Linking ecosystem services and economic development for optimizing land use change in the poverty areas

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ABSTRACT
For the sustainable development of human beings and society, it is important to conserve the ecosystems and alleviate poverty in the low agricultural productivity or ecologically vulnerable areas. To avoid the decrease in ecosystem services (ES) under the effects associated with reducing poverty, we need to carefully consider the relationship between land use changes and the economic development in economically poor areas. We selected the Lingqu County as our study area, which is a national impoverished county in China, and analyzed the impact of poverty alleviation efforts on the ecological and economic sustainability in the region through ES evaluation. The results showed that land use change in the Lingqu County has not changed the ES significantly during 2007–2016. The gross domestic product (GDP) growth rate (15.81%) during 2001–2016, indicates the effectiveness of the poverty alleviation efforts implemented. The rise in the index of ecological and economic relationship during 2001–2016 (from 0.2389 to 0.3629) maintains in a harmonious coordination situation. Presently, the value of ES has not been converted to market-based benefits, and therefore, it is indispensable to find a marketplace for ES (in an innovative way) to promote the high-quality sustainable development of a local economy.

Introduction
Land provides natural resources and potential ecological benefits for human beings to survive and develop. The underlying direct or indirect mechanisms may influence several ecosystem services (ES) and the consequent feedback to human beings, management, policy, and finance may have positive or negative effects (Cord et al. 2017; Bratman et al. 2019; Schirpke et al. 2019). In view of land use change, there are two types of interaction among ES: trade-offs and synergies (Alvarez and Field 2009). Trade-offs are provisioning in which one service increases as another decreases, and synergies increase or decrease simultaneously (Rodriguez et al. 2006; Dade et al. 2019). Over the past decades, anthropological activities have caused continuous land exploitation and utilization, aggravating the demand for natural resources; therefore, ES have severely deteriorated, threatening the sustainable development of the social economy and human welfare (Wohlfart et al. 2017; Cheng et al. 2018). The coordinated development of land use and ecological economy has become a focal issue globally. Moreover, land use change directly affects the interaction of ES encompassing gas regulation, food production, and landscape esthetics (Cord et al. 2017; Feng et al. 2017; Huang et al. 2019). Finding a reasonable relationship between the actual demand for economic increase and the potential environmental implications with respect to land use and its processes would contribute to achieve sustainable development goals.

China has experienced rapid economic development, reflected in its exceptional growth in GDP and becoming the world’s second-largest economy (Rodrik 2014). Land use change, however, significantly alters the supply of ES, with consequent impacts on human well-being. There is an imbalance between the supply and demand of ES, especially in poor areas (Deng et al. 2013; Quintas-Soriano et al. 2016; Wei et al. 2017; Barbier and Hochard, 2018). Additionally, the degradation of ES increases unpredictable risks and exacerbates poverty in some areas (MA, 2005; Zhan et al. 2019). Several previous studies have focused on the quantitative linkages between land use change and ES to better interpret, in a better way, the relationships between the eco-ecological systems in ecologically fragile and poor areas (Daw et al. 2015; Liu, Liang, and Hashimoto 2020). Overall, previous studies about ES and human well-being have concentrated on large scales (nations, watersheds, provinces, and cities) (Scherer et al. 2018; Hu et al. 2019; Ren and Zhou 2019; Xu et al., 2019). However, in...
In economically poor areas, the ecological and economic coupling relationship caused by land use change as a result of poverty alleviation measures from the government is yet to be investigated satisfactorily.

Alleviating global poverty and eradicating hunger in places that have low agricultural productivity are some of the greatest challenges of society (Radosavljevic et al. 2020). Poverty exacerbates the irrational use of natural resources in economically poor areas, where ecological problems result in poverty, leading to the further deterioration of the ecological environment and increasing the ecological problems of the region (Liu and Wuzhati 2013). By 2018, about 35% of the Chinese impoverished counties and 30% of the poor populations suffered from environmental degradation caused by ineffective land management, which directly affected the people’s livelihoods (Liu, Gao, and Yang 2003; Wang and Li 2019). Regions having a high degree of coupling between the ES and poor livelihoods are mainly concentrated in the western region and comparatively less in the eastern and central regions of China (Zhou, Guan, and Yuan 2018). In recent years, China has been promoting ecological civilization construction throughout the country. However, it is still crucial to verify whether poverty alleviation measures improve ecological and economic systems’ sustainability, especially in deep poverty areas.

In this study, we explore the relationship between ecology and economy in poverty areas (based on land use change); we chose Lingqu County as our study area. First, the equivalent factor method was used to analyze the impact of land use change on the value of ES from 2007 to 2016. Second, we calculated the contribution rate of three industries (primary, secondary, and tertiary industry) to analyze the change in the industrial structure and economic development. Third, we created a framework to analyze the relationship between the ecological and economic systems in the county and investigate the factors affecting the degree of eco-economic coupling and coordination. The aim of this study is to explain the consequences of poverty alleviation measures on ecological and economic sustainability and provide valid and effective suggestions for policymakers.

**Study area**

Lingqu is an economically poor county located in the Shanxi province (113°53′~114°33′E, 39°31′~39°38′N) in the northeastern region of the Loess Plateau, which lies in an agro-pastoral ecological vulnerable region. It is a mountainous area with consisting of 85.5% earth-rock mountain and an altitude of 613~2,215 m. The annual average temperature of the region is 7°C (maximum temperature is 37.3°C), while the minimum temperature is −30.7°C. The average precipitation is 432.4 mm, with rainfall mainly from June to September. The administrative area of the county is 2,732 km², and the areas of forest, grassland, and farmland are 106,600 hm², 140,452 hm², and 39,200 hm², respectively. In the county, in 1991, 159,000 of the total population (of 240,000) were poor; However, the county overcame poverty in 2019 due to the efforts of poverty alleviation measures; this was the main reason the county counted was selected to study the effects of poverty alleviation efforts. Lingqu represents a suitable case study to interpret how poverty alleviation affects ecological and economic relationships in the deep poverty areas.

**Materials and methods**

**Quantification of ecosystem service values based on LULC (land use/land cover)**

Based on LULC (land use/land cover), this study estimates the ecosystem service values (ESV) from the net primary productivity of vegetation in the Lingqu County (Xu et al. 2019a), using the method developed by Xie et al. (2015) and Li et al. (2015) (Li et al. 2015; Xie et al. 2015). The data are obtained from the Statistical Bureau of Lingqu County and field investigations from 2017 to 2018. The formula for ESV is as follows:

$$ESV = \sum_{i=1}^{n} \sum_{j=1}^{n} A_i \times V_{C_{ij}}$$

\((i = 1,2, \ldots, 7; j = 1,2, \ldots, 10,11)\)

where ESV is the ecosystem service value (yuan); \(A_i\) is the area of land use type, (hm²); \(V_{C_{ij}}\) is the coefficient of per unit area ecosystem service values.

**Analysis of the trade-offs of ecosystem service based on LULC (land use/land cover)**

Each ecosystem service is distinguished under different land use types and provides trade-offs between each pair of ES. To understand the combined effects of multiple management objectives, the ecosystem services trade-off index (EST) is used to quantify the degree of trade-offs among different types of ES (Bradford and D’Amato 2012; Wang et al. 2019), as shown in formulas (2) and (3). A positive value of EST indicates that the ecosystem services of group \(i\) are dominant in the trade-offs, while a negative value indicated the dominance of the \(ES_{1}\) (food production) group (Pan, Xu, and Wu 2013).

$$ES_{i} = \frac{ES_{i} - ES_{\min}}{ES_{\max} - ES_{\min}}$$

\(\text{where } ES_{i} \text{ is the observed value of ES type } i \text{, and } ES_{\max} \text{ and } ES_{\min} \text{ represent the maximum and minimum values of } ES_{i} \text{, respectively.} \)
\[ \text{EST} = \ln \frac{E_{S_i}}{E_{S_1}} \]  

(3)

The EST could range from negative infinity to positive infinity; a negative value indicates that the “food production” is dominant, while a positive value indicates that it is not dominant. The absolute EST value reflects the degree of the trade-offs levels (Fan et al. 2019).

**Calculation of the industrial contribution rate**

Over several past decades, multiple measures, such as organic agriculture, ecological tourism, and transformation of mining industries, have been adopted to improve human welfare in the Lingqiu County. Using the production function and a Least Squares Regression Model (using Eview10.0), we calculated the industry contribution rate for the county using equation (4) to estimate the industrial economic growth of the area from 2001 to 2016 (Biddle 2012).

\[ C_i = a_i \times \frac{l_i}{G} \]  

(4)

where \( C \) is the industry contribution rate, \( a_i \) is the elastic coefficient, \( l_i \) is the industry growth rate, \( G \) is the growth rate of GDP, and \( i \) represents the three industries (\( i = 1,2,3 \)).

We then derived the elasticity coefficient of economic growth of the tertiary industry according to the Cobb–Douglas production function (Benhabib and M. Spiegel, 1994), and the formula is as follows:

\[ \ln Y = a_0 + a_1 \ln A_1 + a_2 \ln A_2 + a_3 \ln A_3 \]  

(5)

where \( Y \) is the output of the national economy (GDP); \( A_i \) is the output of the tertiary industry; \( a_i \) is the elastic coefficient of the three industries (primary, secondary, and tertiary industry), the economic significance is that a 1% increase in the output of the \( i \) industry will lead to a total output growth of \( a_i \% \), (\( i = 1,2,3 \)). The average growth rate was calculated using the horizontal method given below:

\[ l_i = \sqrt[\frac{A_{ij}}{A_{i0}}] \]  

(6)

where \( l_i \) is the average growth rate of the three industries; \( A_i \) is the output value of the three industries; \( i \) represents the three industries (\( i = 1,2,3 \)), and \( n \) represents years from 2001 to 2016 (\( n = 1,2,3 \ldots, 15 \)).

**Calculation of trade-off coordination degree of ecological economic system**

**Indicators and the weight determination**

The eco–economic system involves many factors in nature, society, and economy. Therefore, the design of the coupling evaluation index of eco-economic system should start from two subsystems (ecological environment and economic development). According to previous studies (Wang and Wu 2012; Chen, Peng, and Xiong 2013; De Vingo et al. 2019; Reddy and Tiwari 2019), 13 indices were used in this study, including the average temperature, per capita farmland, per capita grassland, per capita forest, annual precipitation, sunshine duration, proportion of tertiary industry, proportion of primary industry, population density, energy consumption per ten thousand yuan of output value, urbanization index, and per capita disposable income in urban areas.

The principal component analysis (PCA) method is used to filter the representative indicators among many index factors. According to 80% or more of the set main component cumulative contribution rate, the component feature having a value greater than 1 is selected as the main component. The ratio of the eigenvalue corresponding to each principal component to the sum of the total eigenvalues of the extracted principal components is determined using the weight of the extracted eco–economic system evaluation (Chen, Peng, and Xiong 2013). The weights of indicators are determined from the following formula:

\[ W_{ij} = \frac{C_{ij}}{\sum_{j=1}^{m} \sum_{i=1}^{n} C_{ij}} \]  

(7)

where \( W_{ij} \) is the weight value of the \( i \) system \( j \) indicator, \( C_{ij} \) is the principal component contribution rate of the \( i \) system \( j \) index, \( m \) represents the number of subsystems, and \( n \) is the number of principal components extracted.

**Normalization of indicators**

Because each indicator has different practical significance, the unit and numerical levels are different, and each indicator needs to be standardized. The formula is as follows:

**PositiveIndices**

\[ d_{ij} = \frac{x_{ij} - x_{ij_{min}}}{x_{ij_{max}} - x_{ij_{min}}} \]  

(8)

**NegativeIndices**

\[ d_{ij} = \frac{x_{ij_{max}} - x_{ij}}{x_{ij_{max}} - x_{ij_{min}}} \]  

(9)

where \( d_{ij} \) is the value after the standardized treatment of system \( i \) index \( j \), \( x_{ij_{max}} \) and \( x_{ij_{min}} \) are the maximum and minimum values, respectively, of system \( i \) index \( j \), and \( x_{ij} \) is the initial value of system \( i \) index \( j \).

**Degree of ecological–economic trade-off coordination**

According to the principal component comprehensive model and under the premise that all indicators are selected as the main components, our study uses the variance of each principal as the weight to evaluate the eco–economic coupling system. The calculation formula is as follows:
where \( U_i \) is the synthesis function of subsystem \( i \), \( W_j \) is the weight coefficient, and \( W_{ij} \geq 0, \sum W_j = 1, j = 1, 2, 3 \ldots \).

The eco-economic system is characterized by disorder and order, which is determined by the degree of coupling between the interaction of the ecological subsystems. By extending the coupling degree model using the capacity coupling coefficient model, the coupling degree of the eco-economic system of the Lingqiu County is calculated and analyzed. Because it only involves two subsystems (ecological environment and social economy), formula 10 is adopted (Liao 1999) as follows:

\[
C = \left( \frac{U_1 \times U_2}{(aU_1 + bU_2)^2} \right)^2
\]

where \( C \) is the degree of ecological-economic trade-off coordination, \( U_i \) is the comprehensive efficacy of subsystem \( i \), and \( a = b = 0.5 \) which are the undetermined coefficients (Ma, Jin, and Liu 2013).

From this foundation, the coordination function of the eco-economic system is constructed, reflecting the overall "efficacy" and "synergy" effect of economic and ecological environment construction, while avoiding the possibility of misleading by relying solely on the judgment of the coupling degree. The function can be explained as:

\[
D = \sqrt{C \ast (aU_1 + bU_2)}
\]

where \( D \) is the system coupling coordination degree, \( a \) and \( b \) are as mentioned earlier.

Results

Ecosystem service values changes caused by land use change

The results showed that, in the Lingqiu County, the land use did not change dramatically during the past 10 years (Figure 1). Ecological land (Chen et al., 2019), including garden land, forest, grassland and water, decreased and non-ecological land, including farmland, construction land and unutilized land, increased. The farmland area increased by 410.63 hm² (from 38,806.71 hm² in 2007 to 39,217.34 hm² in 2016). The construction land increased by 280.52 hm² (from 14,083.50 hm² in 2007 to 14,364.02 hm² in 2016) mainly because of the expansion of the town and increase in urbanization. Other land use types decreased primarily by the reduction of grassland and forest. Referring to the land use types in Lingqiu County, farmland and construction land were negatively correlated to the ESV, while the rest were positively correlated. Grassland, water, forest, and garden land transformed into farmland, construction land, and unutilized land to different degrees. The transformation trend is associated with the sustainable development of a county’s ecological economy so that land use types are reconsidered in combination with the socioeconomic and ecological benefits.

In terms of the land use changes in recent years, the ESV of Lingqiu decreased slightly from 2.239 billion yuan to 2.223 billion yuan; the reduction was of 16,333 million yuan and the rate of change was 0.73%. In consideration of the impact of land use change on the ES, the increase in farmland and unutilized land accounted for a slight increase in the value of farmland ES, with an increase of 110.91 million yuan and 35,700 yuan for farmland and unutilized land, respectively. There was 190.47 million yuan decrease.

![Figure 1. Land use change of Lingqiu from 2007 to 2016. Note: Degree of land use change = \( \frac{U_p - U_f}{U_f} \times 100\% \). U_p and U_f is the primary and final time of land use, respectively; T is the research time (Li et al. 2011). FL, farmland; GAL, garden land; FOR, forest; GRL, grass land; WAT, water; CL, construction land; UL, unutilized land.](image-url)
caused by an increase in construction land areas. In addition, the values of the ES in all regions decreased, among which the water ecological value decreased the most, with a reduction of 9.469 million yuan. Overall, the total value of ES in Lingqiu County remained above 2 billion yuan (Figure 2), indicating that a slight change in land use had no significant negative impact on the whole county’s ecosystem. According to previous studies, the ecological lands could provide more indirect ES (regulating services, including GR, CR, EP, and HR; cultural services that include landscape esthetics) than non-ecological lands (Fan et al. 2019; Chen, 2020). This indicates that Lingqiu possessed many potential ecosystem services, such as the regulating and cultural services of ecological land, which could be transformed into market values because of the availability of abundant natural resources.

 Trade-offs for ecosystem services based on land use change

The benefit and trade-off magnitude of different land use and land cover types are shown in Figure 3. All kinds of ES of grassland were much higher than the other lands in Lingqiu, and the forest had the same tendency as grassland among all services. Garden land, construction land, and unutilized land offered lower ES compared with other land use types.

The correlation of the 11 types of ES indicated that food production (FP) and water supply (WS), climate regulation (CR), environment purification (EP), hydrological regulation (HR), and landscape esthetic (LA) were significantly negatively correlated ($P < 0.01$) (Table 1). Each pair of services had a trade-off relationship, and the Pearson correlation coefficients ($R$) were $-0.936, -0.845, -0.881, -0.874$, and $-0.874$, respectively. There was a negative correlation between FP and raw material production (RMP), FP and gas regulation (GR), FP and soil retention (SR), and FP and biodiversity control (BC) at $P < 0.05$. The nutrient cycle maintenance (NCM), WS, and EP were positively correlated at $P < 0.05$. There was no significant correlation between FP and NCM. In addition, other ES showed significant positive correlations at $P < 0.01$.

The EST of FP and WS, FP and CR, FP and EP, FP and HR, and FP and LA were significantly negatively correlated and are shown in Figure 4. Under different land use types, the FP of farmland occupied a dominant position than the other five service types. The performance of WS was particularly prominent, which was as the same as that observed in previous studies (Fan et al. 2019). The FP in gardens, forests, grassland, and unutilized land suffered disadvantages compared to other services. Moreover, the WS performance was particularly prominent among the land use types, which indicated that the ecological land possessed potentially higher ES. FP and the other five services showed different trade-offs between the two land use types of water and construction land. The FP dominated CR, but was dominated by other services in water. In construction land areas, CR, EP, HR, and LA were not related to FP.

Economic performance in Lingqiu County

Due to the implementation of poverty alleviation efforts, the GDP of Lingqiu increased, as revealed by the growth rate of 15.81%, indicating that the poverty alleviation efforts implemented by the government were effective. The secondary and tertiary industries that account more than the primary industry, revealed in the elastic coefficient. This showed that an increase of 1% in the output values of the primary, secondary, and tertiary industries could increase the county’s total

![Figure 2. ESV of Lingqiu from 2007 to 2016.](image-url)
Figure 3. Ecosystem services types for different land use types. Note: FP, food production; RMP, raw material production; WS, water supply; GR, gas regulation; CR, climate regulation; EP, environment purification; HR, hydrological regulation; SR, soil retention; NCM, nutrient cycle maintenance; BC, biodiversity control; LA, landscape esthetics.
GDP by 0.0654%, 0.4636% and 0.4552%, respectively. The contribution rates of the three industries displayed that the tertiary industry devoted 47.64% to economic growth, while the primary and secondary industries devoted 15.31% and 37.03%, respectively (Table 2). The contribution of primary and secondary industries to the economic growth of Lingqiu was much lower than that of the service industry. Judging from the

Table 1. Relationship between different ecosystem service types.

| - | Provisioning | Regulating | Supporting | Cultural |
|---|---|---|---|---|
| FP | RMP | WS | GR | CR | EP | HR | SR | NCM | BC | LA |
| FP | 1 | - | - | - | - | - | - | - | - | - |
| RMP | -0.796* | 1 | - | - | - | - | - | - | - | - |
| WS | -0.936** | 0.928** | 1 | - | - | - | - | - | - | - |
| GR | -0.770* | 1.000*** | 0.928** | 1 | - | - | - | - | - | - |
| CR | -0.845** | 0.991** | 0.967** | 0.992** | 1 | - | - | - | - | - |
| EP | -0.883** | 0.974** | 0.988** | 0.975** | 0.994** | 1 | - | - | - | - |
| HR | -0.974** | 0.957** | 0.989** | 0.957** | 0.980** | 0.995** | 1 | - | - | - |
| SR | -0.825* | 0.966** | 0.956** | 0.996** | 0.999** | 0.989** | 0.973** | 1 | - | - |
| NCM | -0.503 | 0.939** | 0.748* | 0.938** | 0.886** | 0.841* | 0.819* | 0.903** | 1 | - |
| BC | -0.770* | 0.994** | 0.943** | 0.994** | 0.990** | 0.982** | 0.976** | 0.992** | 0.923** | 1 |
| LA | -0.874** | 0.981** | 0.983** | 0.981** | 0.997** | 0.999** | 0.990** | 0.994** | 0.855** | 0.985** | 1 |

Note: FP is food production; RMP, raw material production; WS, water supply; GR, gas regulation; CR, climate regulation; EP, environment purification; HR, hydrological regulation; SR, soil retention; NCM, nutrient cycle maintenance; BC, biodiversity control; LA, landscape esthetics.

**Significant differences at 0.01 level of probability.
*Significant differences at 0.05 level of probability.

Figure 4. Degree of trade-offs among different pairs of ecosystem services presented by the ecosystem services trade-offs indices (EST) (A) water supply/food production, (B) climate regulation/food production, (C) environment purification/food production, and (D) landscape esthetics/food production. Note: FL, farmland; GAL, garden land; FOR, forest; GRL, grass land; WAT, water; CL, construction land; UL, unutilized land.
changes in the county’s industrial structure in the recent years, the tertiary industry has replaced the secondary industry as the leading industry for economic development in Lingqiu County. Because it is a state-level poverty-stricken county in an ecologically fragile area and due to the poor topographical conditions of the region, the agricultural development in Lingqiu is limited. However, the traditional pollution industrial enterprises shut down or transformed due to the environmental protection policy issued by the government with respect to natural resources protection since 2010. Despite the changes in the industrial structure, the growth in the GDP of the county directly indicates that the proposed change could promote economic development.

**Table 2. Performance of three types of industries (primary, secondary, and tertiary industry) and GDP (gross domestic product) in Lingqiu County.**

| Indicators       | Primary industry | Secondary industry | Tertiary industry | GDP     |
|------------------|------------------|--------------------|-------------------|---------|
| Rate of growth   | 0.3701           | 0.1262             | 0.1654            | 0.1581  |
| Elastic coefficient | 0.0654           | 0.4636             | 0.4552            | –       |
| Rate of contribution | 0.1531           | 0.3703             | 0.4764            | –       |

After the fluctuating period 2010–2012, the synthesis function gradually reached the stage of stable development of ecological economy (2013–2016). At the same time, the industrial structure of Lingqiu County changed significantly, and the tertiary industry replaced the secondary industry as the pillar industry for the county’s economic development.

The system coupling degree (C) and the system coupling coordination degree (D) displayed the same change trend, with a gradual increase from 2007 to 2010 that was followed by a slight decrease from 2011 to 2012. An initial increasing trend that was followed by a stable trend was displayed from 2012 to 2016; the coupling degree of the system was maintained at 0.47 (Figure 5), and the coordination degree of the system was 0.36. In summary, the ecological and economic system of Lingqiu County developed from a low to a moderate level during the past 10 years, showing an improved interpretation of the relationship between ecological and economic systems. However, because Lingqiu is a state-level poverty-stricken county, the ecological resources owned by the county were not fully developed, as reflected by the low eco–economic coupling and coordination levels.

**Discussion and conclusion**

Relationship about the mechanisms of ecosystem services trade-offs can provide valuable information, which may influence managers to make decision so that improve human well-being through and use management (Carvalho–Santos et al., 2016; Wang et al. 2019). Land use changes are influenced by human activities that arise from the human demand for food production, spiritual enjoyment, and increasing economic income. At the same time, land use can affect the ESs with respect to its structure, composition, pattern, and intensity (Locher–Krause et al., 2017). Under government guidance, land use changes using different kinds of measures for reducing poverty are beneficial for eco–economic relationship development. Considering human activities for eco–economic sustainability, Shao et al. (2020) indicated that agricultural research investments could directly restrain farmland expansion to prevent land degradation, resulting in an increasing yield and improving ESs (Shao et al. 2020). The Green for Grain Project (GFGP), REDD+ (reducing emissions from deforestation and forest degradation) and some payment for ecosystem services can not only improve human well-being, but also be conducive to environmental protection (Salzman et al. 2018).

Agriculture, agro-processing industry and tourism have been highly integrated in the past decade based on the “Agriculture + traveling” approach, which combines vast fields, ecological villages, circular sustainable concepts, and agriculture civilization in Lingqiu. It connects the county’s beautiful scenic
spots, cultural relics, organic communities, and characteristic villages along the Tanghe River to build a large scenic area covering nearly 100 km$^2$ of more than 20 rural tourist attractions; this includes an ancient architecture tour, landscape tour, organic tour, rural tour, Lantern Festival tour, Festival tour, red tour, and general aviation tour, along with other attractions offered by rural tourism brands. Most examples shown in Table 2 are summarized as “government + company + cooperative (poor households)” and “company + farmer” management modes. The modes not only improve the GDP of Lingqiu but also help poor households to overcome poverty without any negative effects on the environment. The experiences of Lingqiu are listed in Table 3.

Although Xie’s equivalent factor method is a mature and widespread method to quantify ecosystem service values based on land use change (Tolessa, Senbeta, and

Table 3. Industry developed experiences of Lingqiu in the past 10 years.

| Items                                       | Examples                                                                 |
|---------------------------------------------|--------------------------------------------------------------------------|
| Landscap management of farmland             | Rice planting and fish farming. Beiquan village invests 5 million for rearing rainbow trout and sturgeon with 40 acres land and 23 fishponds. It is the largest farming sightseeing base in the north of Shanxi province. |
| Manage rural areas as scenic spots          | Peony planting. Liuke township plants 2200 acres peony, 1600 acres for viewing, which attracts a lot of visitors from outside of Lingqiu. |
|                                             | Daylily planting. There are 1 million acres of daylilies planted and managed together in Lingqiu County (involving 25 villages, 14 cooperatives, and 4 companies). |
|                                             | Ten thousand acres of orchard. This project involves 13 villages with 1507 poor persons and invests 2.5 billion yuan, which improves per capital income by land transfer, working in the farmland, and traveling. |
| Commercialize agricultural activities       | Chehe organic community. It is the first and largest organic community of Lingqiu County which includes organic restaurants, valley parks, and snow paradise attracting 80,000 people each year for enjoying natural scenery and experiencing planting. The system coupling coordination degree increased from 0.345 (2010) to 0.699 (2016). |
|                                             | Cheng touhui organic community. Based on advantaged ecological resources and traffic location, the community develops leisure vacation. The tourism health industry cover the unique original ecological ancient villages, pastoral, canyons, and mountains as carriers. |
|                                             | Beiquan organic community. The cooperative takes the operation mode of “company + farmer,” building grand culture and constructing 40 containers for outdoor camp. Meanwhile, “Lotus festival” and theatrical performances on each Saturday attract a lot of people travelers. Villagers transform their house as homestay and open restaurant to improve income. |
|                                             | Huata organic community. The community creates a folklore characteristic village based on the rich humanities and folklore advantages, while planting trees and flowers on nearly 338 acres. The ecological folklore exhibition hall and fresh agricultural products are the biggest attractions for consumers. |
|                                             | Agricultural museum. The folklore museum includes traditional handicraft workshop, mill, wine workshop, and smithy show factors of production and livelihood; people learn more about the agricultural production process through the visit experience. |
|                                             | Agricultural activities. Peasant sports meeting, theatrical performances, fitness shows and all kinds of celebrated festival attracts ten thousand visitors come from Beijing, Taiyuan, Datong, and Hebei province, which increases the local’s income and promotes the construction of spiritual civilization. |
|                                             | Homestays. Chehe, Long gugou, and other 5 villages have constructed homestay project and pay attention to grand building. These homestays cover accommodation, research, and agricultural civilization experience, which increases income and improves the villages’ appearance. |
Kidane 2017; Dade et al. 2019; Zhao et al. 2020), there are some uncertainties about the methods we used and indicators we chose that may affect the results of this study. We made adjustments in the localization parameter using Xie’s method. Even then, the prices of crops for parameter adjustment and some other prices were influenced by the market, and large area production would lead to a reduced price in the long run when the supply will exceed the demand (Fang, Huang, and Leung 2018; Cui et al. 2019). In addition, with respect to the indicators of the ecological subsystem and that were chosen through PCA, there was no evidence to demonstrate that the indicators of the ecological and economic subsystems were irrelevant. Multiple studies have indicated that ecological and economic indicators exist interactions. For instance, industrial growth is correlated with soil pollution, water consumption, and GDP (Conrad and Cassar 2014; Du and Sun 2017). However, we have verified the precision and feasibility of each subsystem using the KMO (Kaiser–Meyer–Olkin) test, which demonstrates that the results of this study are scientific.

The interaction between ecological protection and poverty eradication is a global challenge to reach sustainable development goals. Currently, China is greatly concerned for the ecological and economic relationships in the poor areas with respect to the implementation of poverty alleviation measures. Lingqiu, which is a deep poverty county and relied on traditional agriculture and coal industry in the past, has gradually adopted new ways of economic development, such as organic agriculture and eco–tourism, for poverty alleviation. These measures have changed the industrial structure; the tertiary industry has replaced the secondary industry as the leading pillar of poor areas to develop the local economy. The relationship between the ecological and economic system had a positive correlation during 2007–2016, although was still at a low-level coordination stage. Under the government policy guidance adopted for economic development, land use change has no negative impact on ecosystem services. However, many potential ES values and abundant natural resources in Lingqiu have not been adequately exploited. It is worth mentioning that ecological protection and economic development are indispensable for sustainability in the course of implementing poverty alleviation measures.

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## Appendix A Weight of eco–economic system

| Subsystem | Indicators | Weight of subsystem | Weight |
|------------|------------|---------------------|--------|
| Eco–environment system | Per capital farmland | 0.5 | 0.086 |
| | Per capital grassland | | 0.103 |
| | Per capital forest | | 0.085 |
| | Annual precipitation | | 0.070 |
| | Sunshine duration | | 0.110 |
| | Annual temperature | | 0.045 |
| Socioeconomic system | Proportion of tertiary industry GDP | 0.5 | 0.002 |
| | Proportion of primary industry | | 0.003 |
| | Population density | | 0.093 |
| | Energy consumption per ten thousand yuan of output value | | 0.152 |
| | Urbanization index | | 0.091 |
| | Urban per capita net income | | 0.154 |
| | | | 0.005 |