

This study explored the economic benefits, environmental impacts, and social benefits of different agroforestry planting patterns. The comprehensive benefits of different agroforestry planting patterns were measured in terms of the four dimensions of net output, carbon emissions, environmental costs, and livelihood capital. These were ranked by the Borda Count. As one of the most well-known aggregating methods, the Borda Count was introduced by Borda in the late 1700s [26]. This methodology has been applied as a data merging method for consolidating ranking results [27].

To the best of our knowledge, there are no systematic papers specifically devoted to a study regarding net output, carbon emissions, environmental costs, and livelihood capital of different agroforestry planting patterns. In this paper, we highlight three aspects. In terms of content, there are numerous studies about agroforestry livelihoods [20,21,24]. Most studies compare the difference between agroforestry and non-agroforestry. However, there is no specific livelihood research that studies different agroforestry planting patterns. In the current research, we studied the livelihood capital of different agroforestry planting patterns. This is of significance for improving the livelihoods of farmers. In terms of research directions, the ecological-economic trade-offs of agroforestry have rarely been analyzed simultaneously [28]. In this study, we took the ecological and economic benefits of specific agroforestry planting patterns into consideration. In terms of methods, the Borda Count has been widely used in the decision-making field. However, there is no specific decision-making research that studies different agroforestry planting patterns. We ranked the seven planting patterns based on the Borda Count. This provided a decision-making method for farmers to select agroforestry planting patterns. The following three questions were answered: First, what method is used to evaluate the impact of agroforestry planting patterns on heritage sites? Second, which indexes are more suitable to analyze the impact of agroforestry on farmers' livelihood capital? Third, through the study of different agroforestry planting patterns, which agroforestry planting patterns are more beneficial to heritage protection?

2. Materials and Methods

2.1. Research Area

Shibing Karst is located in eastern Guizhou Province in southwestern China and lies in the slope transitional zone from the eastern edge of Yunnan-Guizhou Plateau to the low mountains and hills of western Hunan Province (Figure 1). This is the transition zone between the second and third stage of Chinese terrain, which is in the range of 29°05′49″ to 27°13′59″ east longitude [29]. The core area is spread over 102.8 km^2, the buffer zone extends over 180.15 km^2, and the total area is 282.95 km^2. The area is within a mid-subtropical monsoon humid climate zone, with obvious typical mountain humidity characteristics. The annual average temperature is 14–16 °C. The annual average sunshine hours are 1200 h. The annual precipitation is 1060–1200 mm, with uneven seasonal distribution, occurring mainly from April to September, and which accounts for 75% of the annual precipitation. The average annual humidity is 80%, and the frost-free period is 255–294 d. Extensive native forest vegetation and diverse ecosystems have been conserved and maintained in the area, with a forest cover of 94%. There are settlements in the buffer zone and human activities are relatively widespread. The local residents are mainly engaged in agricultural production. The main crops cultivated are flue-cured tobacco, corn, and rice [30].

According to the planting situation in Shibing study area, seven main agroforestry planting patterns in Shibing study area were selected (Figure 2). These were numbered as A1 plum (*Prunus salicina* Lindl) + rape (*Brassica chinensis* L. var. *oleifera* Makino et Namot); A2 plum (*Prunus salicina* Lindl) + passion fruit (*Passiflora coerulea* L.); A3 pear (*Pyrus sorotina*) + potato (*Solanum tuberosum* L.); A4 pear (*Pyrus sorotina*) + corn (*Zea mays* L.); A5 pear (*Pyrus sorotina*) + bletilla (*Buddleja alternifolia*); A6 pear (*Pyrus sorotina*) + polygonatum (*Polygonatum sibiricum*); and A7 tobacco (*Nicotiana tabacum* L.) + rape (*Brassica chinensis* L. var. *oleifera* Makino et Namot). The four planting patterns of A1, A2, A3, and A4 are mainly located in Baiduo Village, Shibing County. The three planting patterns of A5, A6, and A7 are mainly in Shiqiao Village, Shibing County.

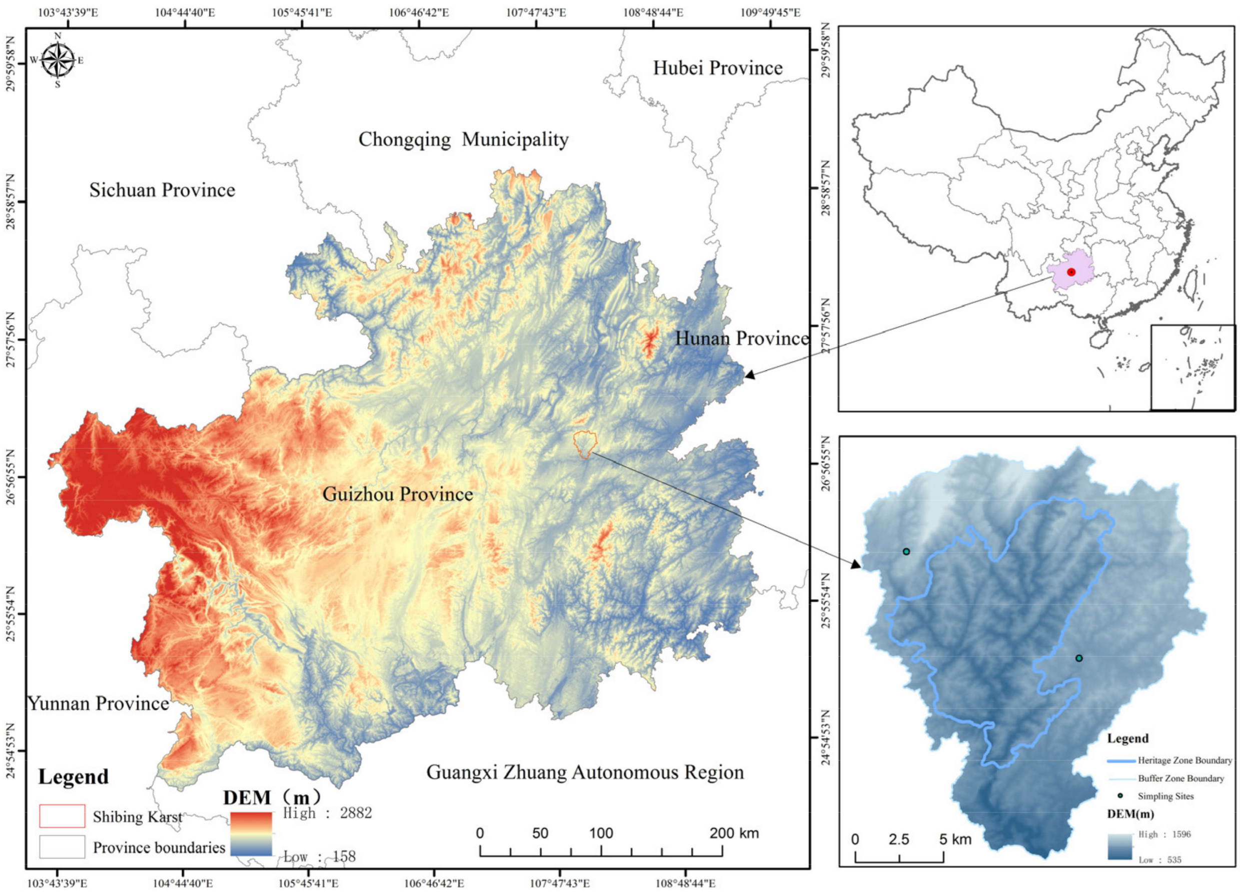

Figure 1. Location of the research area.

Figure 2. Agroforestry planting patterns.

2.2. Methods

The Borda Count was originally an election method in which voters ranked multiple candidates according to their preferences. Subsequently, this method was used in group decision making, and each decision maker would rank each option relative to other options, instead of only voting on the options he liked [31]. This method has good characteristics for the optimal scheme [32]. It can guide decision makers to choose a widely agreed optimal scheme [33]. Borda advocated the following method: each agent ranks all the alternatives, and gives integer marks to each of them: the highest score, which coincides with the number of alternatives, to the most preferred; one point less to the next alternative; and so on, in a descending manner, until the least preferred is reached, which is given only one point [34]. The Borda Count has been used widely, not only in voting, but also to maximize social welfare [35]. Therefore, by calculating the product economic value, carbon emissions, environmental costs, and livelihood asset scores of different agroforestry patterns, the Borda Count was used to comprehensively rank the seven agroforestry planting patterns in the Shibing study area. This provides a quantitative evaluation method for optimizing different agroforestry planting patterns in the buffer zone of heritage sites.

Let the set of schemes $V = \{V_1, V_2, \ldots, V_j\}$. The index set is $C = \{C_1, C_2, \ldots, C_n\}$. The elements in V are arranged in linear order according to the index C_n. The sequence $L = L_1, L_2, \ldots, L_n$, then $B(V_j)$ is the Borda number of V_j.

$$(V_j) = \sum_{i=1}^{m} B_i(V_j) \tag{1}$$

The analysis of environmental negative externalities of agroforestry production is mainly carried out from two aspects: the physiological growth process of crops and the materials used by human beings to regulate the growth of crops. The use of chemical substances causes carbon emissions, soil pollution, water pollution, air pollution, etc., which are the main sources of external environmental costs. The use of pesticides, fertilizers, and agricultural films in the production process of agroforestry has a negative impact on the environment, which can be measured by carbon emissions and environmental costs.

The carbon emission calculation formula is:

$$E = \sum_{i=1}^{n} (Ti \cdot \delta i) \tag{2}$$

where E is the total carbon emission and T_i is the amount of carbon emission sources. δ_i is the carbon emission coefficient (Table 1).

Table 1. Carbon emission coefficients.

Carbon Source	Coefficient	Reference
fertilizer (kg/kg)	0.8956	Oak Ridge National Laboratory [36]
pesticide (kg/kg)	4.9341	Oak Ridge National Laboratory [36]
agricultural films (kg/kg)	5.1800	Institute of Resources and Ecological Environment, Nanjing Agricultural University [37]

The environmental cost calculation formula is:

$$CP = \sum_{i=1}^{n} (Qi \cdot MECi) \tag{3}$$

where CP is the total environmental cost, Qi is the chemical substance input, i represents the agroforestry planting patterns. MEC is the environmental cost per kilogram of chemical inputs. The MEC of chemical fertilizers is 0.08368, the MEC of pesticides is 3.9874, and the MEC of agricultural film is 3.5891 [38,39].

2.3. Data Collection and Calculation

This study utilized a mixed-methods research approach that included 87 quantitative household surveys and key information interviews of the relevant responsible persons of the government. The research team conducted the surveys in Baiduo and Shiqiao villages in Shibing County from 12 April to 18 April 2021. The two villages in the Shibing research area were selected for the following reasons: first, most areas of the two villages are located in the buffer zone and belong to the research scope; second, the development of agroforestry in the two villages is significant; third, both villages are the research areas of the research teams, who have worked in both villages and are familiar with their situation. The investigation process was as follows. First, the relevant responsible persons of the government were interviewed about the situation of the villages. This provided the basic information regarding the villages, including population distribution, labor force, crop distribution, etc. Second, the sampling survey was conducted in the two villages by random sampling. Fifty-six households were surveyed in Baiduo village and 31 households in Shiqiao Village. A total of 87 households were surveyed. The main contents of the survey were: net output of agroforestry (Figure 3); the amount of fertilizer, pesticide, and agricultural film (Table 2); and the indicators of livelihood capital of villagers (Table 3). Third, the information was recalled and sorted via on-site recording and listening to audio recordings.

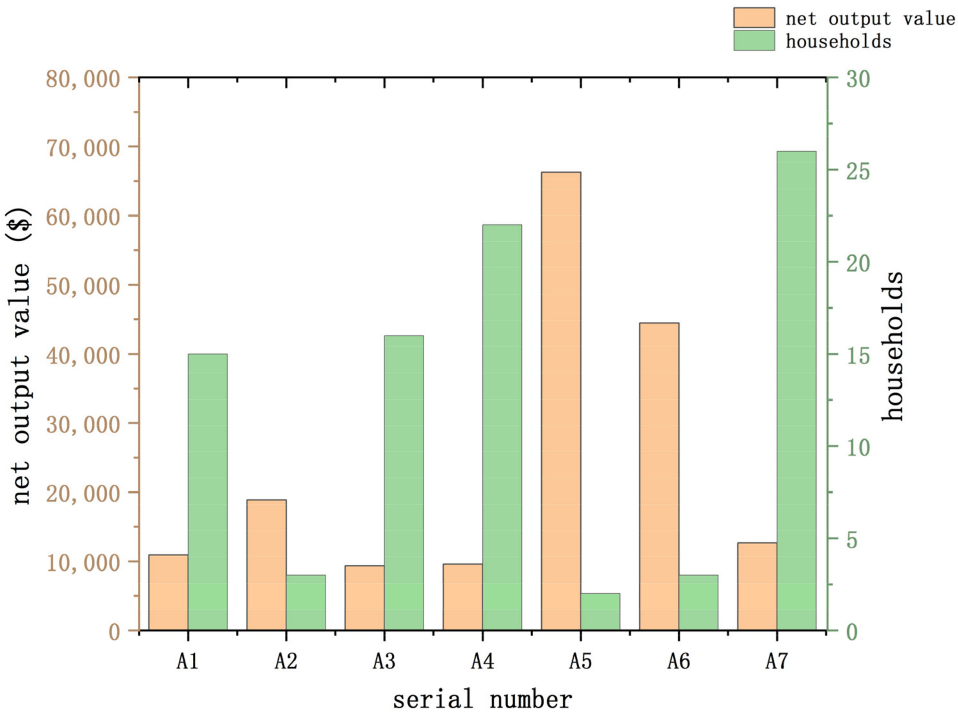

Figure 3. Output value and number of households.

Table 2. Inputs of agricultural supplies.

Serial Number	Patterns	Fertilizer Inputs (kg)	Pesticide Inputs (kg)	Agricultural Films Inputs (kg)
A1	plum + rape	546.67	15.67	0.00
A2	plum + passion fruit	516.67	28.30	0.00
A3	pear + potato	456.25	25.94	13.50
A4	pear + corn	536.36	32.95	15.14
A5	pear + bletilla	600.00	75.00	30.00
A6	pear + polygonatum	675.00	75.00	30.00
A7	tobacco + rape	1153.85	45.00	43.85

Table 3. Livelihood asset indicators.

Asset	Quantitative Indicator
Natural Capital	Size of farmland (area) The quality of farmland (level) Crop diversity (the number of)
Physical Capital	Road conditions (level) Distance of public facilities from home (how far) The traffic tools (the number of) Agricultural machinery (the number of)
Human Capital	Labor (the number of) The degree of education (level) Family health (yes or no)
Social Capital	Political influence (yes or no) Social cost (level) Participation in cooperatives (yes or no)
Financial Capital	Paid work (yes or no) Bank deposits (the number of) Livestock (the number of)

2.3.1. Estimation of Net Output Value

Two main methods are adopted to estimate the net output value. These are the direct inquiry method and the cost-profit calculation method. The direct inquiry method is applicable to a situation in which farmers have a better understanding of net output value. The net output value of each agroforestry planting pattern can be calculated by averaging the net output value that we obtained via the survey. The cost-profit method is suitable for farmers who do not understand the concept of net value. In this case, the researchers helped famers calculate the net output value of each household. Then, the net output value of agroforestry planting patterns was averaged.

2.3.2. Estimation of Agricultural Supplies

Modern agricultural management is facing the challenge of providing sustained high-quality yields without harming the environment [40]. According to the survey of farmers, the inputs of agricultural supplies of each farmer are different. If some farmer's crops are infected with insect pests and need medical treatment, the amount of pesticide used by the farmer will increase. Therefore, Table 2 lists the application status of each agroforestry pattern, which is an average value for each farmer under normal conditions. For example, A1 and A2 do not need agricultural film in the production process, so the amount of agricultural film used is zero.

2.3.3. Livelihood Asset

Agroforestry plays a significant role in increasing agricultural productivity and contributes to sustainable rural livelihoods [41]. Some studies have examined the local management and sustainability of agroforestry practices, constraints encountered, and contributions to household income [42,43]. Hideyuki showed that home gardens are ecologically, socially, and economically diversified, and demonstrated their benefits to human well-being as ecosystem services [44]. The livelihoods of farmers have been greatly improved through agroforestry because they have greater access to food, feed, and fuelwood, which creates more opportunities to obtain livelihood capital. The capital status of farmers is not only the basis for understanding the livelihood strategies adopted and the risky environment in which they are located, but also the entry point for policy intervention in natural resource management and environmental protection.

Rural livelihoods consist of five forms of capital: human capital, social capital, financial capital, natural capital, and physical capital [45] The seven planting patterns of capital overlap and can be converted into each other, including different planting patterns of assets required for sustainable livelihoods. According to the actual situation of the study area, combined with scholars' relevant research on livelihood capital [18,25], the indicators of the capital of rural household livelihood capital were determined. Three indicators were selected for quantification of natural capital: farmland size, farmland quality grade, and crop diversity. The indicators of physical capital are road conditions, distances from homes of public facilities, vehicles, and agricultural appliances. Human capital includes the number of labor forces, the education level of the head of the household, and the health of the family. Financial capital indicators include paid jobs, the amount of bank deposits and the number of livestock. Social capital indicators include political influence, social cost, and whether to participate in cooperatives (Table 3).

In order to make it easier to calculate, the survey results for each of the indicator questions were converted so that the answer choices for questions were on a scale of 0 to 1. The results were assigned as 1 to represent the most desirable response, and 0 to represent the least desirable response. For example, for the question about whether any household member participated in cooperatives, any "yes" answer was assigned as 1 and any "no" answer was assigned as 0. Questions with multiple answer choices (such as Likert scale-type questions) were assigned values within the range of 0 to 1 (for example, 0, 0.25, 0.75, 1) [25]. After the survey results for each question and respondent were converted to fit a scale of 0 to 1, composite asset indexes were able to be created. To create the composite asset index for each of the five livelihood capital assets, the individual indicator scores were averaged for each household [46]. Finally, the asset score of the agroforestry pattern was obtained by a composite asset index.

3. Results

3.1. Net Output Value

Based on the interviews with farmers and the estimation of the net output value of each agroforestry planting pattern, the net output value and number of households of agroforestry planting patterns was obtained (Figure 3). Among the seven agroforestry planting patterns, the A5 and A6 planting patterns have the highest net output value, and both planting patterns contain Chinese herbal medicine. Regarding A5, Bletilla is a Chinese herbal medicine, and its price is relatively high. Regarding A6, the price of Polygonatum is lower than that of Bletilla so its net output value is lower. The cultivation of Bletilla and Polygonatum requires high technical management, so the number of planting households is small. There are five of these households in Shibing County, all of which are relatives of each other. The A3 and A4 planting patterns have the lowest net output value. In these two patterns, potatoes and corn are both food crops, and their prices are low.

3.2. Carbon Emissions

The total carbon emissions of different agroforestry planting patterns are different (Figure 4). The carbon emissions of A7 (1482.57 kg) are the highest. Compared with other planting patterns, the agricultural film carbon emissions of A7 are highest (227.14 kg). In the early period of tobacco growing, agricultural film needs to be covered, and agricultural film is used in large quantities. The tobacco is fertilized several times during the growth process and pesticides are used to prevent pests and diseases. Due to the extensive use of chemical fertilizers, pesticides, and agricultural film, the total carbon emissions of the pattern are large. The total carbon emissions of A1 (566.91 kg) and A2 (602.36 kg) are lower. The two planting patterns do not require agricultural film, so the carbon emissions of agricultural film are zero. The use of chemical fertilizers and pesticides is lower than that of other planting patterns, so the total carbon emissions of the two planting patterns are lower.

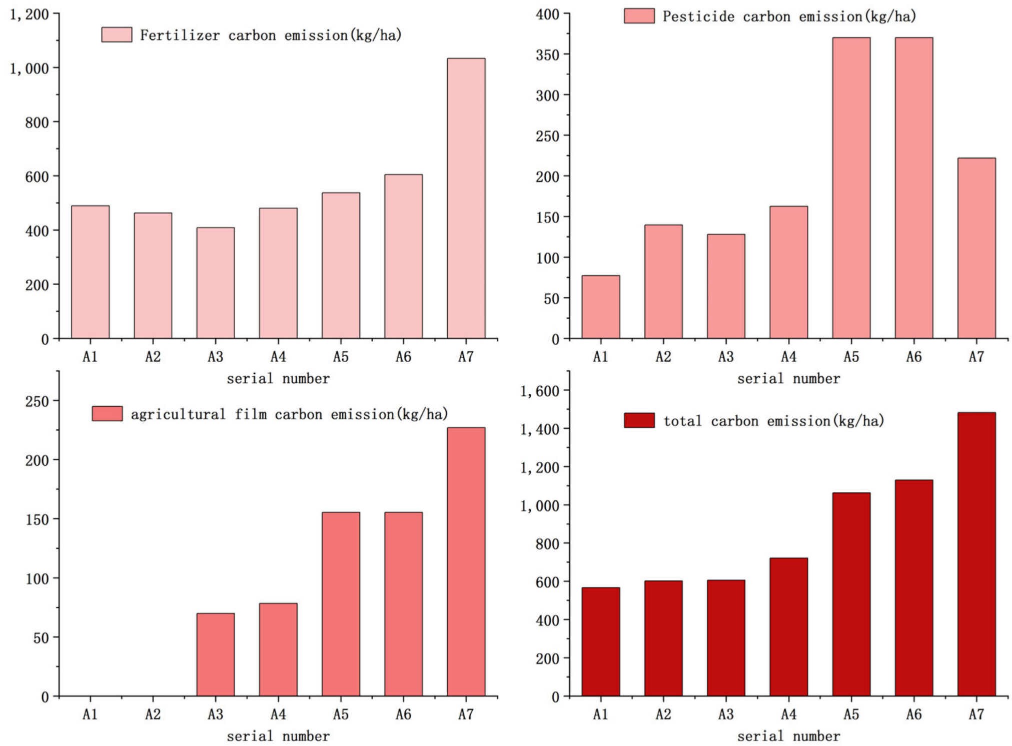

Figure 4. Carbon emissions of different agroforestry planting patterns.

3.3. Environmental Costs

The total environmental costs of different agroforestry planting patterns are different (Figure 5). The total environmental costs of the three planting patterns A5, A6, and A7 are higher because the three plants of Bletilla, Polygonatum, and tobacco all need to be covered with agricultural film. During the growth period, chemical fertilizers and pesticides need to be used. The inputs of chemical fertilizers, pesticides, and agricultural film are different. The environmental cost of A5 is USD 456.94, that of A6 is USD 463.22, and that of A7 is USD 433.38. The proportions of environmental costs of A5 are as follows: the environmental cost of chemical fertilizers is USD 50.28 (11%), the environmental cost of pesticide is USD 299.46 (65.45%), and the environmental cost of agricultural film is USD 107.82 (23.56%). Pesticide is the main source of environmental costs of this pattern (65.45%). The environmental cost of chemical fertilizers of A6 is USD 56.56 (12.19%), the environmental cost of pesticides of A6 is USD 299.46 (64.56%), and the environmental cost of agricultural film of A6 is USD 107.82 (23.24%). The input of chemical fertilizer in this pattern is slightly more than that of A5, and the inputs of pesticide and agricultural film are roughly the same. The environmental cost of chemical fertilizer of A7 is USD 100.56 (22.75%), the environmental cost of pesticide of A7 is USD 179.68 (40.65%), and the environmental cost of agricultural film of A7 is USD 161.73 (36.59%). The input of chemical fertilizer of this pattern is large, and the environmental cost of chemical fertilizer is high. Compared with other planting patterns, the input of agricultural film is the largest. The total environmental cost of A1 is the lowest (USD 108.38). The environmental costs of chemical fertilizers (USD 45.75) and pesticides (USD 62.48) are low, and the environmental cost of agricultural film is zero.

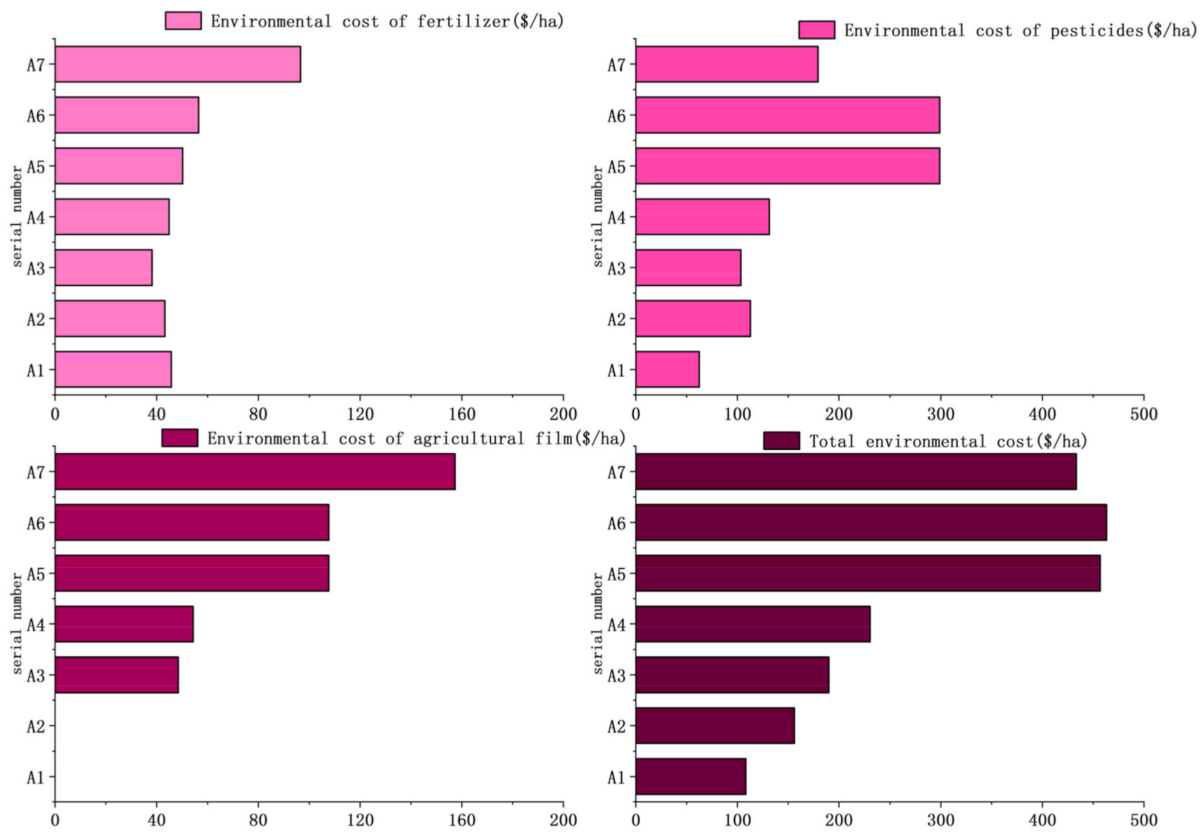

Figure 5. Environmental costs of different agroforestry planting patterns.

3.4. Livelihood Capital

Different agroforestry planting patterns have different impacts on farmers' livelihood capital. The five forms of livelihood capital in different planting patterns can be presented with a spider diagram (Figure 6). The average livelihood capital is 0.4217. The livelihood capital of A6 is highest (0.4986), and second is A5 (0.4729). The pattern with the lowest livelihood capital is A3 (0.3753) (Figure 7).

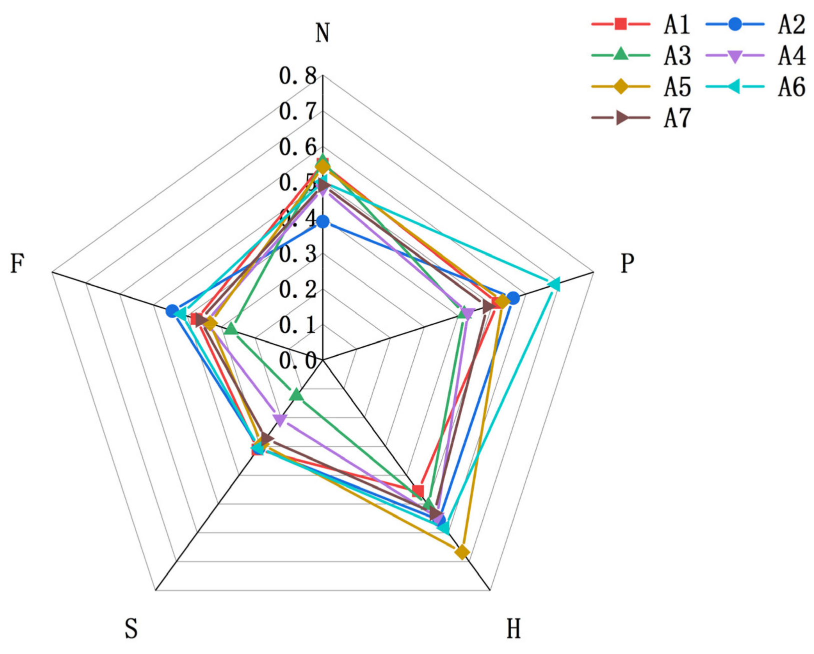

Figure 6. The five forms of livelihood capital of different planting patterns.

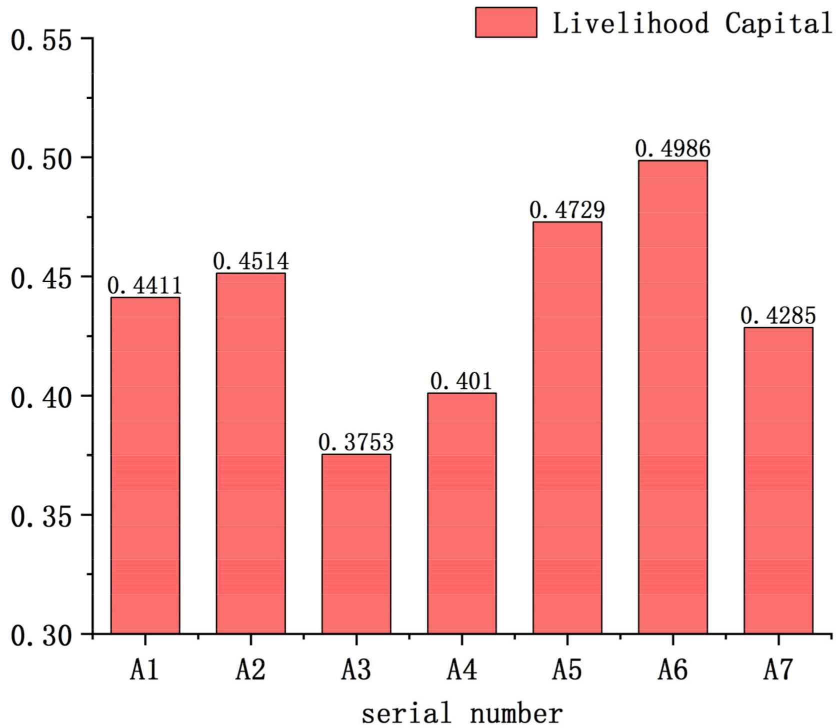

Figure 7. The livelihood capital of different planting patterns.

Among the human asset scores, the agroforestry pattern with the highest score is A5 (0.6667), followed by A6 (0.5833). Farmers in the two planting patterns have a high level of education and good health. The agroforestry pattern with the lowest score is A1 (0.4556). In this agroforestry pattern, the education level of the head of household is low (0.4). Among the physical asset scores, the highest-scoring agroforestry pattern is A6 (0.6875), and the lowest-scoring agroforestry pattern is A3 (0.4180). The number of vehicles and agricultural machinery in A3 is lower than that of A6. Among the natural asset score, A2 (0.3889) has the lowest score, and A3 (0.5573) has the highest score, with a range of 0.1684. The asset scores are very close, and the gap is small. Among the financial asset scores, the score of A2 (0.4444) is highest, and the score of A3 (0.2708) is lowest. The net output value of A2 is higher than that of A3. Among the social asset scores, the score of A1 (0.3111) is highest, and the score of A3 (0.125) is lowest. In A1, the number of farmers participating in a cooperative is more than that of A3. Overall, the average social financial score is only 0.2290, which is a low score.

3.5. Ranking and Optimization of Different Agroforestry Planting Patterns

In order to determine the most suitable pattern of agroforestry in the Shibing World Natural Heritage Site, according to the four dimensions of the net output value, carbon emissions, environmental cost, and livelihood asset score of different agroforestry patterns (Table 4), the Borda Count was used to sort the different agroforestry planting patterns to determine the preferred pattern.

The values of the four dimensions of net output value, carbon emissions, environmental costs, and livelihood asset scores of different agroforestry planting patterns were sorted to obtain four sequences, which were recorded as L1, L2, L3 and L4. Then, the net output of the seven agroforestry planting patterns was ranked as L1: A5 > A6 > A2 > A7 > A1 > A4 > A3 (ranking from large to small). Similarly, the carbon emissions of the seven agroforestry planting patterns were ranked as L2: A1 < A2 < A3 < A4 < A5 < A6 < A7 (ranking from small to large). The environmental costs of the seven agroforestry planting patterns were ranked as L3: A1 < A2 < A3 < A4 < A7 < A5 < A6 (ranking from small to large). The livelihood asset scores of the seven agroforestry planting patterns were ranked as L4: A6 > A5 > A2 > A1 > A7 > A4 > A3 (ranking from large to small).

Table 4. The values of the four dimensions.

Serial Number	Net Output Value ($)	Carbon Emission (kg)	Environmental Cost ($)	Livelihood Capital
A1	10,909.99	566.91	108.23	0.4411
A2	18,854.92	602.36	156.08	0.4514
A3	9351.60	606.54	190.07	0.3753
A4	9601.26	721.37	230.61	0.401
A5	66,280.99	1062.82	456.94	0.4729
A6	44,480.85	1129.99	463.22	0.4986
A7	12,633.12	1482.57	433.38	0.4285

According to Formula (1), using the Borda Count, the Borda numbers of A1 in the four sequences were calculated to be $B_{L1}(A1) = 2$, $B_{L2}(A1) = 6$, $B_{L3}(A1) = 6$, $B_{L4}(A1) = 3$; therefore, the score of A1 is B(A1) = 17. Similarly, B(A2) = 18, B(A3) = 8, B(A4) = 8, B(A5) = 14, B(A6) = 12, B(A7) = 7. Therefore, the preferred order of the seven agroforestry planting patterns is:

$$A2 > A1 > A5 > A6 > A3 = A4 > A7$$

According to the ranking, A2 has the best performance among the seven agroforestry planting patterns, A7 is ranked last, and A3 and A4 share fifth place. The results show that the Borda Count was used to comprehensively consider the four dimensions, which are net output value, carbon emissions, environmental costs, and livelihood asset scores. The optimal pattern of agroforestry in the buffer zone of the Shibing Karst World Natural Heritage Site is A2. The most unsuitable pattern is A7.

4. Discussion

4.1. Consideration of Research Directions and Methods

In terms of methods, Shen et al. evaluated the development modes of community settlements in Taining World Natural Heritage Site using the sequence relation analysis method [47]. Through the establishment of primary indicators and secondary indicators, the index layer is constructed and the weights are set. In this study, the index weights were not distinguished because the weights of the four dimensions could not be determined. The weight needs to be determined by experts after research and consideration. Vallejo et al. assessed the changes in the location and scope of agricultural land use, visually interpreted very high-resolution images, and analyzed the ecological and agricultural areas of interest [48]. This method is suitable for intensive agriculture. In the current study, the agroforestry planting patterns were not highly distinguishable from the image, and the coverage area is small. This method is therefore not appropriate, but it can be used as a reference for other land use planting patterns with a high degree of distinction and a large area.

In terms of research directions, Rosa-Schleich et al. identified 1926 articles through meta-analysis [28]. They believed that although ecological-economic trade-offs are essential to incorporate biodiversity into agricultural production, the agroforestry practices are rarely analyzed simultaneously. Zou et al. evaluated ecosystem services for typical land-use patterns and compared the ecological and economic benefits of seven typical agroforestry planting patterns [49,50]. A diversified agricultural system may provide farmers with a means to combine high ecological benefits with high economic benefits. This also confirms the significance of the analysis in the current study of the practice of agroforestry from the two aspects of ecological and economic benefits. Therefore, in this study, we took the ecological and economic benefits of specific agroforestry planting patterns into consideration, ranked different agroforestry planting patterns, and selected more suitable agroforestry planting patterns. This provided a decision-making method for farmers when selecting agroforestry planting patterns. By sorting the various indicators of different agroforestry planting patterns, the effectiveness of the agroforestry planting patterns can be predicted.

4.2. Consideration of Environmental Indicators

In the development of agroforestry, the environment is affected due to the input of agricultural materials such as chemical fertilizers, pesticides, and agricultural films. The sources of carbon emissions include fertilizers, pesticides, agricultural films, and agricultural machinery fuels [51,52]. However, the agroforestry planting patterns considered in this study are not intensive and agricultural machinery is not used. This study did not consider the carbon emissions of fuel. Due to the different field management approaches of different agroforestry planting patterns, the impacts on the environment are different. It is necessary to highlight the differences between different agroforestry planting patterns. The different impacts on the environment of crops with agricultural film and crops without agricultural films should be considered. Furthermore, for crops that are highly prone to diseases and insect pests, more pesticides need to be sprayed.

4.3. Analysis on the Livelihood of Agroforestry

Nautiyal et al. analyzed the differences between simultaneous agroforestry, sequential agroforestry, home gardens, and community forests [53]. They concluded that the present policy of treating forests and agriculture as closed and independent ecological or production systems needs to be replaced by an integrated land use policy. Quandt illustrated the effectiveness of agroforestry in building livelihood resilience for agricultural households and found that the average livelihood composite asset index for households with agroforestry was 0.440, and that without agroforestry was 0.400 [25]. It is common to study the classification of agroforestry systems, but no specific livelihood research has examined different agroforestry planting patterns. The current study assessed livelihoods and examined the household livelihoods of farmers under different agroforestry planting patterns. This represents a supplement to and improvement of the research of Quandt.

4.4. Deficiencies and Prospects

4.4.1. Index and Weight

Regarding the selection of different agroforestry planting patterns, many aspects need to be considered. We only selected the four dimensions of net output, carbon emissions, environmental costs, and livelihood scores. Thus, there was no consideration of index weights, and the analysis may therefore be incomplete. In a follow-up study, appropriate indexes and weights for the study area should be set, so that the results will be closer to the actual situation of the study area.

4.4.2. Data Error

There were a number of possible data errors in this study. First, the data were gathered from interviews with farmers. Although the actual situation of farmers can be determined, there may be artificial errors as a result of cognitive barriers in the communications with the farmers. Second, due to the vigilance of farmers, the interview content may not be precise enough. For example, when investigating the financial assets of households, some households may have been unwilling to disclose their economic situation. In this case, the investigator can only make an estimate according to the external conditions of the households, such as the degree of luxury of the house and the number of electrical appliances. This process will result in data errors, which can only be carefully overcome as much as possible. Third, the data obtained in this paper only reflect the situation in the study area. Because of the differences in different regions, the calculation results would be different.

4.4.3. Outlook

A future aim should be to further strengthen the basic research on the impact mechanism of agroforestry and environment, especially in the specific process of the interaction between different agroforestry planting patterns and the environment; for example, the impact of different agroforestry planting patterns on biodiversity. In response to different purposes, different evaluation methods and indexes need to be set, and should be paid greater attention. For instance, the use biodiversity evaluation indexes in natural reserves for biodiversity protection should be increased. In protected areas with aesthetic value, more indexes that reflect the beauty of the landscape should be used.

5. Conclusions

The buffer zone of a world natural heritage sites is a protection layer. The agricultural activities in the buffer zone affect the value of the heritage site. This study used the buffer zone of a world natural heritage site as an example, and examined the agroforestry planting patterns. In agricultural activities, agricultural materials such as fertilizers, pesticides, and agricultural films affect the local atmosphere, water, and soil. By calculating carbon emissions and environmental costs, the impact of different agroforestry planting patterns on the environment was measured. Furthermore, the four dimensions of net output value, carbon emissions, environmental costs, and livelihood asset scores were calculated and ranked. The ranking scores were represented by Borda numbers. The scores of the seven agroforestry planting patterns were: B(A1) = 17, B(A2) = 18, B(A3) = 8, B(A4) = 8, B(A5) = 14, B(A6) = 12, and B(A7) = 7. The results showed that the priority sequence of the seven agroforestry planting patterns was A2 > A1 > A5 > A6 > A3 = A4 > A7. According to the ranking, considering the four dimensions, the A2 pattern was the best among the seven agroforestry patterns, and the A7 pattern ranked last. In consideration of the protection of world natural heritage, the planting scale of the better-performing agroforestry pattern can be appropriately increased based on the actual situation of the region, and the use of the poorly performing agroforestry pattern can be reduced. This also provides a new reference method for predicting whether the new agroforestry pattern is suitable for development. The data in this study were mainly derived from interviews with farmers, and there may be errors. Moreover, there was no consideration of the weights of the four dimensions of net output, carbon emissions, environmental costs, and livelihood scores. As a result, the analysis may be incomplete. For future research, appropriate weights for the study area should be set, so that the results will be closer to the actual situation of the study area.

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References

1. Atsri, H.; Abotsi, K.E.; Kokou, K.; Dendi, D.; Segniagbeto, G.H.; Fa, J.E.; Luiselli, L. Ecological challenges for the buffer zone management of a West African National Park. *J. Environ. Plan. Manag.* **2020**, *63*, 689–709. [CrossRef]
2. Kelty, M.J. Species interactions, stand structure, and productivity in agroforestry systems. In *Silvicultural Basis for Agroforestry Systems*; CRC: Boca Raton, FL, USA, 2000; pp. 183–205.
3. Amaral, Y.T.; dos Santos, E.M.; Ribeiro, M.C.; Barreto, L. Landscape structural analysis of the Lençóis Maranhenses national park: Implications for conservation. *J. Nat. Conserv.* **2019**, *51*, 125725. [CrossRef]
4. Murniati; Garrity, D.P.; Gintings, A.N. The contribution of agroforestry systems to reducing farmers' dependence on the resources of adjacent national parks: A case study from Sumatra, Indonesia. *Agrofor. Syst.* **2001**, *52*, 171–183. [CrossRef]
5. Awazi, N.P.; Quandt, A. Livelihood resilience to environmental changes in areas of Kenya and Cameroon: A comparative analysis. *Clim. Chang.* **2021**, *165*, 1–17. [CrossRef]
6. Kormos, C.F.; Bertzky, B.; Jaeger, T.; Shi, Y.; Badman, T.; Hilty, J.A.; Mackey, B.G.; Mittermeier, R.A.; Locke, H.; Osipova, E.; et al. A wilderness approach under the world heritage convention. *Conserv. Lett.* **2016**, *9*, 228–235. [CrossRef]
7. Newmark, W.D. Isolation of African protected areas. *Front. Ecol. Environ.* **2008**, *6*, 321–328. [CrossRef]
8. Hansen, A.J.; DeFries, R. Ecological mechanisms linking protected areas to surrounding lands. *Ecol. Appl.* **2007**, *17*, 974–988. [CrossRef]
9. Laurance, W.F.; Useche, D.C.; Rendeiro, J.; Kalka, M.; Bradshaw, C.; Sloan, S.; Laurance, S.; Campbell, M.; Abernethy, K.; Alvarez, P.; et al. Averting biodiversity collapse in tropical forest protected areas. *Nat. Cell Biol.* **2012**, *489*, 290–294. [CrossRef]
10. Santos, P.Z.F.; Crouzeilles, R.; Sansevero, J. Can agroforestry systems enhance biodiversity and ecosystem service provision in agricultural landscapes? A meta-analysis for the Brazilian Atlantic Forest. *For. Ecol. Manag.* **2019**, *433*, 140–145. [CrossRef]
11. Smith, J.; Pearce, B.D.; Wolfe, M.S. Reconciling productivity with protection of the environment: Is temperate agroforestry the answer? *Renew. Agric. Food Syst.* **2013**, *28*, 80–92. [CrossRef]
12. De Jalón, S.G.; Graves, A.; Palma, J.; Williams, A.; Upson, M.; Burgess, P. Modelling and valuing the environmental impacts of arable, forestry and agroforestry systems: A case study. *Agrofor. Syst.* **2018**, *92*, 1059–1073. [CrossRef]
13. Tiezzi, S. External effects of agricultural production in Italy and environmental accounting. *Environ. Resour. Econ.* **1999**, *13*, 459–472. [CrossRef]
14. Pretty, J.; Brett, C.; Gee, D.; Hine, R.; Mason, C.; Morison, J.; Rayment, M.; Van Der Bijl, G.; Dobbs, T. Policy Challenges and priorities for internalizing the externalities of modern agriculture. *J. Environ. Plan. Manag.* **2001**, *44*, 263–283. [CrossRef]
15. Muhammed, N.; Masum, F.H.; Hossain, M.; Chakma, S.; Oesten, G. Economic dependence of rural people on homestead forestry in Mymensingh, Bangladesh. *J. For. Res.* **2013**, *24*, 591–597. [CrossRef]
16. Stone, M.T.; Nyaupane, G.P. Ecotourism influence on community needs and the functions of protected areas: A systems thinking approach. *J. Ecotourism* **2016**, *16*, 222–246. [CrossRef]
17. Conradin, K.; Hammer, T. Making the most of world natural heritage—Linking conservation and sustainable regional development? *Sustainability* **2016**, *8*, 323. [CrossRef]
18. Erenstein, O.; Hellin, J.; Chandna, P. Poverty mapping based on livelihood assets: A meso-level application in the Indo-Gangetic Plains, India. *Appl. Geogr.* **2010**, *30*, 112–125. [CrossRef]
19. Naughton-Treves, L.; Holland, M.B.; Brandon, K. The role of protected areas in conserving biodiversity and sustaining local livelihoods. *Annu. Rev. Environ. Resour.* **2005**, *30*, 219–252. [CrossRef]
20. Gebru, B.M.; Wang, S.W.; Kim, S.J.; Lee, W.-K. Socio-Ecological niche and factors affecting agroforestry practice adoption in different agroecologies of Southern Tigray, Ethiopia. *Sustainability* **2019**, *11*, 3729. [CrossRef]
21. Thorlakson, T.; Neufeldt, H. Reducing subsistence farmers' vulnerability to climate change: Evaluating the potential contribu-tions of agroforestry in western Kenya. *Agric. Food Secur.* **2012**, *1*, 15. [CrossRef]
22. Sanchez, P.A. Soil fertility and hunger in Africa. *Science* **2002**, *295*, 2019–2020. [CrossRef] [PubMed]
23. Scherr, S.J.; Franzel, S. Trees on the farm: Assessing the adoption potential of agroforestry practices in Africa. *Forestry* **2003**, *76*, 182.
24. Hanif, A.; Roy, R.M.; Bari, S.; Ray, P.C.; Rahman, S.; Hasan, F. Livelihood improvements through agroforestry: Evidence from Northern Bangladesh. *Small Scale For.* **2018**, *17*, 505–522. [CrossRef]
25. Quandt, A. Measuring livelihood resilience: The household livelihood resilience approach (HLRA). *World Dev.* **2018**, *107*, 253–263. [CrossRef]
26. Ecer, F. A consolidated MCDM framework for performance assessment of battery electric vehicles based on ranking strategies. *Renew. Sustain. Energy Rev.* **2021**, *143*, 110916. [CrossRef]
27. Wu, W.-W. Beyond Travel & Tourism competitiveness ranking using DEA, GST, ANN and Borda count. *Expert Syst. Appl.* **2011**, *38*, 12974–12982. [CrossRef]
28. Rosa-Schleich, J.; Loos, J.; Mußhoff, O.; Tscharntke, T. Ecological-economic trade-offs of Diversified Farming Systems—A review. *Ecol. Econ.* **2019**, *160*, 251–263. [CrossRef]
29. Liu, Q.; Gu, Z.; Lu, Y.; Xiao, S.; Li, G. Weathering processes of the dolomite in Shibing (Guizhou) and formation of collapse and stone peaks. *Environ. Earth Sci.* **2015**, *74*, 1823–1831. [CrossRef]
30. Bai, Y.; He, Q.; Liu, Z.; Wu, Z.; Xie, S. Soil nutrient variation impacted by ecological restoration in the different lithological karst area, Shibing, China. *Glob. Ecol. Conserv.* **2021**, *25*, e01399. [CrossRef]

31. Dummett, M. The Borda count and agenda manipulation. *Soc. Choice Welf.* **1998**, *15*, 289–296. [CrossRef]
32. García-Lapresta, J.L.; Martínez-Panero, M.; Meneses, L. Defining the Borda count in a linguistic decision making context. *Inf. Sci.* **2009**, *179*, 2309–2316. [CrossRef]
33. Qiu, Z.; Dosskey, M.G.; Kang, Y. Choosing between alternative placement strategies for conservation buffers using Borda count. *Landsc. Urban Plan.* **2016**, *153*, 66–73. [CrossRef]
34. García-Lapresta, J.L.; Martínez-Panero, M. Borda count versus approval voting: A fuzzy approach. *Public Choice* **2002**, *112*, 167–184. [CrossRef]
35. Neveling, M.; Rothe, J. Control complexity in Borda elections: Solving all open cases of offline control and some cases of online control. *Artif. Intell.* **2021**, *298*, 103508. [CrossRef]
36. West, T.; Marland, G. A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: Comparing tillage practices in the United States. *Agric. Ecosyst. Environ.* **2002**, *91*, 217–232. [CrossRef]
37. Wu, F.; Li, L.; Zhang, H.; Chen, F. Effects of conservation tillage on net carbon flux from farmland ecosystems. *Chin. J. Ecol.* **2007**, *26*, 4.
38. Song, M. Analysis and assessment on environmental costs of arable land utilization: A Ccase of Wuhan city. *China Popul. Resour. Environ.* **2013**, *23*, 76–83. [CrossRef]
39. Xiang, P.; Huang, H.; Yan, H.; Zhou, Y.; Zheng, H.; Huang, X. Environmental cost of rice production in Dongting Lake area of Hunan Province. *Ying Yong Sheng Tai Xue Bao J. Appl. Ecol.* **2005**, *16*, 2187–2193.
40. Reganold, J.P.; Wachter, J.M. Organic agriculture in the twenty-first century. *Nat. Plants* **2016**, *2*, 15221. [CrossRef] [PubMed]
41. Zerihun, M. Agroforestry practices in livelihood improvement in the eastern cape province of South Africa. *Sustainability* **2021**, *13*, 8477. [CrossRef]
42. Kiyani, P.; Andoh, J.; Lee, Y.; Lee, D.K. Benefits and challenges of agroforestry adoption: A case of Musebeya sector, Nyamagabe District in southern province of Rwanda. *For. Sci. Technol.* **2017**, *13*, 174–180. [CrossRef]
43. Renganathan, S. Educating the Orang Asli children: Exploring indigenous children's practices and experiences in schools. *J. Educ. Res.* **2016**, *109*, 275–285. [CrossRef]
44. Mohri, H.; Lahoti, S.; Saito, O.; Mahalingam, A.; Gunatilleke, N.; Irham; Hoang, V.T.; Hitinayake, G.; Takeuchi, K.; Herath, S. Assessment of ecosystem services in homegarden systems in Indonesia, Sri Lanka, and Vietnam. *Ecosyst. Serv.* **2013**, *5*, 124–136. [CrossRef]
45. Rakodi, C. A Capital assets framework for analysing household livelihood strategies: Implications for policy. *Dev. Policy Rev.* **1999**, *17*, 315–342. [CrossRef]
46. Campbell, B.; Sayer, J.A.; Frost, P.; Vermeulen, S.; Ruiz-Pérez, M.; Cunningham, T.; Prabhu, R. Assessing the performance of natural resource systems. *Conserv. Ecol.* **2002**, *5*, 22. [CrossRef]
47. SShen, Y.; Liu, D.; Luo, Y.; Huang, M.; Lan, S. Research on the evaluation model of community settlements development modes of Fujian taining world natural heritage site of "China Danxia". *Chin. Landsc. Archit.* **2020**, *36*, 29–33. [CrossRef]
48. Vallejo, M.; Ramírez, M.I.; Reyes-González, A.; López-Sánchez, J.G.; Casas, A. Agroforestry systems of the Tehuacán-Cuicatlán Valley: Land use for biocultural diversity conservation. *Land* **2019**, *8*, 24. [CrossRef]
49. Zou, Z.; Zeng, F.; Wang, K.; Zeng, Z.; Zhao, L.; Du, H.; Zhang, F.; Zhang, H. Emergy and economic evaluation of seven typical agroforestry planting patterns in the Karst region of Southwest China. *Forests* **2019**, *10*, 138. [CrossRef]
50. Zou, Z.; Zeng, F.; Wang, K.; Zeng, Z.; Tang, H.; Zhang, H. Evaluation and tradeoff analysis of ecosystem service for typical land-use patterns in the Karst region of Southwest China. *Forests* **2020**, *11*, 451. [CrossRef]
51. Ma, Q.; Wang, Y. Evaluating the externally environmental cost of cotton production in Xinjiang. *J. Arid. Land Resour. Environ.* **2015**, *29*, 64–68. [CrossRef]
52. Wang, J. *The Ecological Value and Environmental Cost Research of Agroforestry System in Southern Xinjiang—Take the Typical Area as an Example*; Tarim University: Xinjiang, China, 2016.
53. Nautiyal, S.; Maikhuri, R.K.; Semwal, R.L.; Rao, K.S.; Saxena, K.G. Agroforestry systems in the rural landscape—A case study in Garhwal Himalaya, India. *Agrofor. Syst.* **1998**, *41*, 151–165. [CrossRef]