

## 1. Methods

### FoPIA:

The framework of FoPIA has been described in Figure 1. It was conducted in three phases:

- (1) Preparation phase. We conducted the preparation workshop with transdisciplinary experts, communicated regional land use problems, driving forces and land management and policies. Drafted local LUFs and associated assessment indicators would be prepared for the next phase.
- (2) Participatory evaluation. The second workshop contains four parts. The first part we set down the LUFs and indicators. The second part is a paper-based assessment. With two rounds of assessment and discussion, we obtained the weights of LUFs in terms of their importance for the study site region from 0 (not important) to 5 (extremely important), and if developed as usual, the impacts on local LUFs in the next 10 years has been evaluated by scores between -3 (most negative impacts) to 3 (most positive impacts). In the third part, we assessed the relationship of local land-use types and land-use functions act as the foundation for the visualization of the land-use assessment results in the agent base model. The fourth part provides further suggestions for researchers to do a depth field survey, including choosing the specific study site to make the samples more scientific.
- (3) Analysis of the results followed by the preparation of recommendations. The final phase is to share and discuss the results with local experts and researchers, and provide recommendations. Detailed process in FoPIA has been explained in 2018 by Xue and Zhen (Xue & Zhen 2018). The number of stakeholders for FoPIA workshops were designed to be manageable and effective in the range of 10-15 (Morris et al. 2011). The principle for experts in workshops is transdisciplinary, experienced in local land management, especially for the second workshop which undertakes the main definition and assessment work. We carried out the first preparation workshop in September 2015 with 10 policymakers (Wang & Zhen 2017), with at least 8 years of local work experience. The second workshop was held in May 2017, with 5 policymakers and 5 researchers who were all experts on regional land use and the local participants had at least 9 years of work experience in this field (Xue & Zhen 2018).

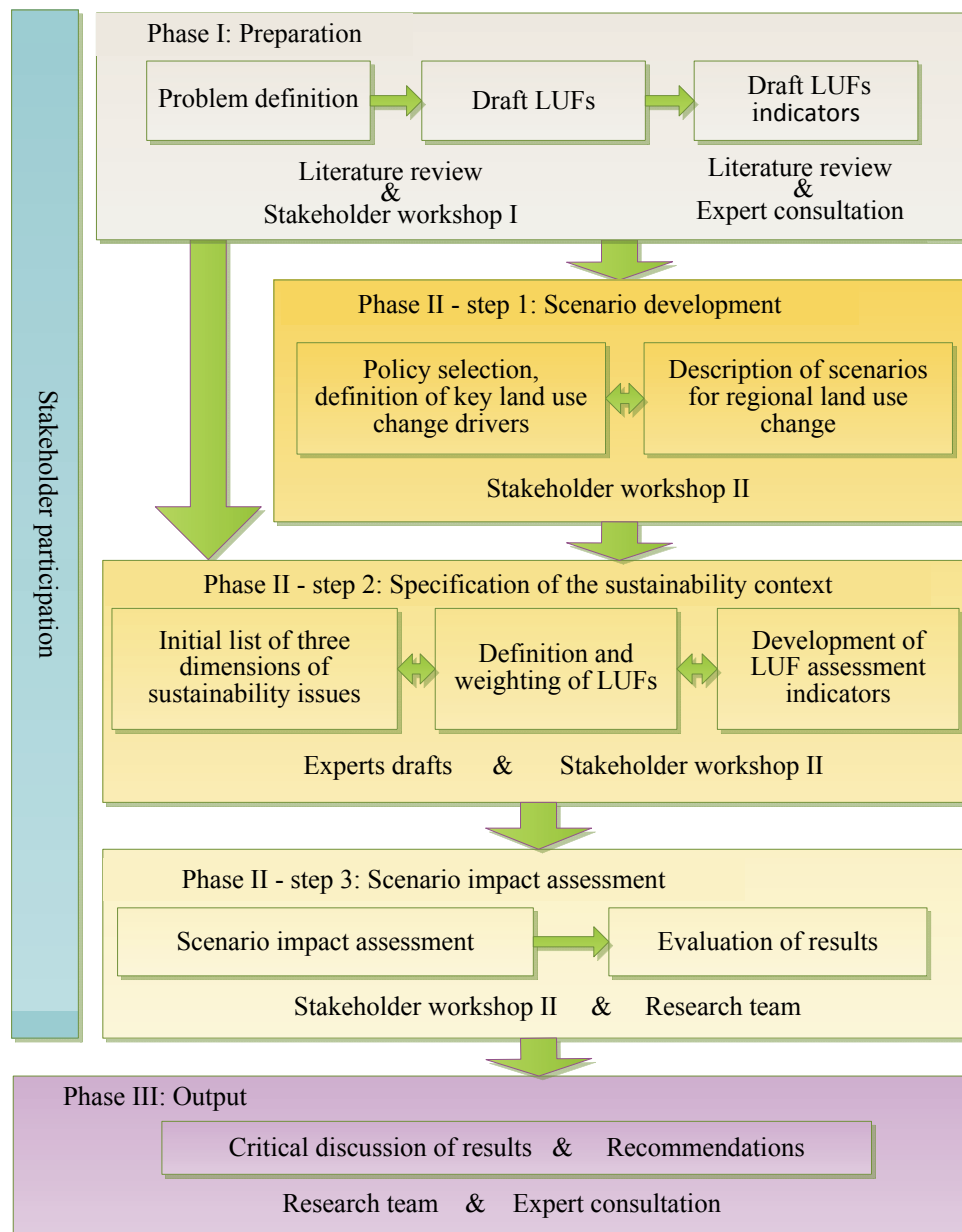


Figure 1. FoPIA framework

### Agent based-model

The model consists of four sub-models with four kinds of agents. Sub-models including individual status transferring sub-model, households' classification sub-model, spatial environment distribution sub-model and households' farmland-use decisions sub-model. Agents are individuals, households, household group, and government. The interface of the agent-based model is in Figure 2 and developed with Java language and RePast simulation platform.

#### (1) Sub-models

##### *Individual status transferring sub-model*

The individual agent behaviours include birthing, educating, farming, migrant working, retiring and dying. Individual status would change with each passing year.

#### *Households' classification sub-model*

According to the household economic sources and the household livelihood demand for farmland and non-agricultural labourers, it would be divided into different groups, present group classifications are subsidy-dependent, pure-farming, part-farming, non-farming and pure-outworking groups.

#### *Spatial environment distribution sub-model*

This sub-model is designed to describe farmland quality. For example, when households choose to plant at reduced scales, they will rent out or abandon farmland plots with inferior qualities. The quality factors of land would be initialized with remote sensing data.

#### *Households' farmland use decisions sub-model*

Farmland-use decision behaviours of the household groups include renting out, renting in, and abandonment of farmland. The households within a group have similar farmland-use behaviours. The percent of each type of household who abandoned or transferred their farmland are extracted by field survey data.

### (2) Agents

The individual agent refers to the family members of a household. The household agent is comprised of individual agents, and the corresponding relationship between the household agent and the individual agent is one-to-many. Households in the same households' group would prefer similar land-use decision-making. Government agents would mainly have macroscopic activation, for example, making rules that land above 25 degrees has to be transferred into forest land.

### (3) Simulation scope and hypothesis

We tried to conduct the simulation of land-use functions under the context of development, as usual, and make the hypothesis that land-use efficiency and abandonment of agricultural land would continue to follow current trends. The resolution for spatial data is 1 square kilometer. The meteorological data and land cover and land change data was provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (<http://www.resdc.cn/>).

The simulate year is from 2015 to 2025, in accordance with experts evaluation in the FoPIA.

(4) From land use change to LUFs change

Through the households' farmland-use decisions sub-model, land use will change. Different land-use types have different contributions to LUFs. According to the matrix of land-use types and LUFs in FoPIA, we embed LUFs into land-use types in this model. The evaluation results of LUFs change would also reflect on the running results map from this model.

**2. LUFs and indicators**

Table 1. Land-use functions and indicators in Guyuan.

Dimension		Land use functions	Regional relevance	Indicators
Economic	ECO1	Residential or non-land-based activities	Construction land, and especially residential land, to meet the basic needs of farmers	Percentage of construction land
	ECO2	Infrastructure	For remote rural areas, the road infrastructure strongly influences the potential for economic development	Density and quality of the transportation network
	ECO3	Land-based production	Provide a basic income for farmers	The output value of primary agricultural and forest industries
Social	SOC1	Provision of work	Basic and traditional forms of employment for farmers	The proportion of agricultural employees
	SOC2	Quality of life	The satisfaction of farmers with their land	Per capita public green space
	SOC3	Food security	Local farmers would not abandon land because it was necessary to ensure that they received a sufficient quantity and quality of food	Per capita grain output
Environmental	ENV1	Provision of abiotic resources	Water and soil are both essential in this semi-arid area	Per capita water resources
	ENV2	Provision of biotic resources	Vegetation cover and diversity indicates an improved environment in this semi-arid region	Vegetation cover of forests and grasses
	ENV3	Maintenance of ecosystem processes	Undisturbed land is the basis for a local environment-friendly life	Soil conservation

Source: Framework for Participatory Impact Assessment (FoPIA) workshop, 2017.

### 3. Contribution rate of land-use types to LUFs

Dimension	LUFs	Cultivated land	Forest	Grassland	Body of water	Construction land	Unused land
Economic	Residential or non-land-based activities	2.86	17.14	10.00	0.00	86.43	11.43
	Infrastructure	11.43	12.86	3.57	12.86	81.43	20.00
	Land-based production	84.71	65.71	55.00	24.29	21.43	12.14
Social	Provision of work	65.71	52.86	42.86	20.71	62.86	7.14
	Quality of life	64.29	69.29	59.29	60.00	64.29	14.29
	Food security	87.86	30.00	27.86	24.29	7.14	11.43
Environmental	Provision of abiotic resources	61.43	77.86	60.71	71.43	23.57	19.29
	Provision of biotic resources	59.29	77.14	61.43	60.71	10.71	11.71
	Maintenance of ecosystem processes	56.43	81.43	59.29	70.00	22.14	18.14

### 4. Questionnaire for household survey

**Supplementary material**

**Number:** \_\_\_\_\_ **Interviewer:** \_\_\_\_\_ **Date:** \_\_\_\_\_ **Location:** \_\_\_\_\_ **City** \_\_\_\_\_ **County** \_\_\_\_\_ **Village** \_\_\_\_\_

**Household questionnaire for Land-Use Functions in Guyuan, China**

**I. Basic information**

1. Basic information of households:

**Name of householder:** \_\_\_\_\_ **Tel:** \_\_\_\_\_

	Gender	Relationship with householder	Age	Nation	Education Level	Occupation 1	Location	Occupation 2	Location	Health condition	Insurance	Insurance fee per year	How long stay out of the village per year	Where to live	Why	
1	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					1 Household income per year?
2	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					
3	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					
4	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					2How long have you lived in the village?
5	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					
6	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					
7	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					3If moved here several years ago, then why?
8	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					
9	<input type="checkbox"/> M <input type="checkbox"/> F			<input type="checkbox"/> Han <input type="checkbox"/> Hui <input type="checkbox"/> _____						<input type="checkbox"/> Good <input type="checkbox"/> General <input type="checkbox"/> Bad	<input type="checkbox"/> Medical <input type="checkbox"/> Social <input type="checkbox"/> Others					
Notes	M:male F:female	1=Householder 2=Spouse 3=Children 4=Grandchildren 5=Grandparents 6=Parents 7=Sisters/brothers 8=Others			1=None 2-Primary school 3-Junior school 4-Senior school 5-University	1=Plant 2=Cultivation (livestock) 3=Work part-time 4=Student 5=None 6=Other	1=Village 2=Beyond village 3= Beyond county 4= Beyond province 5= Beyond country	1=Plant 2=Cultivation (livestock) 3=Work part-time 4=Student 5=None 6=Other	1=Village 2=Beyond village 3= Beyond county 4= Beyond province 5= Beyond country	Good; General (sometimes sick); Bad				1=Beyond village 2=Beyond county 3=Beyond province 4=Beyond country	1=Work 2= Marriage 3=Study 4=Other	Reason: <input type="checkbox"/> for ecology <input type="checkbox"/> for work <input type="checkbox"/> for own willingness <input type="checkbox"/> other

2. Basic information about land (First ask the total number of land, if more than 4, please arrange into 4 by slope or plant type. Confirm whether there is abandoned land:

		Land type	Area ()	Gradient (degree)	Quality	Distance to home	Production (income from land)	Residential area
Last year  Total area _____	Piece1 _____ mu							
	Piece2 _____ mu							
	Piece3 _____ mu							
	Piece4 _____ mu							
20 years ago (1995)  Total area _____	Piece1 _____ mu							
	Piece2 _____ mu							
	Piece3 _____ mu							
	Piece4 _____ mu							
		1. Cropland 2. Gaden 3. Forest land 4. Grassland 5. others			1. Good 2. Medium 3. Bad			

**II. Scenarios**

1. Land transfer:

Period	Willingness	Land type	Area ( )	Plant type	Distance to home	Quality	Contractor	Lease period	Price (yuan /mu)	Reason	
In the past 5 years (around 2010- 2016)	Rent	<input type="checkbox"/> Cropland <input type="checkbox"/> Grassland <input type="checkbox"/> Forest land <input type="checkbox"/> _____				<input type="checkbox"/> Good <input type="checkbox"/> Medium <input type="checkbox"/> Bad	-			<input type="checkbox"/> Good benefits <input type="checkbox"/> _____ <input type="checkbox"/> Enjoy work on land <input type="checkbox"/> Enough labour <input type="checkbox"/> To raise livestock	
	Do you want to rent more?	Yes	<input type="checkbox"/> Cropland <input type="checkbox"/> Grassland <input type="checkbox"/> Forest land <input type="checkbox"/> _____				<input type="checkbox"/> Good <input type="checkbox"/> Medium <input type="checkbox"/> Bad	-			<input type="checkbox"/> Good benefits <input type="checkbox"/> _____ <input type="checkbox"/> Enjoy work on land <input type="checkbox"/> Enough labour <input type="checkbox"/> To raise livestock
		No	<i>Why?</i> <input type="checkbox"/> Poor economic benefit <input type="checkbox"/> Work outside <input type="checkbox"/> Labour shortage <input type="checkbox"/> Aged <input type="checkbox"/> Others _____								
	Rent out	<input type="checkbox"/> Cropland <input type="checkbox"/> Grassland <input type="checkbox"/> Forest land <input type="checkbox"/> _____					<input type="checkbox"/> Good <input type="checkbox"/> Medium <input type="checkbox"/> Bad				<input type="checkbox"/> Good benefits <input type="checkbox"/> _____ <input type="checkbox"/> Enjoy work on land <input type="checkbox"/> Enough labour <input type="checkbox"/> To raise livestock
	Do you want to rent out more?	Yes	<input type="checkbox"/> Cropland <input type="checkbox"/> Grassland <input type="checkbox"/> Forest land <input type="checkbox"/> _____				<input type="checkbox"/> Good <input type="checkbox"/> Medium <input type="checkbox"/> Bad				<input type="checkbox"/> Good benefits <input type="checkbox"/> _____ <input type="checkbox"/> Enjoy work on land <input type="checkbox"/> Enough labour <input type="checkbox"/> To raise livestock
		No	<i>Why?</i> <input type="checkbox"/> Poor economic benefit <input type="checkbox"/> Work outside <input type="checkbox"/> Labour shortage <input type="checkbox"/> Aged <input type="checkbox"/> Others _____								
Plan to abandon?	Yes	<input type="checkbox"/> Cropland <input type="checkbox"/> Grassland <input type="checkbox"/> Forest land <input type="checkbox"/> _____				<input type="checkbox"/> Good <input type="checkbox"/> Medium <input type="checkbox"/> Bad	-			<input type="checkbox"/> Good benefits <input type="checkbox"/> _____ <input type="checkbox"/> Enjoy work on land <input type="checkbox"/> Enough labour <input type="checkbox"/> To raise livestock	
	No	<i>Why?</i> <input type="checkbox"/> Land is basic insurance <input type="checkbox"/> No other work chance <input type="checkbox"/> Others _____									
20 years ago (1995)	Rent	<input type="checkbox"/> Cropland <input type="checkbox"/> Grassland <input type="checkbox"/> Forest land <input type="checkbox"/> _____				<input type="checkbox"/> Good <input type="checkbox"/> Medium <input type="checkbox"/> Bad	-			<input type="checkbox"/> Good benefits <input type="checkbox"/> _____ <input type="checkbox"/> Enjoy work on land <input type="checkbox"/> Enough labour <input type="checkbox"/> To raise livestock	
	Rent out	<input type="checkbox"/> Cropland <input type="checkbox"/> Grassland <input type="checkbox"/> Forest land <input type="checkbox"/> _____				<input type="checkbox"/> Good <input type="checkbox"/> Medium <input type="checkbox"/> Bad				<input type="checkbox"/> Good benefits <input type="checkbox"/> _____ <input type="checkbox"/> Enjoy work on land <input type="checkbox"/> Enough labour <input type="checkbox"/> To raise livestock	



2. Abandoned farmland:

Under which conditions would you abandon your farmland?

Condition		Reasons	Condition	Reasons
<input type="checkbox"/> Quality of land	<input type="checkbox"/> Good		<input type="checkbox"/> Quantity of laborers [ <input type="checkbox"/> have nothing to do with labors]	<input type="checkbox"/> many (>3)
	<input type="checkbox"/> Medium			<input type="checkbox"/> normal (around 2)
	<input type="checkbox"/> Bad			<input type="checkbox"/> few (<=1)
	<input type="checkbox"/> Has nothing to do with quality		<input type="checkbox"/> Job opportunity	<input type="checkbox"/> around village
<input type="checkbox"/> Accessibility	Distance [ <input type="checkbox"/> has nothing to do with distance]	<input type="checkbox"/> < 1 kilometer	<input type="checkbox"/> [have nothing to do with job opportunity]	<input type="checkbox"/> in town
		<input type="checkbox"/> 1-5 kilometer		<input type="checkbox"/> beyond town
		<input type="checkbox"/> > 5 kilometer		
	Resistance [ <input type="checkbox"/> has nothing to do with resistance]	<input type="checkbox"/> cross-mountain	<input type="checkbox"/> Cost on land (eg. fertilization) [ <input type="checkbox"/> have nothing to do with the cost]	<input type="checkbox"/> increased to double
		<input type="checkbox"/> cross-river		<input type="checkbox"/> increased to triple
				<input type="checkbox"/> increased more than triple
	Road [ <input type="checkbox"/> have nothing to do with road]	<input type="checkbox"/> no road	<input type="checkbox"/> Subsidy [ <input type="checkbox"/> have nothing to do with the subsidy]	<input type="checkbox"/> 15 yuan/mu per year
	<input type="checkbox"/> road could walk on	<input type="checkbox"/> 10 yuan/mu per year		
	<input type="checkbox"/> road could drive on	<input type="checkbox"/> none		
Gradient [ <input type="checkbox"/> has nothing to do with gradient]	<input type="checkbox"/> < 5°	<input type="checkbox"/> Price (set corn as an example) [ <input type="checkbox"/> have nothing to do with the price]	<input type="checkbox"/> 2 yuan per kilogram	
	<input type="checkbox"/> 5°-15°		<input type="checkbox"/> 1.5 yuan per kilogram	
	<input type="checkbox"/> 15°-25°		<input type="checkbox"/> 1 yuan per kilogram	
	<input type="checkbox"/> > 25°			
<input type="checkbox"/> Drought frequency [ <input type="checkbox"/> have nothing to do with drought]	<input type="checkbox"/> frequently(1-2/year)		<input type="checkbox"/> Production (set corn as an example) [ <input type="checkbox"/> have nothing to do with production]	<input type="checkbox"/> < 800 kilogram/mu
	<input type="checkbox"/> normal (3-5years once)			<input type="checkbox"/> 800-1400 kilogram/mu
	<input type="checkbox"/> few (10 years once)			<input type="checkbox"/> > 1400 kilogram/mu
<input type="checkbox"/> Waterlogging frequency [ <input type="checkbox"/> have nothing to do with waterlogging]	<input type="checkbox"/> frequently(1-2/year)			
	<input type="checkbox"/> normal (3-5years once)			
	<input type="checkbox"/> few (10 years once)			
<input type="checkbox"/> Whether decisions are impacted by neighbours? [ <input type="checkbox"/> have nothing to do with neighbours]	<input type="checkbox"/> if all neighbours choose to			
	<input type="checkbox"/> if majority (3/4) neighbours choose to			
	<input type="checkbox"/> half of neighbours choose to			
	<input type="checkbox"/> if minority (1/4) neighbours choose to			
	<input type="checkbox"/> none			